PERSPECTIVES IN DEALING WITH SURPLUS MALE FARM ANIMALS

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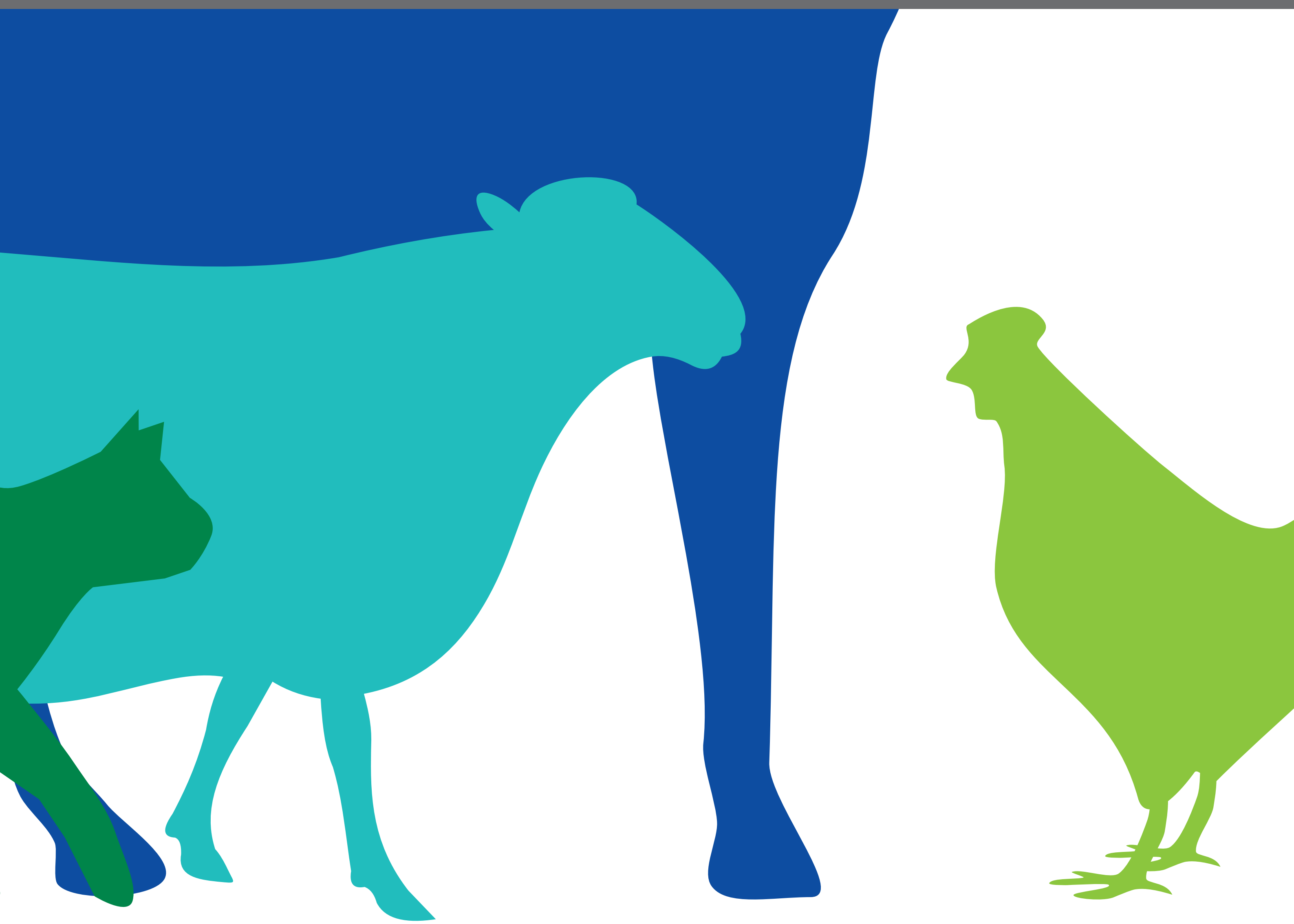

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PERSPECTIVES IN DEALING WITH SURPLUS MALE FARM ANIMALS

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EDITORIAL
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Editorial: Perspectives in Dealing With Surplus Male Farm Animals

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Editorial on the Research Topic

Perspectives in Dealing With Surplus Male Farm Animals

"Sex matters"—this also holds true for animals kept for farming purposes, where female and male animals of most farm animal species are used and managed in different ways. This applies to breeding animals, but also to individuals of highly specialized hybrids and breeds, which produce food for human consumption directly. The production of milk and eggs for instance relies on female reproductive abilities. However, even in these specialized hybrids and breeds, about half of the offspring will usually be male. Due to an antagonism between reproductive and fattening traits, male animals from these specialized strains are not suitable for commercial meat production. From an economic point of view, culling these "surplus" male animals is often more efficient than rearing them. In recent years, the practice of routinely killing large numbers of young, healthy animals has raised moral concerns in society. Due to the shifting status of animals in society, there is a need to develop alternatives for dealing with surplus male farm animals, a variety of which is presented in the contributions to this Research Topic.

The impression of being seen as mere by-products or waste is most strongly manifested in the standard practice of killing day-old male chicks of layer hybrids. Therefore, this practice raises major socio-ethical concerns and is critically discussed or even banned in some countries (1, 2). De Haas et al. conducted an online survey of the Dutch public to assess the awareness of the routine killing of male layer chicks. Even more important with regard to a transfer into practice are their questions on possible alternatives. Is one alternative favored, and are consumers willing to pay more for poultry products that do not require culling day-old male chicks?

There are currently three alternatives to avoid the killing of male chicks: in-ovo sex determination, rearing layer cockerels, and using dual-purpose chickens. The latter of which is receiving increased attention due to its potential to also alleviate several welfare issues associated with conventional high yielding hybrids. In dual-purpose chickens, animals of both sexes gain economic value: the females are kept for egg-laying purposes, whereas the males are reared for meat. However, little is known about the behavior of these hybrids or breeds in conventional housing environments, which were originally designed for specialized hybrids. Malchow and Schrader contribute to closing this gap by investigating the effects of elevated platforms on several behavioral and welfare indicators in male dual-purpose chickens. In contrast, Rieke et al. focused on the potential benefits of dual-purpose hens: are they as prone to feather pecking behavior as conventional layer hybrids? Staying with the females, Daş et al. provided important knowledge on the impact of nematode infections on the immune responses in previously vaccinated dual-purpose hens. These new insights into dual-purpose chickens' behavior, welfare and health are essential for developing and applying animal-friendly husbandry practices.

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The cattle sector faces a similar issue as the poultry industry. Here, specialized breeds are used for dairy or beef production. Male calves of dairy breeds are often only kept for a short period at the lowest costs possible until they are sold or slaughtered, which—in addition to the socio-ethical concerns mentioned above—can lead to serious welfare problems. In their narrative review, Creutzinger et al. detail the welfare challenges associated with raising surplus dairy calves in the U.S. and Canada. The authors highlight that the dairy industry is not only faced with surplus male calves but also with female calves which are not needed as replacements for the lactating herd. In this sense, the case of surplus dairy calves is framed as a "wicked problem" by Bolton and von Keyserlingk. It is demonstrated that such a "wicked problem" calls for approaches that go beyond simple technical solutions. In the methodologies proposed by the authors, integrating the views of the public is key. In this context, Maher et al. surveyed an important yet often underrepresented stakeholder group: the farmers. With the recent expansion of dairy herds in Ireland, farmers also have to deal with an increase in the number of surplus calves. Knowing farmers' views and opinions on how to deal with male dairy calves is a valuable first step for developing alternative approaches that will actually be implemented into practice.

A practical approach to improve the welfare of surplus dairy calves during the short period they are kept is proposed by Boyle and Mee. The authors argue that providing farmers with feedback of results from animal-based welfare indicators collected around slaughter could protect and improve on-farm calf welfare. Therefore, they present a risk-orientated ante- and post-mortem welfare assessment scheme tailored to calves which are younger than 1 month of age. With their investigations of different treatments during transport from the dairy to the veal farm, Marcato et al. join the idea of safeguarding the welfare and health of surplus calves. Are welfare and health affected by the diet the calves are fed prior to transport, by transport duration, or by the type of vehicle used for transport?

Another practical approach to dealing with surplus dairy calves is proposed by Rutherford et al.: as beef consumption increased in the UK over the past decade, why not use male dairy calves to meet this demand in a sustainable way? In their article, the authors give recommendations on which beef production system would fit best the welfare requirements of the dairy calves and the UK market. In contrast, Balzani et al. suggest the use of sexed semen as an option to decrease the number of male calves born. They present a pilot study exploring the perceptions of key stakeholders, such as farmers, veterinarians, and dairy farm advisors, regarding the use of sexed semen as a strategy to reduce the production of surplus male dairy calves.

Finally, this Research Topic focuses on another milk producing species: goats. In some regions of the world, for instance in the Netherlands, goats are almost exclusively bred for milk production. For this purpose, only a small population of the male offspring is needed for reproduction aims. Meijer et al. compare various scenarios of dealing with surplus buck kids in a country, in which there is hardly any market for goat meat. The authors base their recommendations on the sector's experiences and current practices in the Netherlands.

Overall, the body of research included in this Research Topic highlights the variety of alternatives for avoiding the production of surplus male animals or their killing without intentional use. By providing science-based approaches for tackling the issue, welfare friendly, socially accepted, and thus sustainable livestock farming practices can be realized. In addition, the studies on the dual-purpose chickens show that while we are searching for alternatives for the males, we may at the same time encounter ways to improve the welfare of the females.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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ORIGINAL RESEARCH
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Transport of Young Veal Calves: Effects of Pre-transport Diet, Transport Duration and Type of Vehicle on Health, Behavior, Use of Medicines, and Slaughter Characteristics

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The aim of this study was to investigate effects of different early life transport-related factors on health, behavior, use of medicines and slaughter characteristics of veal calves. An experiment was conducted with a 2 × 2 × 2 factorial arrangement with 3 factors: (1) provision of rearing milk or electrolytes before transport, (2) transport duration (6 or 18 h), and (3) type of vehicle (open truck or conditioned truck). The study included male Holstein-Friesian and cross-bred calves ($N = 368$; 18 ± 4 days; 45.3 ± 3.3 kg). Data on health status of calves were collected at the collection center and at the veal farm until week 27 post-transport. Behavior of calves was recorded during transport and at the veal farm until week 13 post-transport. Use of herd and individual medical treatments was recorded at the veal farm. The prevalence of loose or liquid manure at the veal farm from day 1 until week 3 post-transport was lower in electrolyte-fed calves transported in the conditioned truck compared to electrolytes-fed calves transported in the open truck or milk-fed calves transported in both the conditioned and open truck ($\Delta = 11\%$ on average; $P = 0.02$). In comparison with the open truck, calves transported in the conditioned truck had lower prevalence of navel inflammation in the first 3 weeks post-transport ($\Delta = 3$ %; $P = 0.05$). More milk-fed calves received individual antibiotic treatments compared to electrolyte-fed calves at the veal farm ($P = 0.05$). In conclusion, the transport-related factors examined in the present study affected health and behavior of calves in the short-term, but there was no evidence for long-term effects. It remains unknown why no long-term effects were found in this study. Perhaps this absence of transport-related effects was due to multiple use of medical treatments in the first weeks at the veal farm. Alternatively, it might be that the collective effects of the transition from the dairy farm to the veal farm, and of the husbandry conditions during the subsequent rearing period, on the adaptive capacity of calves were so large that effects of individual transport-related factors were overruled.

Keywords: transport, health, behavior, slaughter characteristics, medicine use, veal calves

INTRODUCTION

Calves at Dutch veal farms are usually collected from different dairy farms, including dairy farms from other EU-countries (especially Germany) (1). Collection procedures, which involve mixing of calves from multiple sources, transport to a collection center and subsequent transport to the veal farm result in stress and disease challenges (2, 3). Additionally, placement of calves into a new housing facility and their adaptation to a new feeding regime might also contribute to health problems (3). Transport normally occurs in the first weeks of the life of calves (14–20 days of age) when they are highly susceptible to microorganisms against which they have no colostral antibodies (4, 5). Poor condition of calves directly post-transport (calves with failure of passive transfer of immunity, dehydration and navel inflammation) is negatively linked to long-term performance of calves (6, 7). A high dehydration score, sunken flanks, diarrhea and navel infection upon arrival at the veal farm are related to mortality in the first 21 days post-transport (8). Dehydration may result from feed and water withdrawal around transport and is associated with body weight losses. Severe body weight loss during transport (over 10%) increases the risk of lameness and mortality in calves (6, 9). Transport is also related to incidence of respiratory diseases in calves after arrival at a feedlot (10). Overall, transport is a challenge for young veal calves, but it remains unknown which specific transport-related factors play a dominant role. Several transport-related factors have an effect on health (8) and behavior (e.g., standing vs. lying), thus influencing the recovery time of young calves during and in the immediate post-transport period (11). In a previous study (12), we examined the effects of pre-transport diet (milk vs. electrolytes), transport duration (6 vs. 18 h), and type of vehicle (open truck vs. conditioned truck) on the physiological status of young veal calves at the beginning of the rearing period. The aim of the current study was to investigate the effects of these transport-related factors on health (including the use of medicines) during the entire rearing period, behavior and slaughter characteristics of calves at the veal farm. We hypothesized that feeding milk, transportation of calves for 6 h in a conditioned truck, and likely the interaction between these factors, might contribute to less health problems and behavioral signs of discomfort compared to the other treatments.

MATERIALS AND METHODS

Experimental Overview

The experiment had a 2 × 2 × 2 factorial arrangement, including the following factors: (1) provision of rearing milk or electrolytes prior to transport; (2) transport duration (6 or 18 h); (3) type of vehicle (open truck or conditioned truck). The experiment included 368 bull Holstein Friesian and crossbred calves [18 ± 4 days; 45.3 ± 3.3 kg body weight (BW)], transported over two consecutive weeks (N = 184 calves/week). Calves were transported from a collection center in Bocholt-Barlo, Germany, where they stayed from 4.00 a.m. until 14.00 p.m., to a Dutch veal farm in Veghel. All animals followed current practices, including handling and mixing procedures at the collection center and transportation, and all calves were in compliance with the minimal weight and health requirements [BW > 36 kg; age: minimum 14 days; no signs of disease and injury (13)]. The experiment was approved by the Central Committee on Animal Experiments (the Hague, the Netherlands; Approval Number 2017.D-0029).

Handling of Calves at the Collection Center, During Transport and at the Veal Farm

At the collection center, calves were randomly allocated to one of the eight treatment groups by the manager. Calves were fed *via* a bucket with nipples, with 1.5 l of rearing milk (125 g of milk powder/l; per kg of milk powder: ME = 4028 kcal, CP = 190 g, crude fat = 157 g, digestible lysine = 18.7 g; made with plant-based ingredients; Tentofok KO, Tentego, The Netherlands) or a mixture of electrolytes (20 g of electrolytes/l of water; per 100 g of powder: Na = 7.3 g and moisture = 3.8 g; Navobi, Staverden, The Netherlands) dissolved in 1.5 l water.

After feeding, calves rested for ∼2 h and thereafter they were loaded on the vehicle. The vehicle consisted of two parts: the truck was conditioned, which means it was provided with a side-ventilation system, it was isolated, and the climate was controlled regarding in and outlet of air (KVM Livestock Transport System^{TM}, Kleventa BV, Lichtenvoorde, The Netherlands). Settings were according to those provided by the manufacturer and applied by the transporter. The trailer was regular, open and lacked a ventilation system or climate control. Temperature and relative humidity in both vehicles are shown in **Appendix 1**. Both truck and trailer were divided into four compartments with straw bedding, two at the lower deck (3.60 m length × 2.45 m width × 1.35 m height) and two at the upper deck (3.60 m length × 2.45 m width × 1.45 m height). Each compartment contained 23 calves of one treatment group at the same stocking density (0.383 m^2 per calf). Treatments were distributed in the vehicle according to a design that allows for estimation of all main effects and relevant interactions [for details see Marcato et al. (12)]. After loading, transport was conducted by two drivers, switching every 3 h. Neither food nor water was provided to calves during transport. After 6 h transport, the truck arrived at the veal farm and all calves were unloaded. Calves assigned to 6 h transport were placed in the veal farm, whereas the calves assigned to 18 h transport were reloaded on the truck and trailer (in the same compartments as before) and transported for another 12 h. Calves in the 6 and 18 h transport treatment groups were appropriately distributed across the truck and trailer and, therefore, located in both upper and lower decks [see Marcato et al. (12)]. Unloading calves located in an upper deck after 6 h of transport required that calves located in the lower deck had to be unloaded first; in some instances these latter animals belonged to the 18 h transport treatment group. In order to avoid unwanted confounding between transport duration and unloading and reloading of calves in part of the calves subjected to 18 h of transport, we decided to unload all calves after 6 h of transport and subsequently reload the animals in the 18 h transport treatment group, placing them in the appropriate compartment.

At the veal farm, calves were distributed across 64 pens that were divided over 8 similar compartments. Each compartment included 8 pens, with 5 or 6 calves per pen. Treatments were randomly distributed across pens in every compartment. Calves were housed individually within each pen for the first 3 weeks post-transport. Subsequently, calves were kept in groups.

Calculation of the Sample Size

The number of experimental units required in the present study was based on a power analysis. Our experimental design was based on the principle that pen (or group) was the basic, independent experimental unit. We have extensive experience with multifactorial experiments with veal calves, and in one of the previous studies we used 16 pens per level of main effects, and 4 pens per treatment combination (14). Using this setup, we were able to detect differences between two treatment levels of about one unit standard deviation (SD) with a power of 0.80. However this latter experiment was performed on an experimental farm, under relatively standardized conditions, and using a specific and relatively standardized subset of calves. We anticipated that both the variation in conditions and between calves would be higher during the current experiment which took place under commercial conditions. A recent power analysis that we performed using a very large data set with carcass weights recorded both under experimental and commercial conditions (15) supported this latter assumption, and suggested that under commercial conditions the SD could be 1.5 times higher than under more controlled experimental conditions. Power analysis showed that in order to maintain the same statistical power, the number of experimental units should be approximately doubled. Therefore, in the present experiment, we used 32 pens per level of main effects, and 8 pens per treatment combination.

Health Assessment

Health assessment of calves was performed at the collection center (during the resting period), and at the veal farm, on day 1, and in weeks 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, and 27 post-transport by two observers. Inter-observer reliability was tested before the experiment for both health and behavioral observations (k-coefficient = 98%). Two protocols were used for health assessment. The first one, shown in **Appendix 2**, was used at the collection center and at the veal farm from day 1 until week 3, when the calves were housed individually. The second protocol was according to the one used by Brscic et al. (5) based on the Welfare Quality® Protocol on veal calves, and appropriate for use at pen level. This latter protocol was used to clinically score calves from week 5 until 27 post-transport (**Appendix 3**).

Processing of Health Data

Appendices 2, 3 show a complete list of health variables assessed at the collection center and at the veal farm, throughout the entire rearing period. Each health variable was first expressed at pen level as a percentage reflecting the number of calves displaying a health problem divided by the number of calves in the pen (**Tables 1**, **2**). These percentages were averaged per treatment. Prior to statistical analyses, some health variables

TABLE 1 | Effects of pre-transport diet, type of vehicle and transport duration on health variables of young veal calves assessed at day 1 after arrival at the veal farm.

	Pre-transport diet				Type of vehicle				Transport duration			
Parameter	**Electrolytes**	**Milk**	**SE[a]**	***P*-value**	**Conditioned truck**	**Open truck**	**SE**	***P*-value**	**6 h**	**18 h**	**SE**	***P*-value**
Navel inflammation	8.9	9.7	2.2	0.21	6.7	11.9	2.1	0.16	9.9	8.6	2.1	0.05
Eye discharge	7.1	6.3	2.1	0.39	5.0	8.4	2.0	0.49	6.1	7.3	2.1	0.76
Sunken eyes	38.3	40.9	3.2	0.63	35.7	43.5	3.2	0.08	36.5	42.8	3.2	0.31
Drooped ears	9.6	12.9	2.0	0.08	11.1	11.3	2.0	0.83	9.7	12.8	2.0	0.69

All parameters are expressed as an average proportion at pen level (N = 5 or 6 calves/pen). Data are shown as raw means ± SE[a].
[a]SE, standard error.

TABLE 2 | Effects of pre-transport diet, type of vehicle and transport duration on health variables of young veal calves assessed from day 1 until week 3 after arrival at the veal farm.

	Pre-transport diet				Type of vehicle				Transport duration			
Parameter	**Electrolytes**	**Milk**	**SE[a]**	***P*-value**	**Conditioned truck**	**Open truck**	**SE**	***P*-value**	**6 h**	**18 h**	**SE**	***P*-value**
Navel inflammation	8.0	7.2	1.2	0.93	5.9	9.2	1.2	0.05	8.3	6.8	1.2	0.04
Joint problems	2.3	1.3	0.8	0.57	1.5	2.1	0.8	0.37	1.9	1.8	0.8	0.17
Loose or liquid manure	22.8	30.7	2.6	<0.01	24.8	28.7	2.6	0.30	26.1	27.4	2.6	0.15
Eye discharge	7.1	6.2	1.1	0.63	6.5	6.9	1.1	0.75	6.7	6.6	1.1	0.80
Sunken eyes	39.0	40.3	2.5	0.52	38.6	40.7	2.5	0.70	39.8	39.5	2.5	0.71
Drooped ears	13.9	13.3	1.6	0.80	13.4	13.8	1.6	0.92	13.7	13.5	1.6	0.39

All parameters are expressed as an average proportion at pen level (N = 5 or 6 calves/pen). Data are shown as raw means ± SE[a].
[a]SE, standard error.

collected until week 3 post-transport were grouped as follows: (1) navel inflammation = navel with score 1 and 2; (2) loose or liquid manure = loose manure (with score 1) and liquid manure (with score 2); this category includes either infectious diarrhea or feeding-related loose or liquid manure, but it was not possible to make this distinction based on the visual clinical assessment.

To qualitatively compare health data recorded at the collection center with those recorded at the veal farm, a proportion was calculated as follows: (sum of calves displaying a health problem/total number of calves) × 100 (see **Table 3**).

Behavioral Observations

The first behavioral observations were conducted at the collection center during the resting hours after the application of the feeding treatment. Two observers conducted behavioral observations, using the scan sampling technique according to Martin et al. (16). Behavior of calves was assessed every 5 min for 1 h according to an adapted version of the ethogram used by Webb et al. (17) (**Appendix 4**). After the rest period, calves were loaded in the truck and trailer according to their respective treatments. Every compartment of both truck and trailer contained a camera that recorded standing and lying behavior throughout the 6 and 18 h of transport. Behavior was also assessed at the veal farm where cameras ($N = 8$, each positioned in every compartment of the stable) recorded standing vs. lying behavior during the first 24 h after arrival. In addition, two observers assessed behavior of calves by direct observations and using an instantaneous scan sampling technique at 5 min intervals for 1 h. These direct observations were done after arrival of calves, and in weeks 1, 3, 5, 9, and 13 post-transport (always after feeding). Behavioral variables shown in **Appendix 4** were grouped into 3 main categories prior to statistical analyses: (1) comfort behavior = licking another calf, self-grooming, rubbing, chewing, eating, and drinking; (2) discomfort behavior = tongue playing, manipulating objects, manipulating another calf, urine drinking, and repetitive calling; (3) playing behavior = mount/leap/jump/back/turn, head-butt, running.

TABLE 3 | Severity of health problems at the collection center, on day 1 post-transport and in the first 3 weeks at the veal farm.

Health variables	Place and time		
	Collection center: before transport	Veal farm: day 1	Veal farm: day 1 until week 3
Signs of pneumonia	2.7	0.3	2.3
Eye discharge	3.8	6.5	6.6
Nasal discharge	1.9	0.5	3.9
Loose or liquid manure	5.4	5.2	26.7
Navel inflammation	6.5	9.2	7.4
Sunken eyes	18.7	39.7	39.4
Joint problems	2.1	0.5	1.7
Drooped ears	5.4	11.1	13.5

Values represent proportions at batch level calculated as following: (the number of calves displaying a health problem/the total number of calves) × 100.

Use of Medicines

Use of antibiotics and other medicines during the entire rearing period was recorded at the level of both herd and individual calf. Information on individual treatments included the following data: (1) whether the calf was treated or not with antibiotics or other medicines (this category included products such as anti-inflammatories, multivitamins, anti-coccidiosis, with the exclusion of antibiotics) during the rearing period; (2) single or repeated antibiotic/medical treatments during the rearing period; (3) age at which treatments were applied; (4) type of antibiotic or medication used. Herd treatments (applied on all calves, *via* the milk) were also recorded, including the age at which they were applied and the type of medication used.

Slaughter Characteristics

Slaughter characteristics were assessed per calf and included carcass weight (kg), color of the meat (scale 1–10 points, from pale to dark red color), fat coverage (scale 1–5 points, from low to very high fat coverage) and conformation class (scale 1–15 points, from excellent to poor carcass quality) (18).

Statistical Analyses

All data were analyzed in SAS 9.4 (SAS Inst. Inc., Cary, NC). Health and behavioral data (expressed as a proportion of health problems or behaviors per pen) determined on day 1 and directly post-transport, respectively, were analyzed with a generalized linear mixed model with Pseudo Likelihood or equivalently Penalized Quasi Likelihood (PQL) (19), employing SAS procedure GLIMMIX. At this stage, calves were individually housed inside pens. The systematic part of the model comprised the following fixed effects:

$$\mu + \text{Batch}_i + \text{Uplo}_j + \text{Bafr}_k + \text{Diet}_l + \text{Type}_m + \text{Duration}_n + (\text{Diet}_l \times \text{Duration}_n) + (\text{Diet}_l \times \text{Type}_m) + (\text{Duration}_n \times \text{Type}_m) + (\text{Diet}_l \times \text{Type}_m \times \text{Duration}_n) \quad (1)$$

Here, μ is a base level and Batch_i = batch ($i = 1, 2$), Uplo_j = position in the vehicle (j = upper or lower deck), Bafr_k = position in the vehicle (k = front or back), Diet_l = pre-transport diet (l = rearing milk or electrolytes), Type_m = type of vehicle (m = open or conditioned truck), and Duration_n = transport duration (n = 6 or 18 h) are main effects. The model also comprised two- and three-way interactions between diet, type of vehicle and transport duration. Interactions were considered not significant when $P > 0.05$. In addition, random effects for pen and compartment at the veal farm were included in the linear predictor. The logit link function was used in concert with the variance function of the binomial distribution, which included a multiplicative dispersion factor that was estimated from the data. Here and in subsequent analyses, for all fixed effects, approximate F-tests were used (20). Interactions that were not significant were excluded from the model (when higher order interactions were already excluded, i.e., respecting the hierarchy of interaction terms). Subsequent pairwise comparisons were done with Fisher's LSD method.

Health data and direct behavioral observations (expressed as proportion of health problems or behaviors per pen) assessed from the arrival of calves at the veal farm until week 3 post-transport were analyzed with a generalized linear mixed model (again PQL and GLIMMIX). Until week 3 post-transport, calves were still individually housed inside pens. The systematic part of the model comprised the following fixed effects:

$$\mu + \text{Batch}_i + \text{Uplo}_j + \text{Bafr}_k + \text{Diet}_l + \text{Type}_m + \text{Duration}_n + \text{Time}_o + (\text{Diet}_l \times \text{Duration}_n) + (\text{Diet}_l \times \text{Type}_m) + (\text{Duration}_n \times \text{Type}_m) + (\text{Diet}_l \times \text{Time}_o) + (\text{Duration}_n \times \text{Time}_o) + (\text{Type}_m \times \text{Time}_o) + (\text{Diet}_l \times \text{Type}_m \times \text{Duration}_n) \quad (2)$$

in the same notation as before and additionally with $\text{Time}_o =$ sampling moment (o = T0 for behavior or day 1 for health, week 1 and 3) as main effect. Three-way interactions between diet, type of vehicle and transport duration, and two-way interactions between pre-transport diet, type of vehicle transport duration and time were also included in the model. Interactions were considered not significant when $P > 0.05$. The model comprised random compartment effects. For the repeated measurements on the same pen a first order auto regressive model (based on the actual distance between time points) was adopted.

Health data assessed from week 5 until 27 and direct behavioral observations assessed from week 5 until 13 were also analyzed with the generalized linear mixed model (Equation 2). During this period, calves were housed in groups instead of individually. Between week 5 and 27 post-transport, the presence of loose or liquid manure, as well as thick and white manure, were recorded as a binary response at pen level (i.e., present or not present). These variables were also analyzed with the generalized linear mixed model (Equation 2).

Data on individual treatments with antibiotics and other medicines during the entire rearing period were expressed as binary data (0 = calf not treated at individual level with antibiotics or medicines; 1 = calf treated at least once at individual level with antibiotics or medicines during the rearing period). These data were analyzed with a generalized linear mixed model (analysis with PQL and GLIMMIX) similar to model 1, but for binary data.

Continuous data on carcass weight at slaughter were analyzed with a linear mixed model (analysis with restricted maximum likelihood with SAS procedure PROC MIXED) with fixed and random effects as in Equation 1 and additional normally distributed error (or residual) terms. Residuals were checked for normality and homogeneity of variance and data were log transformed when deemed necessary.

Carcass weight was also analyzed in relation to the number of individual medical treatments. The number of individual medical treatments was introduced as a qualitative factor in the model 1, comprising three main levels: 0 = calf not treated; 1 = calf treated once or twice; 2 = calf treated > 2 times.

In all analyses, effects with $P \leq 0.05$ were considered significant, whereas those with $0.05 < P < 0.10$ were considered as a tendency toward significance.

RESULTS

The results of the present study will be shown in four main domains: health, behavior, use of medicines and slaughter characteristics. In each of these domains, effects of main factors, which included pre-transport diet, transport duration and type of vehicle, will be reported. Three-way and two-way interactions were never significant, with the exception of the interaction between pre-transport diet and type of vehicle on loose and liquid manure which is described in the first paragraph.

Health

The day post-transport, there were no significant effects of treatments on individual health parameters (**Table 1**). Drooped ears tended to be higher in milk-fed calves than in electrolytes-fed calves ($\Delta = 3.3\%$; $P = 0.08$) and sunken eyes tended to be higher in calves transported in the conditioned truck than in calves transported in the open truck ($\Delta = 7.8\%$; $P = 0.08$).

For the average prevalence of loose or liquid manure from day 1 until week 3 post-transport there was an interaction between pre-transport diet and type of vehicle. The percentage of calves with loose or liquid manure was lower (18%) in electrolytes-fed calves transported in the conditioned truck compared to electrolytes-fed calves transported in the open truck (28%) and milk-fed calves transported in both the conditioned and open truck (31% on average; $P = 0.02$). The percentage of calves with navel inflammation was higher in calves transported in the open truck and calves transported for 6 h compared to calves transported in the conditioned truck and calves transported for 18 h ($\Delta = 3.3\%$ and $\Delta = 1.5\%$, respectively; $P \leq 0.05$; **Table 2**).

Prevalences of navel inflammation and loose or liquid manure changed significantly in the first 3 weeks post-transport ($P < 0.01$). Navel inflammation decreased from day 1 (9%) until week 3 (4%), whereas loose or liquid manure gradually increased in this period (from 5% on day 1 to 39% in week 3). In addition to the effects of time on health problems in the first 3 weeks post-transport, **Table 3** shows the trend of health problems from the collection center until week 3 post-transport. Overall, the prevalence of the majority of health problems gradually increased in the period between the collection center and week 3 post-transport. Prevalences of loose or liquid manure and sunken eyes in the first 3 weeks post-transport more than doubled compared to the same prevalences at the collection center ($\Delta = 22\%$ and $\Delta = 20\%$, respectively).

Overall, prevalences of health problems from week 5 until 27 were relatively low (<10%), with the exception of coughing (12%), and there were no significant differences due to transport factors. As shown in **Figure 1A**, the prevalence of coughing changed significantly in this period ($P < 0.01$) and was highest between week 15 and 21 post-transport (15%). Besides coughing, abnormal breathing and nasal discharge, the other two clinical signs of respiratory disease, were below 5%. Raw means for all three signs of respiratory disease beyond week 5 at the veal farm are also shown in **Table 4**. **Figure 1B** shows the prevalence of gastrointestinal problems at the veal farm. Thick manure was present only from week 5 until 13 (average prevalence 11%), whereas it disappeared in the remaining part of the fattening period. The average prevalence of loose or liquid manure from week 5 until 13 was 10%, decreased slightly ($\Delta = -3\%$) from week 15 until 21, and increased again ($\Delta = 5\%$) from week 23

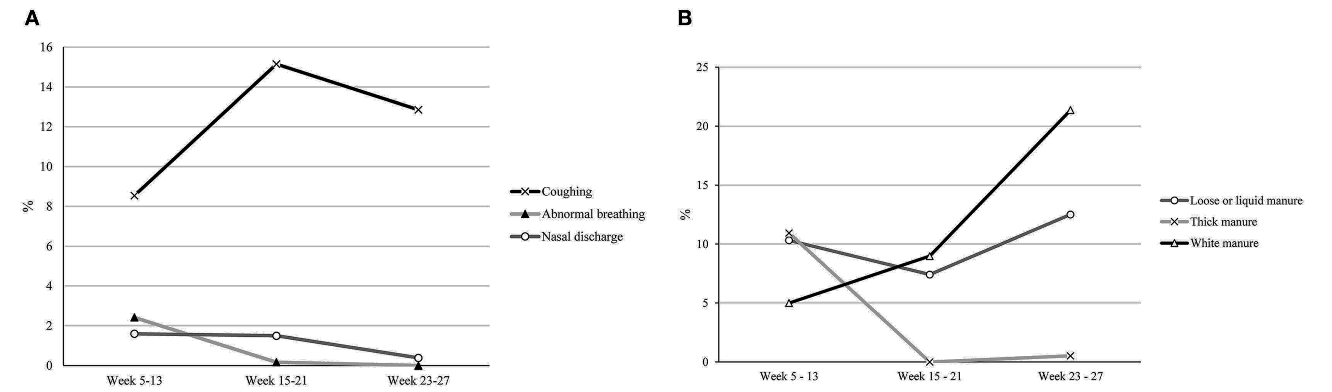

FIGURE 1 | (A) Prevalence of coughing, abnormal breathing and nasal discharge in veal calves between week 5 and 27 post-transport (expressed at average proportions at pen level). **(B)** Prevalence of loose or liquid manure, thick manure and white manure in veal calves between week 5 and 27 post-transport (expressed as average proportions of pens).

TABLE 4 | Raw means recorded for coughing, abnormal breathing and nasal discharge in veal calves between week 5 and 27 post-transport.

	Weeks post-transport											
Health variable	**Week 5**	**Week 7**	**Week 9**	**Week 11**	**Week 13**	**Week 15**	**Week 17**	**Week 19**	**Week 21**	**Week 23**	**Week 25**	**Week 27**
Coughing	6.1 ± 1.2[a]	5.3 ± 1.2	9.8 ± 1.5	7.7 ± 1.3	13.7 ± 1.5	16.3 ± 1.6	15.1 ± 2.1	15.8 ± 1.8	13.4 ± 1.6	19.1 ± 1.9	10.1 ± 1.7	9.3 ± 1.5
Abnormal breathing	2.6 ± 0.8	2.7 ± 1.0	5.4 ± 1.1	0.3 ± 0.3	1.1 ± 0.6	0.4 ± 0.4	0.3 ± 0.0	0	0	0	0	0
Nasal discharge	2.6 ± 1.0	0.8 ± 0.6	1.3 ± 0.6	0.5 ± 0.4	2.7 ± 0.8	4.6 ± 1.3	1.1 ± 0.7	0	0.3 ± 0.3	1.1 ± 0.6	0	0

All health variables are expressed as an average proportion at pen level (raw means ± SE[a]).
[a]SE, standard error.

until 27. White manure substantially increased during the entire rearing period (from 5 to 21%).

Behavior

During transport (61 vs. 39%) and directly post-transport (77 vs. 23%), calves spent most of the time lying compared to standing, but no significant differences were found between treatment groups. On the day post-transport, calves transported for 18 h showed more signs of discomfort compared to calves transported for 6 h (9 vs. 6%; $P < 0.01$). Additionally, calves transported in the conditioned truck showed more signs of discomfort behavior compared to calves transported in the open truck (9 vs. 5%; $P = 0.01$).

During the first 3 weeks post-transport, calves increased their time in a standing position (from 23% on day 1 to 51% in week 3 post-transport), and calves showed a gradual increase in comfort behavior (from 5% on day 1 to 15% in week 3 post-transport) and a decrease in discomfort behavior within this time frame (from 7% on day 1 to 4% in week 3 post-transport) ($P < 0.01$).

In the period between week 5 and 13 post-transport, comfort behavior gradually increased (from 30 to 53%) ($P < 0.01$). Play behavior increased up to a 4% in week 9 and subsequently, it decreased to 1% in week 13 post-transport ($P < 0.01$).

Use of Medicines

The percentage of calves individually treated with antibiotics at least once during the rearing period at the veal farm was 33%. Among this fraction of calves, 70% of animals were treated once, 21% were treated twice and 9% were treated more than twice during the rearing period. More milk-fed calves received individual antibiotic treatments compared to electrolyte-fed calves throughout the rearing period (38 vs. 28%, respectively; $P = 0.05$). The percentage of calves that received at least one other medical treatment during the rearing period was 18%. Among this fraction of calves, 69% of animals were treated once, 23% were treated twice and 8% were treated more than twice. No significant differences were found between treatment groups on the use of other medical treatments. In the first 6 weeks at the veal farm, 25% of calves were individually treated with antibiotics and 22% of calves were treated with other medicines. In the following 6 weeks, calves were still individually treated for antibiotics (23%) and for other medicines (4%), but from week 13 until 27 calves were not treated at all, neither individually nor batch-wise. Besides individual treatments, calves were subjected to 5 herd treatments (on day 3, 13, 22, 37, and 47) with oxytetracycline HCl (1.43 g/100 kg/twice a day), doxycycline (1 g/100 kg/day), Tilmovet 250 mg/ml (5.45 ml/100 kg/twice a day), Ampisol 100% (2.26 g/100 kg/day), and doxycycline (0.58 g/100 kg), respectively. These herd treatments were provided *via* the milk for an average of 11 feedings per herd treatment.

Slaughter Characteristics

No significant differences were found between treatment groups in relation to carcass weight (164.7 kg ± 18.4; range: 96–215 kg), conformation class (11.9 points ± 1.0; range: 8–15) and color of the meat (5.9 points ± 1.3; range: 2–10) at slaughter. **Figure 2** shows a significantly lower carcass weight of calves receiving > 2 individual medical treatments compared to carcass weight of calves not treated or treated once or twice ($P < 0.01$). **Figure 3** shows That the color of the meat of calves receiving > 2 individual medical treatments tended to be darker than the meat of calves not treated or treated once or twice ($P = 0.06$).

DISCUSSION

Health and Use of Medicines

In the current study, health problems in young veal calves increased in the post-transport period compared to pre-transport values at the collection center. Thus, transport (including mixing and handling procedures and feed withdrawal) and the adaptation of calves to the new housing and feeding system at the veal farm were challenges for calves. Health outcomes measured at the veal farm were expressed at pen level, although calves were individually housed in the first 3 weeks post-transport. We used this approach because individually housed calves were not randomly distributed across the barn, but housed pen-wise, thus each pen contained 5 or 6 calves in adjacent baby boxes. Most of the effects of transport-related factors were evident in the first 3 weeks after arrival at the veal farm; this is also the period in which most of the medical treatments were applied. The day post-transport, the prevalence of sunken eyes, which is a clinical characteristic related to dehydration, was lower than the prevalence rate shown by Wilson et al. (21) (40 vs. 61%, respectively). Dehydration is associated with different factors, including transport and diarrhea (22, 23). In a previous study (12) we reported that up to 70% of the calves used in the current experiment were dehydrated (based on skin elasticity) already before transport. This explains why application of the treatments resulted in a large number of calves with sunken eyes upon arrival.

Pre-transport diet fed at the collection center had an impact on loose or liquid manure in the first 3 weeks post-transport, where milk-fed calves showed more loose or liquid manure than electrolyte-fed calves. Feeding milk prior to transport is a good remedy against energy depletion or hypoglycemia (24), which was also visible on most of energy related parameters measured in blood of calves in this experiment (12). However, time feeding milk may also contribute to alterations in fecal consistency related to transport stress and consequently intestinal atrophy, whereas feeding electrolytes is a good approach to treat calves displaying metabolic acidosis and diarrhea (24, 25). The different composition of the pre-transport diet might also explain the higher use of antibiotics in milk-fed calves compared to electrolyte-fed calves in the present experiment. Feeding more nutrients, especially before a challenge, such as transport, may increase fecal abnormalities in pre-weaned calves in the first weeks of life (26) and it may result in higher antibiotic use (27). However, since we were not able to make the distinction between infectious or feed-related diarrhea during our clinical assessment, we cannot rule out the possibility that some of the antibiotic treatments in the current study were applied without a proper clinical justification. This may have affected the difference in antibiotic treatments between milk-fed and electrolyte-fed calves. The significant interaction between pre-transport diet and type of vehicle means that the prevalence of loose or liquid manure was lowest in electrolyte-fed calves transported in the conditioned truck in comparison with electrolyte-fed calves transported in the open truck, and milk-fed calves transported in both the conditioned and open truck. Apparently, in combination with the pre-transport diet, the environment in the conditioned truck exerted some kind of protective effects on the likelihood of calves exhibiting loose or liquid manure during the first 3 weeks of the rearing period. As indicated above, however, we do not know whether this decrease concerns loose or liquid manure with an infectious or non-infectious origin.

In comparison with the open truck, transporting calves in the conditioned truck also reduced the prevalence of navel inflammation in the first weeks post-transport. At present, it remains unknown which environmental factors comprising the conditioned transport in our experiment (such as draft or differences between in and outlet airflow) contributed to these effects on calf health at the beginning of the rearing period; these environmental and climatic factors need to be defined and recorded in more detail in future research. In a recent study by Renaud et al. (8), involving close to 5,000 calves, navel inflammation at arrival was associated with early

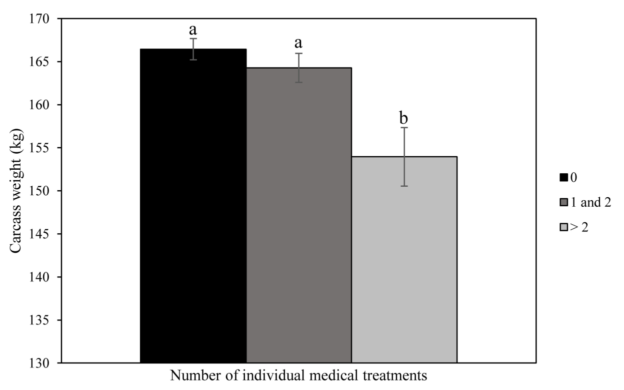

FIGURE 2 | Effects of number of individual medical treatments of veal calves throughout the rearing period on carcass weight at slaughter.

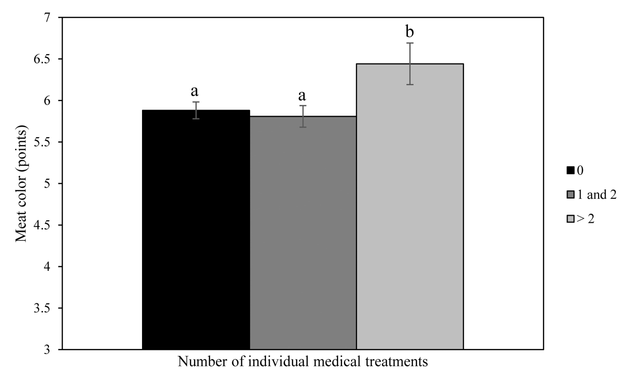

FIGURE 3 | Effects of number of individual medical treatments of veal calves throughout the rearing period on meat color at slaughter.

mortality at the veal farm (≤21 days post-transport). Therefore, the significant lower navel inflammation in calves transported in the conditioned truck found in the current experiment might be relevant at population level for reducing mortality at the veal farm, provided that conditioned transport would be used at a large scale.

In the first 3 weeks post-transport, navel inflammation decreased significantly and this is in line with Wilson et al. (21), although the starting prevalence rate in our study was lower (9 vs. 32%, respectively at the first sampling moment). Navel inflammation can be caused by environmental conditions during transport (e.g., lack of bedding on the truck, overcrowding) or by farm management practices before transport to the collection center (e.g., poor hygiene, lack of navel antisepsis) (6, 28). In the current experiment, it is likely that navel inflammation was already present at the dairy farm, because all calves were transported on a straw bedding and transport density was not high. Therefore, preventive measures at the dairy farms (high hygiene status, early intake of high-quality colostrum, navel dipping) are necessary to avoid this condition in the veal farm (6). Loose or liquid manure increased over time in the first 3 weeks at the veal farm. The prevalence of loose or liquid manure at day 1 post-transport was lower than reported by Wilson et al. (21) (5 vs. 16%), but higher in week 3 post-transport (39 vs. 17%). It appeared that, besides transport, calves struggled to adapt to a new feeding regime (based on milk replacer diets) at the veal farm. In addition to gastrointestinal problems, clinical signs of respiratory disease, gradually increased at the veal farm. Respiratory disease in white veal calves is often of a slow progressive nature, and likely due to presence of maternal immunity and frequently applied metaphylactic antimicrobial therapy (29). The starting prevalence of respiratory disease indicators was in line with the prevalence of bovine respiratory disease (BRD) shown by Pardon et al. (30) in the first 17 days post-transport at the veal farm (<5%). However, in Pardon et al. (30), 40% of calves showed signs of BRD at day 18 post-transport, a prevalence much higher compared to the 4% in the current experiment. However, prevalences obtained in different studies may be difficult to compare, because of differences in health protocols: the current experiment separately considered nasal discharge, coughing or abnormal breathing as clinical signs of respiratory disease, whereas Pardon et al. (30) defined BRD cases based on the simultaneous presence of depression, cough, higher rectal temperature and nasal discharge. Pardon et al. (31) reported peak prevalences of respiratory disease in veal calves between 2 and 6 weeks post-transport. In the current study, the highest prevalence of coughing occurred at a later stage (between week 15 and 21 post-transport) and this might be due to a reinfection of calves with respiratory pathogens after the first weeks post-transport (29). Next to respiratory disease, the prevalence of white manure and loose or liquid manure in the last weeks of the rearing period indicates that calves might struggle to adapt to the feeding scheme at the veal farm. Besides these health problems, there were no significant differences between the experimental treatments in prevalence of other health problems from week 5 until 27.

The current findings showed that health of calves destined to veal production can be already compromised at the collection center (as indicated by high prevalence of dehydration, sunken eyes and navel inflammation). Thus, in addition to transport-related factors such as examined in the present experiment, further attention on factors and (e.g., early rearing) conditions experienced by veal calves prior to arrival at a collection center is merited. The existence of relatively mild effects of transport factors on health problems in the immediate post-transport period, and the absence of significant effects in the longer term might be due to several reasons. First, it could be suggested that the transport and arrival at the veal farm as applied in the current experiment did not represent a severe enough challenge to significantly disturb the homeostasis of calves. However, this is highly unlikely given the profound overall effects of the experimental treatments on, for example, the physiological status (12) and a number of aspects of the clinical health of our calves (**Table 3**). Secondly, the collective effects of the transition of calves from the dairy to the veal farm (including transport and mixing with other calves at the collection center), and of the husbandry conditions during the subsequent rearing period (including dietary changes, and, again, mixing with other calves) might be so large that they overrule potential effects of individual transport factors as examined in the present experiment on health and adaptive capacity of calves. Thirdly, the high use of antimicrobials and medical treatments both at herd and individual calf level in the first 6 weeks of the rearing period may have masked potential effects of the transport-related factors on the health status of calves in the current experiment.

Behavior

Behavior of calves is influenced by transport (11, 32). In the current study, calves spent more time lying than standing during transport, which was similar to other studies. Eicher and Morrow (33) showed that calves had a preference for lying (70% of the trip duration). Knowles et al. (22) reported that young calves (<1 month old) spent ∼80% of their time lying down during 24 h transport duration. Overall, young calves prefer to lie more during transport compared to adult cattle (34), thus space requirements should account for these preferences. Calves not only showed more lying behavior during transport, but also directly post-transport and up to 24 h post-transport calves spent most of their time lying than standing. This suggests that transported calves might have experienced stress coupled with fatigue after the journey (32). Standing behavior almost doubled a week post-transport, suggesting that calves were beginning to recover from the journey. Calves mainly showed signs of discomfort the day and the week after transport, suggesting that transport caused a disturbance in their homeostasis and calves were able to cope with this challenge toward the end of this period. On the day post-transport, the highest prevalences of discomfort behavior were shown by calves transported in the conditioned truck and by calves transported for 18 h. Apparently, and intuitively logically, long-term transport (18 h) was more challenging to calves than short-term transport (6 h). The fact that calves transported in the conditioned truck exhibited more discomfort behavior in comparison with animals transported in the open truck warrants specific attention. This finding would suggest that transporting calves in a conditioned truck may be favorable for some health characteristics (such as naval inflammation, see above), but unfavorable in terms of behavioral signs of discomfort on the day post-transport. Again, this underlines the need for further research on conditioned transport, and its effect on calf health and behavior. Beyond the first week post-transport, discomfort behavior declined and the gradual increase in comfort behavior might be an indication that calves were adapting to the new environment. Playing behavior significantly increased until week 9; beyond this age the prevalence of this behavior remained relatively low. These changes might be age-related, but may also have been affected by the reduction in space availability in the pen (35). Transport-related factors did not significantly affect veal calf behavior from week 5 until 13; thus, similar to health, the various transport-related factors examined in the present study seemed to exert significant effects on behavior in the short term only.

Slaughter Characteristics

In the current study, transport-related factors had no significant effect on either carcass weight, meat color, or conformation class. Notably, carcass weight was negatively related to the number of individual medical treatments. These results are in line with Pardon et al. (36) who demonstrated that antimicrobial drug use (ADU) was negatively associated with hot carcass weight of veal calves. Every increase in ADU by 1% was associated with 1.5 kg loss in hot carcass weight. Pardon et al. (36) also showed that carcass weight decreased severely with an increasing number of episodes of bovine respiratory disease and diarrhea. Moreover, Pardon et al. (36) showed that the odds for undesirable red meat color were lower with an increase in ADU (OR = 0.86 per percentage increase in ADU; 0.95-CI: 0.76–0.98; $P < 0.05$). This was in contrast with the results of the current experiment that revealed a tendency to darker meat color in calves treated >2 times with medicines. It can be hypothesized that calves which received more than two medical treatments were the ones that were more sick and lagging in condition.

CONCLUSIVE REMARKS

The current study shows that pre-transport diet and type of vehicle affected health and behavior of veal calves in the short term, but had no effects in the long run, including on slaughter characteristics. Perhaps transport-related effects were masked due to multiple use of medical treatments in the first weeks after arrival at the veal farm. Additionally, it might be assumed that the collective effects of the transition from the dairy farm to the veal farm, and of the husbandry conditions during the subsequent rearing period, on the adaptive capacity of calves were so large that the effects of individual transport-related factors were overruled. Despite the lack of treatment effects, the high prevalence of health problems merits more research on strategies to improve health of calves at the veal farm. Further studies are needed on ways to increase the resilience of veal calves during the transition from the dairy farm to the veal farm. These studies should also address transport-related factors in combination with (innovative) husbandry strategies both at the dairy farm and at the veal farm. Correspondingly, there is a need to define and record the (required and appropriate) environmental and climatic conditions and factors during conditioned transport of young calves, and to further study their relationship with calf health and welfare.

DATA AVAILABILITY STATEMENT

In principle, the raw data supporting the conclusions of this article are confidential. However, upon request to the corresponding author, data sharing will be considered after consultation with the stakeholders.

ETHICS STATEMENT

The animal study was reviewed and approved by Central Committee on Animal Experiments (the Hague, the Netherlands; Approval Number 2017.D-0029).

AUTHOR CONTRIBUTIONS

FM wrote the manuscript and performed the statistical analyses. HB, BK, BE, MW-F, and KR contributed to manuscript revision, read, and approved the submitted version. All authors contributed to the conception and design of the study.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2020.576469/full#supplementary-material

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A Perspective on the Use of Sexed Semen to Reduce the Number of Surplus Male Dairy Calves in Ireland: A Pilot Study

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The production of surplus male offspring illustrates a socioethical concern in the dairy industry. In this article, we highlight the animal health and welfare implications of production outputs for surplus dairy calves, namely veal production, dairy calf to beef production, and euthanasia. Moreover, we present a pilot study focus on exploring the perception of key industry actors within the dairy industry in Ireland regarding the use of sexed semen as a mitigation strategy to reduce the production of surplus male dairy calves. A pilot survey was completed by farmers ($n = 6$), veterinarians ($n = 17$), and dairy farm advisors ($n = 11$). All the veterinarians, 80% of the farmers, and 62% of the advisors believed that the use of sexed semen had a positive influence on herd welfare. All participants identified the same barriers to the implementation of sexed semen: lower conception rate, lower availability, and higher cost. The reviewed literature highlights the importance of tailored communication to support knowledge exchange between stakeholders and key industry actors such as dairy farmers, their veterinarians, and advisors. Research to understand stakeholders' perception is pivotal to address socioethical concerns such as the surplus male dairy calves.

Keywords: animal welfare, stakeholder knowledge, sexed semen, bobby calves, surplus offspring, neonatal mortality, veal calves, bull calves

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INTRODUCTION

The increased demand for animal products led to the industrialization of the agriculture system in the northern hemisphere in the mid-nineteenth century, in particular milk production has increased exponentially per farm, per cow, and per input of feed and labor (1). Retailers' control of milk supply chains has enabled supermarkets to sell milk below production cost to attract customers (1). Inevitably, the low retail pricing has put dairy farmers under financial pressure, which has been a driver to herd expansion for farmers to remain competitive (2). Following the abolition of milk quota in the European Union, dairy herd expansion was encouraged by the Irish government and supporting research bodies. To maintain economic sustainability, dairy farmers in Ireland followed this guidance to expand their herd (3).

Between 2015 and 2016, milk production in Ireland increased by 18.5%, supported by an increase in the number of dairy cows by 23% from 2013 to 2017 (4). Irish dairy farming is seasonally grassland-based, providing a lower cost production system by maximizing pasture utilization. Compact calving in the spring is a key strategy to support production efficiency and is characterized by a 6-week calving period. Compact calving has increased from 61 to 72%, and the mean calving date has advanced from the 11th to the 3rd of March between 2008 and 2017; by 2018, 84% of calvings occurred between January and April (compared with 74% in 2008) in Irish dairy herds (5). Such technical successes have been achieved in spite of ongoing labor challenges (5).

At the same time, there is growing political emphasis on environmental and social sustainability of agriculture, and farmers are seen as the actors best positioned to improve their sustainability credentials and safeguard animal health and welfare, which may in the short-term impact economic returns (6). Animal welfare (AW) is an ethical concept and is subject to societal input (7). The management of surplus male dairy calves is an emblematic example of the ethical context of AW (7). The low economic value of male dairy calves, of Jersey and Jersey-cross sires influences the production outcomes. In Ireland, there are three main outcomes for surplus male dairy calves: export to continental Europe for veal production, dairy to beef production, and euthanasia. Societal concerns have been expressed, in the national and international media, regarding live exports and euthanasia of young calves. Alternatives to the production of low-value surplus male dairy calves are required to mitigate against reputational risks to the industry and the corresponding social license to operate. Such alternatives may include novel breeding or selection methods, the use of less-specialized breeds which may have additional advantages, such as improved resilience, or rearing animals for special markets (8). For example, embryo sex predetermination has been a goal of the beef and dairy production system since its industrialization (9). Despite being available since 1990s, this technique is not widely used, particularly in Ireland where sexed semen needs to be imported (8). Most of the research on sexed semen deals with technical aspects of sex determination and breeding of dual-purpose breeds, and there is little on the knowledge and preferences of actors working in the dairy sector regarding this alternative solution. To date, only a limited number of stakeholders' views on surplus male dairy calves have been identified (10), and currently, there is no evidence on industry actors' views on strategies for avoiding surplus male dairy calf production in Ireland. This indicates a need to understand the various perceptions of sexed semen that exist among industry actors namely, farmers, veterinarians, and advisors.

To move away from the production of surplus offspring, the Federation of Veterinarians of Europe highlighted the need to promote key stakeholders' collaboration to address and design new solutions (11). In this regard, understanding stakeholders' views and values of AW concepts can lead to more effective development of collaborative knowledge exchange, policies, and management of initiatives directed at improving AW, socially accepted, and thus sustainable livestock farming practices (12, 13). Our thesis is that industry actors play an important role for the implementation of an alternative solution to surplus male dairy calves. We use a pilot study to illustrate the AW implications of surplus male dairy calves, factors that influence the use of sexed semen and show how the perception of actors in the dairy sector in Ireland influences the decision-making process.

ANIMAL WELFARE IMPLICATIONS FOR SURPLUS MALE DAIRY CALVES

Unlike female dairy calves, which can be reared as replacement heifers, male dairy calves, especially of Jersey and Jersey crossbreed, are surplus to requirements and depending on the breed may be unsuitable for beef production. Dairy farmers in Ireland are currently faced with three main options: live export for veal production (production of food not for human consumption, such as pet food), calf to beef production (excluding Jersey and Jersey crossbreeds), or euthanasia (14). **Figure 1** shows a summary assessment of the main AW outcomes for surplus male dairy calves by modifying the Welfare Quality® Four Principles of Good Feeding, Good Housing, Good Health, and Appropriate Behavior during transport and at killing (15).

Veal Production or Bobby Calves

There is no viable veal production industry in Ireland. Male dairy calves destined for veal production in continental Europe are exposed to stressors during marketing and transport within 2 weeks of birth (8). When animals are sold through markets, travel time and fasting may be prolonged, and grouping with unfamiliar animals is increased presenting significant hazards to calf health and welfare (16). In New Zealand, calf mortality was reported at 0.12% in 2016 (17). Long distance transport of young male "bobby" calves in Australia to slaughter plants was associated with approximately 0.6% mortality during transport due to adverse environmental stressors (18). In Ireland, calves are exported by road, sea, and air to continental Europe for veal production (19). Irish animals travel to the Continent on roll-on, roll-off ferries direct from Ireland to France (a sea journey of around 18.5 h) (19).

Dairy Calf to Beef Production

Dairy to beef production, which utilizes male dairy calves, has been reported to be a more efficient way of producing beef (20). Approximately 50% of beef in the UK originates from the dairy herd (21), 18% of dairy calves are raised as young bulls in France, and 20% are crossbred between a dairy dam and a beef sire (22). While research from Denmark on dairy calf to beef production has encouraged farmers to increase the use of beef breed sires by approximately 20% (23), currently, it accounts for 12% and 8% in Sweden (24).

Euthanasia

The killing of surplus offspring might not be an AW issue *per se*, provided that the killing is performed humanely following best practice (25). There are several AW risks with on-farm euthanasia, for instance the application of inadequate killing methods or the treatment of the animals before killing, particularly since they lack economic value (26). In addition to AW considerations, the killing of surplus male livestock raises moral concerns as the animal is seen as an surplus "by-product" or waste, which disrespects its intrinsic value (26).

FIGURE 1 | Summary assessment of the animal welfare (AW) outcomes of young male dairy calves during transport (blue frame) and killing (light green frame), modified from Welfare Quality's® four principles: Good Feeding (yellow frame), Good Housing (green frame), Good Health, and Appropriate Behavior (light green and blue frame). List of main hazards (in the internal rectangular boxes) and welfare outcomes (in the external circles) in young male dairy calves.

SEXED SEMEN AS AN ALTERNATIVE SOLUTION

Flowcytometric separation of X- and Y-bearing semen (sexed semen) was first adopted for cattle breeding in 1989 (27). The main purpose of this technology is for production of higher genetic merit heifers. Despite the technology advancements including 90% female determination (8, 28), genetic gain (29), and reduced incidence of dystocia (8), the implementation of sexed semen on-farm is influenced by the reduced conception rate (CR) and the additional cost (€38 vs. €18 sexed vs. conventional semen in Ireland) compared with conventional artificial insemination (8).

Industry Actors' Knowledge on Sexed Semen Use—Pilot Study

A pilot survey was completed online by farmers ($n = 6$), veterinarians ($n = 17$), and advisors ($n = 11$) involved in dairy production in Ireland. Data were collected *via* an anonymized online web-based survey distributed by representative organizations involved in the dairy sector, using snowball techniques. A draft of the survey was peer reviewed by two national experts in genetics and breeding prior to finalization. Three surveys were developed, designed for each industry actor's category to explore the perception of the use of sexed semen and its potential to support dairy cow and calf welfare. The surveys were structured in four parts: (i) general information about farming experience, herd size, and frequency of sexed semen use, (ii) the advantages of using sexed semen, for example, for AW, biosecurity, productivity, to reduce male calves, and to increase heifer calves born; (iii) the disadvantages of sexed semen, for example, commercial and breed availability, price, and low conception rates (CR); and (iv) the perceptions of the use of sexed semen including knowledge (cost, CR, use) and social influencers (media, advisors, veterinarians, producers).

RESULTS

Experience working in the dairy sector varied with industry actor's category. Veterinarian respondents had on average 8 years in practice (range 3 to 23 years), advisors 15 years (range 1 to 32 years), and farmers had 32 years (range 12 to 43 years) of experience. Herd size of veterinarians' clients ranged from a mean small herd size of 27 animals (range 12 to 50) to a mean large herd size of 689 animals (range 250 to 2,000). The advisors' clients ranged from a mean small herd size of 37 animals (range 20 to 70) to mean large herd size of 524 animals (range 250 to 1,000). Farmers had a mean herd size of 135 animals (range 70 to 222). All the farmers questioned had increased their herd size since the end of milk quota by an average of 45 animals (range 15 to 92). **Table 1** summarizes the survey's responses.

All the veterinarians (17/17), 80% of the farmers (5/6), and 62% of the advisors (7/11) believed that the use of sexed semen had a positive influence on herd welfare. Veterinarians researched the use of sexed semen more than advisors or farmers and commented on the benefit to AW of using sexed semen to improve calving, for example, "*heifers have easier parturition and smoother transition to lactation,*" more time for calves, for example, "*A farmer will always (sometimes subconsciously) look after heifer calves better,*" and farmer labor "*as it improves farm efficiency then it decreases farm workload etc. which would have a positive knock-on effect on welfare.*" Advisors who commented on the positive impact of sexed semen often used an economic frame of reference, for example, "*it may have some effect if the calves for sale are higher in value then they may be looked after better vs. a low value calf destined for sale,*" "*in theory more heifers and less bulls but conception rates have been low,*" and "*there is enough easy calving sires available through conventional semen.*"

When asked general questions about use, cost, and conception rate, farmers estimated that average sexed semen conception rate was 61% (range 50 to 76%), advisors estimated 60% (range 50 to 85%), and veterinarians 64% (range 50 to 80%). Performance was a determinant of whether to use sexed semen, for example, "*I don't agree with using it on heifers because you could be breeding the next generation from unproven animals*" (veterinarian), "*conception rates are low normal around 40%. Top bulls not available*" (advisor).

The average cost of a straw of semen was estimated at €38 (range 25 to 48 euro) by advisors, €35 (range 14 to 60 euro) by veterinarians, and €46 (range 38 to 60 euro) by farmers. A smaller proportion of advisors (4/11) and farmers (1/6) believed that sexed semen justified the investment, whereas 87% of the veterinarians (15/17) agreed that the benefits of sexed semen justified the investment. A key benefit referred to by industry actors was genetic gain; for example, "*Once the conception rates mirror those of normal (non-sexed) semen then it is a no-brainer for dairy farmers as a tool to improve farm productivity*" (advisor), "*more renewal of herd with less losses in male dairy calves and quicker genomic selection*" (advisor), "*increase productivity of dairy farms*" (veterinarian). In contrast financial issues were a disincentive, for example, "*due to expansion of herd size and associated costs many farmers cannot allocate the time and resources*" (advisor), "*if conception rates are low due to sexed semen, then it can create knock on problem for the milking herd, for example, loss of production with lower number of cows calving down in the first 3 weeks*" (advisor).

When asked about knowledge on the use of sexed semen, advisors (7/11) and veterinarians (14/17) indicated a wider use whereas farmers (6/6) reported that they would only use sexed semen as a replacement strategy for heifers. Farmers (4/6) used sexed semen but mainly in heifers, often for performance reasons, for example, "*used in strong heifers, very poor results in cows*" (advisor), "*only heifers perceived as too expensive with low conception rates in*" (veterinarian).

TABLE 1 | Survey responses (expressed in percentage and euro) of farmers ($n = 6$), veterinarians ($n = 17$), and advisors ($n = 11$) involved in dairy production in Ireland, to explore the knowledge and perception on using sexed semen to reduce surplus male offspring.

Perceptions[a]	Factors	Farmers (%)	Advisors (%)	Veterinarians (%)
Advantages	Increases heifer calves born	67	100	87
	Reduces male calves born	100	88	73
	Increases productivity	33	25	53
	Improves biosecurity	0	12	27
	Improves cost benefit	20	38	87
	Improves herd welfare	80	67	100
Disadvantages	Conception rates	100	100	86
	High costs	83	50	73
	Breeds availability	33	75	75
	Commercial availability	17	13	40
Knowledge	Costs	46 euro	38 euro	35 euro
	Heifer use	100	38	20
	Conception rate	61	60	64
Social influencers	Producers	50	67	38
	Veterinarians	0	27	15
	Advisors	50	67	75
	Media	0	33	13

[a]*Questions asked about sexed semen technology were as follows: Advantages: it increases heifer calves born; it reduces male calves born; it increases productivity; it improves biosecurity; it improves cost-benefit; it improves herd welfare. Disadvantages: it reduces conception rates; it has high costs; not many breeds available; it is not commercially available. Knowledge: how much sexed semen cost; what is the desired use of sexed semen; what is the conception rate using sexed semen. Social influencers: producers influence the use of sexed semen; veterinarians influence the use of sexed semen; advisors influence the use of sexed semen; media influence the use of sexed semen.*

When asked who or what was the main influencer for farmers deciding to use sexed semen advisors believed that they were the main social influencer (75%; 7/11) followed by salespersons (50%; 5/11, i.e., AI tech companies). The majority of the veterinarians believed that both peers (67%; 10/17) and advisors (67%; 10/17) were the main influencers for farmers. Few veterinarians believed that they influenced the farmer's decision (20%; 4/17) and indicated that salespersons had a greater influence (33%; 5/17). Farmers recognized their peers (50%; 3/6) and advisors (50%; 3/6) as having the main influence on their decision to use sexed semen. Farmers also identified their own research activities as the major influence on their decision (80%; 4/6).

DISCUSSION

This pilot study presents a perspective on the knowledge and understanding of key actors in the Irish dairy sector on the application of sexed semen as a potential mitigation strategy to reduce the production of surplus male dairy calves. Production outputs for male dairy calves, depending on the breed, include dairy calf to beef, veal production and, where there are no cost-efficient alternatives, euthanasia. In Ireland, as there is no viable veal industry, calves are exported live to continental Europe, used in dairy calf to beef, and or euthanized. Whatever the production output, it is essential that calf welfare standards are maintained.

The pilot survey identified that sexed semen was used mainly to improve genetic gain, it showed concerns over reduced pregnancy rates in cows and preferential use in heifers, findings which are in agreement with Holden and Butler (8). The key determinants for the survey participants were the lower conception rates achieved with sexed semen compared with conventional semen and lack of availability of sexed semen from high genetic merit sires in Ireland. The barriers to using sexed semen identified in this pilot study were similar to Johnson (9) even if recent evidence asserted that sexed semen can be successfully used in both heifers and multiparous cows, high-value bull semen is widely available in most of the developed countries, and methods of extended semen storage, particularly for liquid semen are in place (28, 29).

Moreover, the pilot survey's respondents perceived the cost of sexed semen as a barrier. Interestingly, veterinary practitioners and farm advisors estimated the cost to be higher than farmers. In-depth interviews with Swedish farmers revealed a number of concerns regarding the use of sexed semen for production of higher genetic merit heifers, namely lower conception rates, more difficult calving and increased stillbirths, an increased risk of disease transmission, and that sexed semen was considered were more time consuming and could lead to poorer animal welfare, such as calving difficulties and diseases (30). Some of the perceptions by Swedish farmers are not based on current evidence and demonstrate suboptimal dissemination of research findings and knowledge exchange. Other studies have reported asymmetrical perception (31) and poor communication (32) between farmers and their veterinarians.

Knowledge and tailored communication for effective understanding between the farmer and veterinarian were the most important factors influencing uptake of AW innovations (33). Undoubtedly, knowledge empowers people in decision-making and behavioral change. Since the late 1980s, Hemsworth (34) showed a positive correlation between knowledge and willingness to improve AW.

Lack of knowledge has been identified as the cause of failure to recognize problems, also referred to as farm blindness "a misperception by farmers that what they see every day on their own farm is normal" (35). In this regard, farm blindness is less likely to happen when farmers engage in knowledge dissemination, for example, farming discussion groups (36).

While the majority of each industry actor cohort agreed that sexed semen could positively impact AW, only veterinarians believed that the benefits of sexed semen justified the investment to improve AW. The financial costs of implementing improved AW practices were identified as a key external factor influencing farmers' perspectives of AW by Balzani and Hanlon (12). However, the issue of management of surplus male dairy calves goes beyond external costs, because of the implications for reputation risk to the industry. Accounting for reputational risk into a cost-benefit analysis may provide an important decision-making tool to support the implementation of sexed semen to reduce the number of surplus offspring.

The pilot survey explored industry actors' perceptions of key influencers. There is increasing evidence about models of communication between scientists, veterinarians, advisors, and farmers. Indeed, Vigors (37) reported that "the words used to communicate AW to non-specialists may be more important than knowledge of welfare itself." Outcomes of 110-veterinarians and 116 farmers interviews about dehorning cattle showed that veterinarians had a poor understanding of farmers' priorities, that affected their guidance on methods to improve calf welfare (38). In this context understanding farmers' goals was a key skill for veterinary practitioners to encourage improvement of AW (39). Furthermore, a review on farmers' and veterinarians' attitudes toward cattle welfare showed that the farmer–veterinarian cooperation reduced barriers to improvements in dairy cattle welfare, achieved by identifying shared concerns about AW, reframing their unique perspectives as complementary roles, and promoting communication about priorities and goals (40).

Several authors concluded that beliefs and acceptance among farmers may be influenced through a communication strategy (33, 35, 41). Purwins and Schulze-Ehlers (42) suggested that there may be a value in facilitating positive word-of-mouth. The same view has been proposed by Horseman (43) of farmers sharing their positive experiences on handling facilities, and by Hennessy and Heanue (36) testing farmer action and discussion groups for effective peer-to-peer learning. Duval (44) used a participatory approach to enhance knowledge exchange between farmer and scientist.

Study Limitations

This pilot study served to explore perception and knowledge among dairy farmers, farm advisors, and veterinarians in Ireland regarding sexed semen as a mitigation strategy to address surplus male dairy calves. The authors acknowledge that the pilot study contained a small and imbalanced sample size. However, the insight provided by the pilot survey serves as a guide for further investigation. Follow-on studies would benefit from engaging with more stakeholders including the processors and consumers.

CONCLUSION

The use of sexed semen will not entirely eliminate the problem of surplus male dairy calves, as other strategies are needed to reduce the numbers of surplus female dairy calves. The use of beef sires in dairy herds would produce both male and female calves that have a higher value for the beef and veal markets (11). According to Seidel (20), beef production is on the cusp of change, and by 2050, he envisaged that beef sucklers will be replaced by the use of sexed semen, and the establishment of dairy calf to beef systems. This shift in the beef industry would reduce the GHG emissions (45), partially addressing societal concerns regarding surplus dairy calf production and climate change (8).

While sexed semen is a promising mitigation strategy, its implementation may elicit societal ethical concerns that are underexplored (46). However, the alternatives to sexed semen such as live export of young calves for dairy-beef or veal production and euthanasia, may also conflict with societal views (47). Ethical analysis of livestock production science is increasing, providing an important contribution to the development of policy and practice (48). Farmers have been left in a difficult position, and societal debate and greater stakeholder engagement is required to support major changes in policy such as dairy herd expansion and the *socioethical concern* of surplus male dairy calves (49).

Whether mitigation strategies are adopted will depend on resources, the interest, and knowledge of industry actors and other stakeholders. Therefore, stakeholders' perception is pivotal to understand barriers to behavioral change and supporting AW innovations. Further research is required to engage the full spectrum of stakeholders to identify the most effective means of strategic support for dairy farmers to reduce the production of surplus calves.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The study complied with UCD Research Ethics Guidelines and qualified for exemption from full ethical approval by the University College Dublin Human Research Ethics Committee (UCD HREC) (LS-E-18-151-Hanlon). The participants provided their informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The survey was designed by AH and CA. CA performed the data collection. AB performed the data analysis for the manuscript and developed the first draft of the manuscript. AH reviewed and amended the manuscript during its development. All authors contributed to the article and approved the submitted version.

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REVIEW
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Perspectives on the Management of Surplus Dairy Calves in the United States and Canada

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The care of surplus dairy calves is a significant issue for the United States and Canadian dairy industries. Surplus dairy calves commonly experience poor welfare as evidenced by high levels of mortality and morbidity, and negative affective states resulting from limited opportunities to express natural behaviors. Many of these challenges are a result of a disaggregated production system, beginning with calf management at the dairy farm of origin and ending at a calf-raising facility, with some calves experiencing long-distance transportation and commingling at auction markets or assembly yards in the interim. Thus, the objectives of this narrative review are to highlight specific challenges associated with raising surplus dairy calves in the U.S. and Canada, how these challenges originate and could be addressed, and discuss future directions that may start with refinements of the current system, but ultimately require a system change. The first critical area to address is the management of surplus dairy calves on the dairy farm of origin. Good neonatal calf care reduces the risk of disease and mortality, however, many dairy farms in Canada and the U.S. do not provide sufficient colostrum or nutrition to surplus calves. Transportation and marketing are also major issues. Calves can be transported more than 24 consecutive hours, and most calves are sold through auction markets or assembly yards which increases disease exposure. Management of calves at calf-raisers is another area of concern. Calves are generally housed individually and fed at low planes of nutrition, resulting in poor affective states and high rates of morbidity and mortality. Strategies to manage high-risk calves identified at arrival could be implemented to reduce disease burden, however, increasing the plane of nutrition and improving housing systems will likely have a more significant impact on health and welfare. However, we argue the current system is not sustainable and new solutions for surplus calves should be considered. A coordinated and holistic approach including substantial change on source dairy farms and multiple areas within the system used to market and raise surplus dairy calves, can lead to more sustainable veal and beef production with improved calf outcomes.

Keywords: dairy bull calves, animal welfare, veal, sustainability, calf health

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INTRODUCTION

Each year a portion of calves born on dairy farms are either unsuitable or not required to replace the milking herd, and these calves are commonly referred to as "surplus" animals. Surplus calves are 95% male (1–3) and the sale of these animals generally provides only a small percentage of income for dairy producers. The remainder of surplus calves are comprised of females not retained in the herd because enough replacement animals can be produced from 60% of the lactating herd (4) and infertile females that are a twin to a male calf. Historically, surplus dairy calves have been viewed as a "low-value by-product of the dairy industry" (5), which potentially results in surplus calves receiving poorer care than is given to calves perceived as "valuable" by dairy producers and calf raisers. In the United States and Canada, surplus calves are generally sold from the dairy farm of origin within days after birth, and common market destinations include "bob" veal (marketed <3 weeks of age and 150 lb), "formula-fed" or "special-fed" veal which accounts for the largest proportion of surplus calves (marketed at ∼20 weeks of age) (6), or dairy-beef (marketed at 12–14 months of age) (7). Most surplus calves in the U.S. and Canada are raised for meat; however, it is not uncommon for calves to be euthanized on the dairy farm shortly after birth. Approximately 5% of dairy farmers in Canada reported euthanizing at least one male calf at birth (8). The driving factors of euthanizing male calves after birth is unclear; however, it is likely driven by the lack of market demand.

Historically, surplus calf production systems, including veal farms, have struggled with negative stigma, including societal concerns about animal welfare (9). Calves are removed from dairy farms as neonates (10), and are often transported long-distances with one or more stops at auction markets or assembly stations (11, 12) before arriving to calf raisers where they are housed individually and fed low planes of nutrition (13). Poor care surplus calves receive during the first few weeks of early life contributes to high rates of morbidity and mortality. Previous research has shown surplus dairy calves arrive to calf rearing facilities in the U.S. (11) and Canada (2) in poor health with signs of discomfort due to disease (14). Despite public scrutiny, little research has been done to determine best practices to promote the care of these animals. The research to date has mainly focused on characterizing problems within the current system, while less work has focused on corresponding solutions. The goals of this narrative review are to: (1) summarize current early life challenges of surplus dairy calves in the U.S. and Canada, (2) identify how such challenges originate and could be addressed, and (3) propose short- and long-term considerations for addressing these problems, including the development of an industry vision for how to manage these animals using perspectives from multiple stakeholders.

CHALLENGES WITH THE CURRENT SURPLUS CALF PRODUCTION CHAIN

Surplus dairy calves face significant health and welfare challenges shortly after birth. Male surplus calves may be especially vulnerable to poor outcomes due to a lower standard of care after birth compared to female calves that remain in the herd as replacement animals (10, 15). Despite this, there is no mechanism for recording important aspects of calf care that may not be evident when they are marketed (e.g., colostrum provision and navel antisepsis). After leaving the dairy farm, calves often have long transport times and irregular feeding schedules (16). Additionally, commingling with unfamiliar animals from multiple sources and exposure to livestock markets are significant risk factors for disease spread (17). Thus, the early management of surplus dairy calves presents a significant risk to calf health, and such management practices are inextricably linked to their welfare and ability to thrive within veal and/or dairy-beef production systems.

Management on Dairy Farms

Successful health outcomes for calves entering veal and dairy-beef production rely on appropriate husbandry on the dairy farm of origin. Calf care requires substantial time on dairy farms; however, it results in little to no immediate financial payoff, which is especially true for surplus dairy calves. For example, Wilson et al. (18) found for Canadian producers the necessary time and effort to care for newborn calves were barriers to the adoption of better management practices, especially for male calves. In interviews, dairy producers discussed an ethical desire to take good care of neonatal calves, but their actions were frequently misaligned (18). Specifically, male calves often receive worse care after birth than female calves on dairy farms. For example, Canadian studies have found males are more likely to receive colostrum with bacterial contamination (19) and lower volumes of colostrum (20) than female calves. Less research has been done in the U.S., however, (10) found male calves were more likely to be fed *via* different routes (e.g., suckling the dam) with a longer delay to the first feeding of colostrum. As a result of differences in colostrum feeding practices, male calves on Canadian dairy farms had lower serum total protein (used to determine successful passive transfer of immunity) than females (20). These results indicate improved colostrum feeding practices are needed for male calves.

In addition to FTPI, many calves experience health challenges. For example, 37% of male calves had at least one health abnormality such as diarrhea or navel disease at dairy farms before transportation to a calf raiser (21). This study further identified the importance of calf health on the dairy farm, as the presence of health abnormalities on dairy farms was significantly associated with subsequent mortality risk at the calf raiser.

Transportation

Many countries have transportation regulations to meet the needs of young animals which may differ from mature animals. For example, (22) and the European Union (23) require that transported calves' navels are healed and dry and are a minimum age of 4 and 10 d, respectively. Comparatively, the U.S. and Canada have fewer requirements for animals in transport. Canada recently introduced new regulations that limits transport duration of pre-weaned calves to 12 consecutive hours before requiring access to food, rest, and water (24). The new Canadian regulations also state that calves shipped to assembly yards or auctions must be 9 days of age or older, and that calves have healed navels in order to be transported. In the U.S. pre-weaned calves fall under the transportation regulations established for all food production animals which limits transport to no more than 28 continuous hours (25).

There is a paucity of information regarding the distance or length of time calves are transported in the U.S. and Canada. A study in the U.S. estimated calves 7–10 days of age were transported between 450 and 977 km from livestock auctions in the northeast to calf raisers in Ohio (11). In the northwestern U.S. and western Canada, calves (animals weighing <275 kg) can be transported over 1,300 km (16). While exact transport durations have not been recorded, an expert panel reported that across Canada calves are frequently transported between 12 and 16 h (12). Outside of these studies, there is no research in the U.S. and Canada to our knowledge that describes the distance surplus calves are transported from dairy farms to livestock auctions and/or calf raisers.

Transportation includes multiple stressors such as handling, commingling with unfamiliar animals, exposure to new environments, food and water deprivation, and fluctuating temperatures (26). Feed and water deprivation during transportation likely contributes to the large number of calves that are dehydrated (27, 28) and in poor body condition (28, 29) upon arrival to calf raisers. Beyond physical changes, feed deprivation for long periods of time likely results in severe hunger and thirst. Expanding views of animal welfare include affective states, and to address these concerns, it may be prudent to better understand transport from the calf's perspective. Young calves may experience fear in response to novel environments (i.e., the trailer, auction, and new housing) and handling. An understanding of the calves affective state in response to transport should be used in conjunction with physical changes to inform future policy changes.

Livestock Auctions

Livestock auctions are the most common destination for calves after leaving the farm. Roughly 40% of male calves born in the U.S. are sold through auctions, with the remainder sold directly to a calf raiser (30%) or dealer (18%) (30). Most small (68%) and medium (58%) sized herds sell surplus calves through an auction, whereas large farms more commonly sell calves directly to a calf raiser or another type of grower (30). Similar to the U.S., the majority of surplus calves in Canada are sold through auctions with a smaller proportion of calves sold directly to calf raisers (12). Marketing calves through auctions or other avenues was found to be largely dependent on region. Although auctions provide an avenue for buyers to visually assess animals, there are several significant health and welfare challenges that occur due to this method of marketing.

Livestock auctions represent a high biosecurity and infectious disease risk (31). Auction markets frequently assemble multiple livestock species, including adult cull cattle and neonatal calves, from different source farms in a common environment. Furthermore, most auction facilities cannot be effectively cleaned and disinfected, and thus, are a common point of direct or indirect transmission of infectious diseases. Multidrug resistant strains of *Salmonella* spp., a bacterium known for intestinal outbreaks in calf populations, including Dublin, Typhimurium, and Newport are common causes of disease outbreaks at veal and dairy-beef facilities (32). Surplus calves, which frequently have FTPI (11), are particularly at risk for infection. The exposure and infection of surplus calves at auctions facilitates the dissemination of pathogens that are important causes of disease in cattle and humans.

The health status of surplus calves delivered to livestock auctions likely influences both the spread of pathogens and subsequent disease susceptibility. At livestock auctions in Quebec and British Columbia, 43 and 21% of calves, respectively, had at least one health abnormality identified during a clinical exam (28, 33) which highlights that many calves arrive to auctions with health challenges. Health abnormalities included omphalitis, nasal or ocular discharge, depressed attitude, coughing, joint inflammation, and diarrhea. Omphalitis (characterized by navel swelling, discharge or evidence of pain) accounted for the greatest percentage of health abnormalities in both studies. Surprisingly, Marquou et al. (33) reported 12% of calves had neonatal characteristics (wet or difficulty standing) and 7% had wet umbilical stalks or navels, which may suggest calves arrive to auctions younger than previously reported. It is unclear if health abnormalities observed at livestock auctions begin during transport or on the dairy farm. Further research could help identify if transportation to auction markets contributes to development of health abnormalities observed in surplus dairy calves. Furthermore, livestock auctions negatively impact the affective state of young calves. Livestock auctions may not be equipped to routinely provide feed or water, and the abrupt commingling with unfamiliar animals causes additional stress. Wilson et al. (28) described the condition of pre-weaned calves at a livestock auction in British Columbia. The authors found calves did not have access to forage, milk, or water at the auction facility. Calves were housed in group holding pens, until the time of sale, then calves were most commonly placed in a sale ring alone. Once sold, calves were moved to a pen with access to a chute system that included a ramp to load calves onto a livestock trailer. Depending on the length of subsequent transport, calves likely experience long durations without access to milk or water; resulting in hunger and dehydration (34–36). Further, commingling with unfamiliar animals (37) and novel environments (38) are substantial social stressors for dairy calves.

Calf Raisers

Surplus calves arrive to calf raisers in variable health condition, sometimes already experiencing respiratory or enteric disease (3, 11). Calves that arrive to veal facilities with health abnormalities are at greater risk of morbidity and mortality (2, 27), making calf health upon arrival important from both a welfare and productivity standpoint. Various strategies to combat disease have been utilized in the veal industry, including "all-in all-out" animal movement, individual housing, and prophylactic use of antimicrobials; however, our understanding of how such strategies can improve calf health needs to be further refined. Current industry practices and gaps in evidence-based best management practices are discussed throughout this section.

Calf Health

At the time of arrival to calf raisers, some calves suffer from poor body condition, navel inflammation, respiratory disease, or FTPI (11, 29, 39). Specifically, between 6 and 43% of male calves have FTPI upon arrival to calf raisers in the U.S. and Canada (11, 29, 39) and 30–60% of calves are clinically dehydrated (11, 39). Calves also frequently arrive to calf raisers in emaciated body condition or low body weight (29, 39). The presence of these health abnormalities, specifically low body weight, dehydration, and navel inflammation, are associated with increased risk of morbidity and mortality (1, 2, 27). Long durations without access to milk or water during transportation and at auction facilities, commingling, and variable care on the dairy farm of origin likely contribute to high rates of health abnormalities upon arrival to calf raisers. Importation of calves from multiple farms and commingling within livestock auctions also result in high infectious disease pressure. Severe outbreaks of clinical salmonellosis are relatively common, and result in high levels of mortality in calves (32). "All-in all-out" practices (raising calves in similarly aged groups) and other internal biosecurity measures are commonly utilized; however, the introduction of pathogens will be difficult to control as long as calves are routinely aggregated in livestock auctions prior to arrival at the calf-raiser.

Given the multiple challenges from birth to arrival at calf-raisers (**Figure 1**), the first few weeks at the calf-raiser are a high-risk period. Over an 11 week period at a calf raiser in Ontario, 7.5% of calves died and almost 90% were treated with antimicrobials at least once for disease (27, 40). Scott et al. (27) and Renaud et al. (2) also found 68% of calves were treated with antibiotics and 42% of calf deaths, respectively, occurred within the first 3 weeks after arrival to calf raisers. Consistent with the previous studies, Winder et al. (1) found 7.6% of calves died over a 20 week period and the most common reasons for death included emaciation (21%), respiratory disease (16%), gastrointestinal causes (14%), and sudden death (13%). It is likely that the condition of calves on arrival is responsible for the high rates of early morbidity and mortality, however, death caused by emaciation and respiratory disease suggest that nutrition and housing strategies are inadequate. These causes of death also imply that there is a degree of calf suffering prior to death that needs to be addressed.

Antimicrobial Usage

Current antimicrobials use rates are influenced by high disease susceptibility and prevalent health abnormalities. For example, almost 90% of calves raised at a grain-fed veal facility in Ontario were treated with antimicrobials at least once during an 11-week period (27, 40). High rates of antimicrobial use has been associated with the development of antimicrobial resistance in commensal and pathogenic bacteria within the digestive and respiratory tract of veal calves (41, 42) and increased carriage of antimicrobial resistant bacteria in calf caretakers (43). Retail grain-fed and milk-fed veal products have also harbored antimicrobial resistant bacteria, highlighting the potential for negative public health consequences (44, 45). Similarly, antimicrobial use may be associated with the emergence of a multidrug resistant strain of *Salmonella* Heidelberg in dairy calves. The strain caused severe outbreaks in calf populations and a multi-state outbreak of salmonellosis in people that resulted in 56 illnesses and 17 hospitalizations (46). A direct effort to improve calf health should be made to reduce antimicrobial use, thus limiting the development of antimicrobial and multi-drug resistant pathogens.

Housing

Housing at calf raising facilities, particularly within the veal industry, has been criticized by the public [e.g., (47)] and animal welfare groups. It is commonplace to house calves individually with limited space for the first 8 weeks following arrival to calf raisers. Individual housing of calves is used a biosecurity measure to prevent respiratory disease [reviewed by (48)], which is a leading cause of morbidity and mortality in veal calves (49). However, the potential health benefits of individual housing are inconclusive as prolonged individual housing in veal facilities (>4 weeks) is a risk factor for nasal discharge and coughing (50). Furthermore, individual housing profoundly limits calves' ability to perform natural behaviors, such as play or social grooming (51, 52). Overall, housing calves in social isolation negatively impacts their physiology, behavior, and welfare [reviewed by (48)] likely due to the lack of both physical and social stimulation. A lack of stimulation may result in boredom and lead to the development of abnormal behaviors (53). In addition to socially restricted housing environment, access to the outdoors or pasture, under most circumstances, is not provided. Limited work has evaluated indoor vs. outdoor rearing systems. A recent study in Switzerland trialed the concept of an "outdoor veal calf" raising system and found a reduction in antimicrobial use and mortality (54). In this study, calves were not moved from the source dairy until 3 weeks of age and considerable effort was made to avoid livestock markets when sourcing calves, which mitigated major challenges faced by surplus dairy calves in the U.S. and Canada.

In some parts of the U.S. and Canada, public scrutiny has resulted in regulation and policies that impact how calves are housed and raised. For example, group housing after weaning and increased space allowance per calf is required in Canada (55) and by the Veal Quality Assurance program (56) in the U.S., as well as specific state legislation. For example, veal calves raised in California must have enough room to stand up, lie down, fully extend their limbs, and turn around freely (47). In addition, management practices that physically restrict animal movement, such as tethering, are prohibited through industry

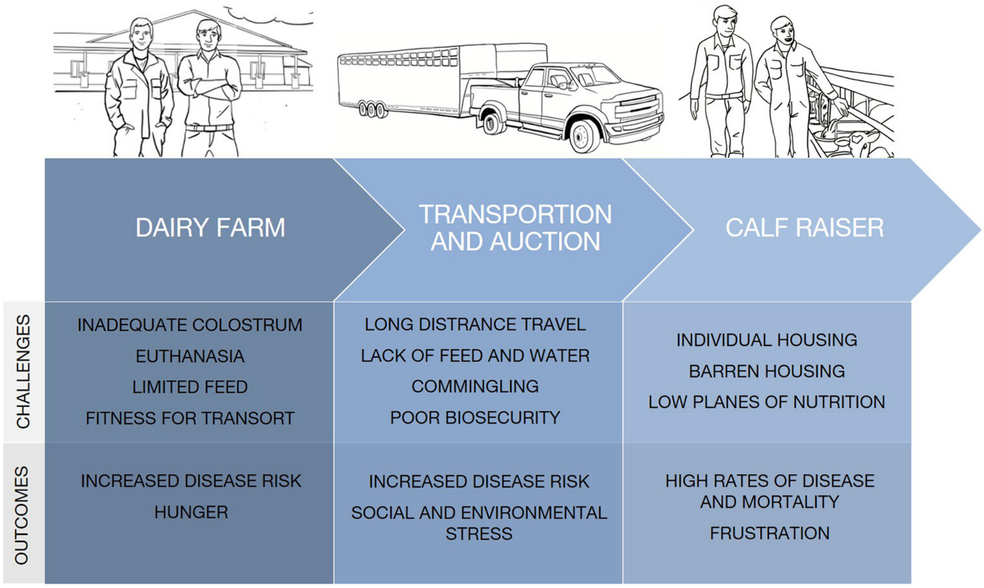

FIGURE 1 | Challenges surplus calves experience from birth through early life management. Surplus calves frequently receive poor care on dairy farms of origin, then many calves are transported long distances and may be marketed through livestock auctions before arriving at the calf raiser. Each stage of the surplus calf production system presents unique challenges to calf health, affective states, and the ability to perform natural behaviors.

and legislative initiatives in the U.S. and Canada. Changes is housing systems are likely needed to reduce disease and promote the performance of natural behaviors. However, existing facilities may require significant adjustments to meet the needs of calves as some facilities are converted structures from old barns that were not designed to promote calf health and welfare (57).

Nutrition and Feeding

Feed programs must be designed to fit the nutritional needs of calves and delivered in a way that allows them to express natural behaviors. The volume of milk fed to surplus calves at calf raising facilities in the U.S. and Canada is unclear, however, it is likely low based on estimations from publications carried out on commercial veal facilities (58). In a 2010 survey of heifer raisers in the U.S., it was found that 76% of farms fed 1.89 L of milk twice daily per calf (59). Clearly, traditional limit feeding has many negative impacts on the calf. Specifically, when compared to traditional planes of nutrition (4 L of milk or less per day), higher planes of nutrition have been associated with improved immune function, resolution of diarrhea, and greater body weight gain (60–63). In addition to poor health and growth, limit feeding results in calf hunger. While no research has been performed on surplus calves, pre-weaned female calves fed <8 L of milk per day exhibit behavioral signs of hunger (64). An additional concern with certain special-fed veal calves, specifically for milk-fed veal calves, is the contribution of feeding strategies to abomasal damage, which has a prevalence at harvest ranging from 70 to 100% (65, 66). Abomasal damage is multifactorial in origin and could be due to inaccessibility to the outdoors and water, limited forms of roughage, bucket feeding, large and infrequent milk meals, and limited space allowance [reviewed by (13)]. Feeding calves low volumes of milk reduces productivity and health and leads to negative affective states, and it is unclear why the practice persists.

Along with providing low milk volumes in surplus calf production systems, milk delivery methods typically prohibit nutritive sucking behavior. Researchers have extensively documented the behavioral and physiological importance of sucking behavior for young calves (67, 68). Sucking deprivation results in frustration (69) and the performance of oral stereotypies which indicate the calves' environment is insufficient to meet their needs (70). Even still, it is standard practice to feed milk *via* open bucket or trough instead of a nipple or bottle throughout surplus production systems in the U.S. and Canada. Alternative feeding practices, such as providing milk through a bottle or an artificial nipple (71) may partially resolve these negative outcomes.

CONSIDERATIONS FOR THE FUTURE OF SURPLUS DAIRY ANIMALS

Currently, surplus dairy calves face several challenges in early life compromising their health, welfare, and the sustainability of the dairy and surplus calf industries. Here we offer both short and long-term recommendations for improving the lives of surplus dairy calves. In the short-term, we suggest dairy producers and calf raisers adopt practices that improve care of young animals, drawing from research using both dairy heifer calves and surplus calves. We also describe alternatives to the current system, such as direct to farm marketing and breeding for dairy-beef. In the long-term, we recommend the dairy industry develop a vision for the future of surplus animals that is sustainable.

SHORT-TERM CHANGES OF THE CURRENT SYSTEM

Management From Arrival at Calf Rearing Facilities

Given health and welfare concerns, as well as concerning rates of antimicrobial use and resistance, the quality of calves arriving to calf raising facilities must improve. However, changes within calf raising facilities are also merited. Recent research has identified several calf characteristics measured at arrival to a calf-raising facility that were associated with an increased risk of morbidity and mortality as well as production losses. For example, clinical and blood measures could be used to identify and selectively manage calves that are deemed to be at high-risk for morbidity and mortality. Additional management changes at the veal or calf rearing facilities also need to be considered including providing a higher plane of nutrition, utilizing feed additives, and improving the housing environment.

Using Clinical Parameters to Identify and Manage High-Risk Calves

Several clinical indicators assessed on arrival at a calf raising facility are associated with morbidity and/or mortality. Physical indicators include the presence of an abnormal fecal consistency, umbilical infection, dehydration, cough, and a sunken flank (2, 27). As these indicators are quick, simple, and have a reasonable repeatability following veterinary training, they could be used to create a selective therapy program in which calves arriving with the presence of these health abnormalities would be classified as high-risk and treated accordingly. A selective treatment strategy could lead to more prudent antimicrobial use and lead to a reduction in the use of blanket antimicrobials at arrival. This selective strategy was attempted by von Konigslow et al. (72), where a blanket oral antimicrobial strategy was compared to therapy provided to high-risk calves. No difference in morbidity was found during the first 14 days and there was a two-thirds reduction in antimicrobial use on arrival, however, calves in the selective therapy group had a greater risk of mortality compared to those that received blanket oral antimicrobials. This suggests that the use selective therapy requires further refinement to reduce antimicrobial use while still effectively reducing disease.

Body weight upon arrival has been consistently associated with future risk of morbidity and mortality, where calves with a higher body weight have a lower risk of disease (2, 50, 73). Arrival weight was also found to be the greatest influencer on the breakeven purchase price that should be paid for calves due to the lower risk of disease but also improved growth (74). Calf raisers should be encouraged to purchase calves that have a higher body weight; however, some portions of the current system inhibit the calf raiser from having complete control of purchasing calves with high body weight. Hence, until the issues from the source dairy farm are addressed (8, 10), calf raising facilities will need to develop strategies to manage calves arriving with a low body weight. Calves could be given a higher plane of nutrition, colostrum replacer or other bioactive compounds to improve gut health or potentially provided with antimicrobials. More work is needed to both increase the body weight of calves on arrival and ensure calves with low body weight are treated and monitored optimally.

Using Blood Parameters to Identify and Manage High-Risk Calves

There has been a significant body of literature assessing the utility of blood parameters in predicting future disease risk in veal calves. Many parameters, such as haptoglobin, creatinine kinase, and cholesterol (29, 40, 73), are likely not realistic to make a rapid assessment of calves arriving on farm due to a lack of the availability of calf-side tests. There are, however, potentially practical calf-side tests that are available to identify calves at high-risk of disease based on serum proteins. For example, greater concentrations of immunoglobulin G (IgG) have been consistently associated with reduced disease occurrence in veal calves (29, 40, 75). On-farm IgG tests are becoming available which could allow for precise selection of calves with FTPI, however, the test performance has been variable when compared to radial immunodiffusion (3, 76, 77). Therefore, measuring serum total protein is likely the most accurate and accessible test available. The utility of this test to diagnosis individual calves with FTPI may be limited, however, it was found to correctly classify passive transfer status in 89% of calves at arrival to a veal facility (3). Managing calves with FTPI remains a challenge, but nutritional strategies, such as using colostrum supplementation, could be explored.

Recently, an on-farm machine leukocyte differential cell counter was validated (78) and used to predict disease, where calves with high levels of neutrophils or low levels of lymphocytes were at a greater risk of mortality (79). This on-farm machine could be used in combination to provide rapid risk assessment to identify and treat high-risk calves. Additional research is required in this area to determine the best strategy for managing these high-risk calves at either the individual or group-level.

Nutritional Strategies

Creating customized nutritional strategies for calves with low body weight may be effective to mitigate disease risk and in general, increasing the plane of nutrition is a significant area for improvement. Calf raisers should focus on increasing the volume of milk provided to all calves to a minimum daily intake of 20% body weight in whole milk (80). Additionally, recent research suggests certain feed additives may aid in reducing the reliance on antimicrobials in calf-rearing systems. Specifically, supplementing colostrum and microbial-based probiotics and prebiotics has led to promising effects on health and growth. For example, supplementation with colostrum or colostrum replacer for the first 14 days of life has been shown to promote gastrointestinal health and weight gain while reducing antimicrobial use and disease prevalence in dairy heifers (81, 82). Even when supplemented for shorter durations, 2 to 4 days after birth, providing colostrum to dairy heifers improved weight gain and a decreased the risk of abnormal respiratory scores

(83, 84). The benefits are likely related to antibacterial and antiviral lactoferrins and proinflammatory cytokines that can aid in combating infectious diseases in the gastrointestinal tract (85, 86). Supplementation with colostrum days after birth could be a promising option for calf raisers to reduce disease occurrence.

The use of microbial-based feed additives could also play a role in improving the gut health of young calves [reviewed by (87)]. Specifically, yeast supplementation during the pre-weaning period has been associated with a reduced incidence and severity of diarrhea in male dairy calves and calves raised for veal (88, 89), especially male calves with failed transfer of passive immunity (90). Supplementation with lactic acid bacteria has also been shown to reduce the risk of diarrhea [reviewed by (91)], particularly when male calves experienced high incidences of diarrhea (92, 93). There are, however, inconsistent results with supplementation (87), suggesting that other management practices may be important to consider. Nonetheless, the use of these microbial-based feed additives could be used in place of oral group antimicrobials provided to male and female calves as there is little evidence to support that practice (94).

Improving Outcomes Associated With Transport

The best way to reduce negative outcomes from long-distance transportation is to eliminate transportation of young calves by raising animals on the dairy farm of birth until slaughter, or until calves are old enough to cope with transportation. In the event calves continue to be transported, the duration of transportation, number of stops, and exposure to severe weather conditions should be minimized. In addition to transportation conditions, some nutritional and therapeutic strategies may improve calf outcomes during and after transportation. For example, Marcato et al. (95) found calves fed milk (1.5 L) before 6 h transportation had greater plasma glucose and lower serum NEFA concentrations compared to calves given electrolytes (1.5 L); however, the authors found no treatment differences for calves transported for 18 h. Elevated NEFA and BHB concentrations are indicative of a negative energy balance, likely caused by feed deprivation. Feeding colostrum before transportation may reduce the depletion of body reserves compared to milk replacer because of the high fat and protein content (96). Depending on the length of transport and time spent at livestock auctions, it is not uncommon for calves to go without access to feed for more than 24 h. Ideally, young calves would not be transported longer than regular intervals between normal physiologic windows for nursing. However, limited research suggests that feeding a meal to calves immediately before transportation and at a regularly scheduled rest stop could reduce hunger and dehydration associated with transportation.

Another strategy that could potentially improve transportation outcomes is providing a non-steroidal anti-inflammatory drug before transportation. Non-steroidal anti-inflammatory drugs (NSAIDs) produce anti-inflammatory, anti-nociceptive and anti-pyretic effects. A study that assessed the administration of an NSAID (meloxicam) to young Jersey calves ($\leq$3 d of age) before transportation, found calves that received meloxicam had greater feed intake and growth following arrival to a calf raiser, compared to calves that did not receive meloxicam (97). However, the sample size was small (n = 21) and calves were only monitored for 4 days after arrival to the production facility. Some of the health abnormalities observed on arrival, such as navel inflammation and elevated rectal temperature (27), may be prevented with an NSAID. Cost-effective and easily accessible therapeutic strategies could be quickly implemented as dairy farmers already have colostrum and milk replacer on farms, and frequently use NSAIDs on farm for calf-related purposes, such as dehorning.

Benchmarking

One of the challenges directly related to surplus calf production is the lack of integration in the production chain. Many calves are marketed through auctions or third-party purchasers, leaving dairy producers with little to no knowledge of calf performance after removal from the dairy farm. However, providing dairy farmers with feedback regarding calf performance at calf raisers may motivate producers to improve animal care on the dairy. For example, Atkinson et al. (98) found dairy farmers made improvements to their colostrum management or milk feeding practices when they became aware of issues following the delivery of benchmark reports. Further, after providing dairy producers with benchmark reports of dairy heifer calf health and growth, producers identified challenges on their farm and made changes to directly address them (99). Similar to benchmarking, it may be beneficial for calves sold through auctions to have a record of their dairy farm of origin and/or details regarding early life care. Thus, we suggest increasing transparency between dairy farms of origin and calf purchasers and/or raisers may be a motivator to improve surplus calf care before removal from the dairy farm.

ALTERNATIVES TO THE CURRENT SYSTEM

Direct From Farm Purchasing

Auctions are a clear source of poor animal health and welfare for surplus calves (28). One alternative would be to avoid auctions and directly transport calves from the dairy farm of origin to a calf raiser. Eliminating marketing calves through livestock auctions could reduce the exposure of calves to environmental pathogens, decrease time spent being transported, and reduce stressors associated with auctions. Directly selling calves to buyers could also potentially improve calf care on the dairy farm. For example, Wilson et al. (18) found that dairy farmers in Ontario preferred selling calves directly to a purchaser instead of through an auction when possible and were motivated to maintain good relationships with direct calf buyers by supplying them with healthy calves. We encourage more work on possible barriers and opportunities for transporting calves directly from dairy farms to nearby calf raising facilities.

Crossbreeding With Beef Animals

A second alternative to the current system is shifting toward breeding dairy cows with beef breeds to create cross-bred calves (e.g., Aberdeen Angus, Wagyu, and many others). There is currently little research on cross-bred calves, but the use of beef semen on dairy farms has reportedly grown substantially in recent years, such that beef breeds now represent 19 and 10% of semen used in dairy herds in 2019 in the U.S. and Canada, respectively (100, 101). In an exercise to envision global dairy farming in 2067, Britt et al. (102) anticipates breeding dairy cows differently depending on their genomic value; cows with high value will be bred using sexed semen for females to be raised as replacements, and cows with lower value will be bred to beef sires.

Researchers have considered dairy beef crossbreeding to have both economic and environmental benefits (103–105). For example, Pahmeyer and Britz (105) modeled the economic consequences of various breeding practices on German farms and found that breeding cows using sexed semen for replacement females and beef sires for surplus animals increased profits on average by €79.42 per cow per year. This increased profit is likely in part due to higher calf sale price based on the improved meat quality of cross-bred calves compared to purebred dairy beef animals (106). Holden and Butler (107) also describe the possible economic benefit of crossbreeding surplus animals, in addition to the potential reduction in greenhouse gases of this system compared to traditional beef. Researchers from New Zealand estimate a 29% decrease in greenhouse gases per kg in carcass weight from dairy-beef animals compared to traditional beef (108). As greenhouse gas emissions become regulated in various countries, the production of a lower impact dairy-beef animal may also be appealing to consumers attempting to reduce their carbon footprint.

The impact of crossbreeding on the health and welfare of calves is not well-understood. If crossbred calves are reared similarly to current purebred dairy calves used for beef and veal (e.g., shipped within a few weeks of age and co-mingled at new facilities or livestock auctions), the same concerns described in this review paper will still exist. However, there may be potential benefits to crossbreeding. For example, cross-bred calves may be considered a "higher value" animal due to their genetics. Increasing the monetary value of calves may in turn increase the motivation of the dairy farmers to take good care of these calves from birth.

Raising Surplus Calves on Dairy Farms

Another potential refinement of the current system is to rear surplus calves on the dairy farm of origin, eliminating health and welfare challenges associated with long-distance transport and livestock auctions during the pre-weaning stage. In their vision of the dairy industry in 2067, Britt et al. (102) anticipates that future dairy farms will incorporate dairy-beef into existing or shared facilities. Rearing surplus animals on the farm of origin would require additional infrastructure and costs associated with rearing, but costs can be recovered by the sale of a high value animal later in life (105).

Retaining surplus animals on the dairy farm of origin would also allow dairy producers the option to transition to alternative dairy systems that allow for contact between the cow and her pre-weaned calf. Cow-calf contact systems are being studied as a form of housing that meets the growing public concern over the welfare of dairy animals (109). In two companion systematic review papers, Beaver et al. (110) and Meagher et al. (111) describe the concerns and advantages of this type of management system, including potential health challenges and improvements in affective states for cows and calves [e.g., improvement of emotional states in calves; (112)]. We encourage more research to identify options for cow-calf contact systems that incorporate surplus dairy animals.

The Future of Surplus Dairy Animals

Like the rest of the dairy industry in the U.S. and Canada, decisions about the future of surplus dairy animals should be grounded in "sustainability" (113). Sustainability is a complex concept, but frameworks often include a balance of environmental, economic and social or ethical pillars. We argue that, for reasons described throughout this review paper, the current system for surplus dairy animals in the U.S. and Canada is not sustainable. A detailed assessment of the economic, environmental, and social impacts of various management systems for surplus dairy animals is outside the scope of this review. However, we recognize some "refinements" we recommend are not sustainable in the long term by these metrics.

If the current practices for surplus dairy animals remain unchanged, there are two main risks. First, policy changes beyond the control of the dairy industry may result in drastic management changes over a short period of time. For example, Canada recently introduced new transport regulations that will dramatically change the way some calves are moved. For many dairy producers, these new regulations will require calves to stay on the farm for longer periods than usual. There are currently no similar laws in the U.S. for pre-weaned calves, but it is possible that new regulations similar to those in Canada and the European Union will be implemented at some point by retailers. For example, some large-scale changes to farming practices in the United States swine and poultry industries have resulted from retailers responding to consumer and citizen concerns over animal welfare [e.g., elimination of gestation stalls and conventional cages; (114)]. The dairy industry is not immune to similar changes if management practices continue to be misaligned with public attitudes and values.

Secondly, the dairy and surplus calf industries are at risk of losing their "social license" to farm without government oversight. Social license refers to "the process by which a community grants or withholds permission to an industry to conduct its business" (115). That is, farmers are generally afforded the ability to make their own decisions about how to rear their animals. However, many current practices on dairy farms are "misaligned" with public values, resulting in distrust of the industry (116). Surprisingly little research has assessed public values about surplus dairy calves. When asked about food animal agriculture in general, the public strongly values naturalness, such as pasture access as well as indoor environments that allow for the expression of natural behavior, freedom of movement and socializing with companions [reviewed by (117, 118)]. The current system for rearing surplus dairy calves is heavily reliant on unnatural housing (e.g., indoor housing with mechanical ventilation or outdoor housing with low space allowance), isolated social environments (e.g., individual pens), and inadequate feeding programs (low milk allowances compared to what they would drink from the dam) which are in direct contrast to public values.

A main aspect of current surplus calf management that is misaligned with public views is the practice of euthanizing healthy newborn calves. In the UK, several organizations are opting to ban the routine euthanasia of surplus dairy calves, likely in response to public concerns about the practice (119). This response is not surprising, given that the public has responded similarly to the euthanasia of healthy surplus zoo animals [e.g., Marius the giraffe; (120)] as well as male chicks in the egg laying industry (121). Ethical concerns over the mass culling of healthy male chicks has resulted in a ban of this practice in France, Switzerland, and Germany, leaving the egg laying industry to find alternative management solutions. Thus, if the dairy industry in the U.S. and Canada does not proactively find alternatives to the routine euthanasia of surplus dairy calves, changes to this practice may occur top-down.

To avoid these risks, we recommend the dairy and associated industries in the U.S. and Canada take a pro-active approach to the fate of surplus dairy calves. This approach should consider viewpoints from multiple stakeholders both within and outside of the dairy industry. For example, Weary and von Keyserlingk (116) recommend engaging with the public over controversial issues within the dairy industry using qualitative social science research. Understanding public expectations can help inform decision-making that promotes sustainable practices. Other social science and mixed methods approaches that have been used to help resolve complex issues are also recommended, such as deliberative democracies (122), participatory research including dairy farmers (123) and sustainability science (124). A qualitative research approach is also needed to understand the motivations and barriers to adoption of best management practices for dairy, veal, and other calf raisers (18, 99). Determining how to encourage producers to adopt new management practices for surplus calves will likely be key to seeing industry wide changes. Ideally, a diverse research approach can help the dairy industry construct a vision for surplus animals that meets the needs of multiple stakeholders centered around improving calf health and welfare.

CONCLUSION

Approximately half of calves born to dairy cows, including all male and non-replacement female calves, are sold from the dairy farm to calf-raisers within the first few days to weeks of life. Sub-optimal care of surplus calves generally begins at birth and continues throughout production. Surplus calf management practices during early life include poor colostrum management, long-distance transportation, marketing through livestock auctions, individual housing, and low planes of nutrition. Poor treatment of calves likely results in negative affective states, and high rates of morbidity and mortality. Short-term changes to surplus calf production including minimizing transportation and eliminating marketing calves through livestock auctions, crossbreeding, and raising calves on the dairy farm are options to improve calf outcomes. In the long-term, a holistic approach that takes producer perspectives, social concerns, industry viewpoints, and calf outcomes into account is needed to redesign a sustainable future for surplus calves.

AUTHOR CONTRIBUTIONS

KC, JP, GH, SL, KP, DW, and DR: conceptualization. KC, JP, GH, SL, KP, and DR: investigation and writing—original draft. GH and DR: funding acquisition and supervision. All authors contributed to the article and approved the submitted version.

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REVIEW
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The Dispensable Surplus Dairy Calf: Is This Issue a "Wicked Problem" and Where Do We Go From Here?

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Surplus dairy calves consist of all dairy bull calves and any heifer calves not needed as replacements for the milking herd. The fate of these surplus calves varies by region; for example, in Australia and New Zealand they are often sold as "bobby" calves and slaughtered within the first weeks of life; whereas, in North America they are normally sold within the first weeks of life but reared for 16–18 weeks as veal or longer as dairy beef. Regardless of region, demand for these calves is often very low, driving down prices and in some cases leaving farmers with no alternative options other than on-farm euthanasia. The notion that dairy cows must give birth to produce milk and that the calves are immediately separated from the dam, many of which will end up immediately being sold as surplus calves, has become a topic of public concern. These concerns have increased given the growing number of pictures and stories in the media of on-farm euthanasia, dairy calves being transported at very young ages and frequently receiving sub-standard levels of care. In this paper we describe the status quo of this complex, value-laden issue that without transformative change is at great risk for continued criticism from the public. Moreover, despite many attempts at refinement of the existing approach (i.e., the pursuit of technical improvements), little has changed in terms of how these surplus dairy calves are managed and so we predict that on its own, this approach will likely fail in the long run. We then set out how the current surplus calf management practices could be viewed to fit the definition of a "wicked problem." We conclude by calling for new research using participatory methodologies that include the voice of all stakeholders including the public, as a first step in identifying sustainable solutions that resonate with both society and the livestock industry. We briefly discuss three participatory methodologies that have successfully been used to develop sustainable solutions for other complex problems. Adoption of these types of methodologies has the potential to help position the dairy industry as a leader in sustainable food production.

Keywords: animal welfare, dairy calves, participatory methodologies, ethics, complex problems

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INTRODUCTION

The issue of surplus calves in dairy production has historically been limited to the fate of the male calf (1–3). However, the increasing use of sexed semen to strategically breed replacement females (4) combined with the growing demand for beef crossbreeding on the remainder of the herd (5), has resulted in an increasing proportion of these surplus calves being female. The current fate of most of these dispensable surplus calves is fraught with criticisms due in large part to a history of poor management, such as inadequate colostrum provision (6), transportation within a week of birth, young calves being sold through auction yards, and high rates of morbidity and mortality [see (3, 7)]. Given the increased concerns raised by critics regarding contentious practices in animal agriculture [i.e., see example of male chicks in Germany described by Brümmer et al. (8)], we predict an increasing awareness of potentially contentious issues being circulated through news reports and social media posts.

Citizens are increasingly expressing concern for the quality of life of farm animals (9). Without understanding societal values, food animal industries may implement improvements that are intended to improve animal welfare but are viewed as unacceptable to the public. For example, as described by Weary et al. (10), after years of public outcry over the use of confined housing for laying hens, millions of dollars, and years of research were spent on developing new "modified" cages that incorporated the latest collective scientific knowledge on social group size, space allowance and needs of the hens in these systems (11, 12). However, these "modified" systems failed to resonate with the key societal demand for cage-free systems; had the egg industry done the necessary consultation and reflection on these public values, the industry investment and scientific effort may have been more wisely devoted to improving cage-free rearing systems. To avoid similar missteps by the dairy industry, we suggest that future solutions must integrate the views of the public in developing approaches to address contentious practices, potentially contributing to the social license to farm.

The thoughts and ideas that are presented in this paper arose as a consequence of weekly online video discussions undertaken by the two authors who live on opposite sides of the world over a 10-month period, that began at the outset of the COVID-19 pandemic. In our weekly conversations, we discussed many unique challenges facing our respective dairy industries but quickly realized that regardless of where one lives, the fate of the surplus dairy calf is an ever-present challenge. Moreover, the majority of the available scientific literature suggests that most, if not all, research dedicated to surplus calves has focused on "technical issues" such as whether male dairy calves receive sufficient colostrum (6) or describing the *status quo* which includes most surplus calves either being transported off the farm at less than 1–2 weeks of age or euthanized at birth (13). Hence our discussions moved to focus on what alternative solutions could be found that would support a more socially sustainable dairy industry.

This paper summarizes these discussions into four parts beginning with a short description of the *status quo* of surplus dairy calf management and the case for change. In this section we have, given our respective locations, primarily used examples from Australia and Canada but when possible also included examples from other countries. We then argue that attempts to date to improve the welfare of surplus calves have been limited to technical solutions that have focused on refinement of existing practices and discuss why this approach may fail in the long run. We then explore whether the challenge of surplus dairy calf management may fit the definition of a wicked problem, before finally moving to describe how the use of participatory methodologies may assist with developing sustainable paths forward. We have also included real-world examples where these types of approaches have been used to effectively tackle wicked problems and discuss how research is needed on adapting these approaches so that they may be applied to the fate of the surplus dairy calf (and arguably other contentious issues).

THE STATUS QUO

In order to produce milk, cows must give birth to a calf (14) that, under natural circumstances, would suckle the cow until weaning occurs when calves are 7–9 months of age (15). In contrast, the majority of conventional dairy farms separate calves from the dam within 24 h of birth (16, 17). For the dairy industry to produce milk efficiently, farmers strive to achieve a yearly calving cycle; namely, every cow produces one calf every year. Considering replacement rates of lactating dairy herds (18), ∼30–50% of the calves born on farms will be reared as replacement milking females while the remaining surplus female calves and all male calves must be managed through alternative pathways. In a study of calves sold at auction for veal operations in Quebec, Canada, 13% of calves sold were female (19), indicating that the issue of surplus dairy calves can no longer be confined to a focus on male calves alone.

Since the 1940s, genetic selection has seen the modern dairy cow become highly specialized, producing more milk from less inputs and improving overall efficiency (20). However, it appears that this selection for high milk production has been largely at the expense of beef production traits. In comparison to specialized beef breeds, many dairy breed offspring exhibit reduced average daily gains, lower dressing percentages and less desirable carcass conformation (21, 22), impacting their suitability for, and use in, profitable meat production systems.

As a result of their perceived lack of suitability for beef production, the majority of surplus dairy calves in Quebec and Ontario, Canada's major dairy provinces, enter the veal industry [see (23)] and are slaughtered when they are 16–18 weeks old (24), a management practice that has not changed dramatically in decades despite consumption rates of veal declining in North America; as of 2016 the annual veal consumption within Canada has dropped below 1 kg per person and to less than 100 g per person in the United States (25, 26). The continued reliance on the veal industry as a viable and sustainable market by the Canadian dairy industry and elsewhere must be questioned, particularly given that animal welfare and ethical concerns are the most commonly cited reasons for not consuming veal (27).

Concerns regarding the welfare of young surplus calves are not limited to North America. In Great Britain, the 0–3 months death rate at slaughterhouses for male dairy calves has increased from 17.4% in 2011 to 26.16% in 2018, in contrast to that of female dairy calves and beef calves of both sexes which has remained low (<0.5%) (28). In Australia, there is little in the way of established veal or dairy beef markets resulting in most surplus dairy calves entering the bobby calf market (29) where they are slaughtered within the first weeks of life (30).

The reduced suitability of dairy breed calves for beef production is also reflected in the value attributed to them, with Brown Swiss and Jersey calves attracting the lowest prices in a recent Canadian study, followed by calves with Holstein genetics, while cross-bred calves with beef genetics sold for higher prices (7). Similarly, Buczinski et al. (31) found that beef cross-bred calves sold through auction markets of Quebec had better sale prices than Holstein; whereas, colored dairy calves had lower sale characteristics than both Holstein and beef cross-bred calves. We speculate that the low inherent value of surplus calves motivates, at least in part, their sale at a young age. Wilson et al. (7) also report that Holstein dairy calves sold at auction were similar in body weight (∼47 kg) to those of newborn female Holstein calves born in the same region in Canada (32) and elsewhere (33), suggesting that the majority of the Holstein calves in these studies were less than a week old when sold. It should be noted that in Canada, as of February 20, 2020, new federal regulations prohibit transporting calves with unhealed navels, and require that calves under 9 days of age be transported directly from farm to farm without going through an auction or assembly yard. The maximum trip length must be no longer than 12 h—shorter than typical trips for many surplus calves being transported in Canada which often exceeds 12 h and may be up to 48 h in duration (3). Unweaned calves aged 9 days or older can be sold at auction, but the total trip from dairy farm to calf grower cannot exceed 12 h except in specially equipped transport trailers (34). Similar regulations exist in Australia where, amongst other requirements, calves must not be transported before 5 days of age (unless consigned directly to a calf rearing facility), must be fit and healthy and fed within 6 h of transport with a maximum journey of 12 h [see (35)].

Given that the core business focus of most dairy farmers is on milk production, and that surplus calves are often of low value and in some cases are viewed as a "waste product" (36), it is not surprising that the standard of care provided to these calves is often lower than that afforded to arguably higher value replacement female calves. In a recent Canadian survey, 9% of farmers indicated that they did not always feed colostrum to male calves (a practice essential for managing the incidence of disease), and 17% did not provide the same quantity of feed to male calves as they did to heifer calves (23). This was further supported by the views of Canadian veterinarians in one study, where participants noted that if bull calves are "…*worth twenty bucks, they get fed, sort of*" and that "*they might not even really get colostrum*" (36). In the UK, male dairy calves were also found to have the highest on-farm mortality rates in the first three months of life when compared to female and beef breed calves (28). High rates of health abnormalities including diarrhea, dehydration, navel inflammation and low body condition have also been reported in calves sold at auction in Canada (7, 19) and upon arrival at milk-fed veal calf facilities (2, 37, 38). The most recent data from the US National Animal Health Monitoring System indicates the majority of the 42 operations surveyed sold their bull calves before weaning, with most doing so when the calves were less than 1 week old and about half of these were sold via an auction yard (6).

The transportation required to relocate surplus calves from the farm on which they are born to either a rearing facility or to slaughter also impacts their welfare. Calves are often transported within a week of life (29), including within a day of birth (3), with mortality of calves less than a week old increasing exponentially with distance traveled (39). Particularly worrisome is that the time spent during transport usually equates to time that they do not have access to milk; a fact that has been shown to directly impact their welfare (1). This notion that time off feed is a risk factor for mortality was acknowledged by a group of Canadian dairy industry experts who noted that young calves have limited body reserves to meet the demands of transport, which can have a duration of up to 48 h including a rest stop (3). These experts also noted that stress caused by handling can suppress immunity to disease [see also Burdick et al. (40)], that commingling of calves from different farms exposes them to new pathogens [see also Damiaans et al. (41)] and that calves do not always receive appropriate quantity and quality of feed and water while in the transport continuum (3).

Given the economic challenges associated with surplus calves, it is not surprising that in some instances they are euthanised on-farm shortly after birth (23, 29); a decision that in some cases likely arises as the farmers are forced to make the trade-off that the value attributed to a calf is less than the cost of rearing it, a fact likely exacerbated when there are minimum age requirements for transport. Decisions regarding euthanizing healthy calves shortly after birth is likely compounded in situations where farmers face a lack of access to housing facilities for these surplus calves (23). While the majority of Australian farmers euthanising calves do so with firearms (29), the use of blunt force trauma (euthanasia via a sharp blow from a solid object to the head) continues to be used by some, posing a significant risk of poor welfare outcomes resulting from issues with operator training and error (42). In one survey of Canadian farmers, an average of 19% of calves were euthanised at birth and of those respondents that euthanised calves, 34% reported using blunt force trauma, a practice that is not acceptable under both the Canadian Code on the Care and Handling of Dairy Cattle (23) and by the American Veterinary Medical Association see (43), and is also against Australian Dairy Farmers policy [see (44)]. Objectively, immediate and effective euthanasia following birth may be a preferable welfare option than experiencing standards of care that are common to surplus calves, such as long periods off feed, transportation or other known stressful conditions (e.g., cold) that can increase the risk of disease. Despite this, the killing of a newborn will not be accepted easily by the public due to ethical concerns; a point that will likely increase reputational risk to the industry. For example, the publishing of an undercover video taken on a dairy farm operating in Chile, with links to the New Zealand dairy industry, reporting that over 6,000 calves had been killed using blunt force trauma resulted in public outcry in New Zealand [described by (45)]. The voices of criticism following publication of the video were sufficient to enact changes in the New Zealand Animal Welfare Act (46) making it *"illegal to kill a calf by blunt force to the head, except in emergency circumstances."* Clearly, the fact that the surplus calf is viewed as dispensable and killed immediately following birth in some regions of the world or allowed to live but given substandard care (at least relative to the female replacement heifers) is not socially sustainable and so alternative options must be explored.

The Case for Change

The *status quo* of how surplus calves are cared for has, as argued above, primarily been brought about in part because these animals have an inherent low economic value and in part because the dairy industry is focused on the milk production aspects of their industry. However, the rising value attributed to the maintenance of public trust in the dairy industry has initiated discussions about the need to improve the way surplus calves are managed (45, 47). Commonly recognized challenges facing agriculture more broadly include a general public that is becoming increasingly disconnected from food production (48), combined with an increase in concern about how food is produced (49, 50).

When it comes to dairy farming, concerns about the welfare of animals are amongst the most commonly cited by the public (51). Indeed, the management of bobby calves has been rated as one of the most significant issues facing the Australian Dairy Industry and is recognized as a key barrier hindering the long term sustainability of the industry (52). There is a growing sensitivity globally that this issue must be addressed, exemplified by the views of a Canadian veterinarian who noted that "*if the public was more aware of what was going on there, it's not probably going to make good press*" (36). Unsurprisingly, when Australian study participants having little knowledge of the dairy industry were informed about the reason for the slaughtering of bobby calves, they responded with a high level of outrage and farm animal welfare standards were perceived as being inadequate (48). There is also some evidence in the media that the issue of surplus calves will likely be tied to cow calf separation (53, 54) which we predict will add additional complexity to this issue.

The increasing force of the social push-back by members of society regarding the management of surplus dairy calves has potential economic consequences, particularly in light of the rising interest in socially responsible finance (55), with some banks now promoting lending positions that exclude systems and processes that have negative impacts on animal welfare [see (56)]. It may also contribute to difficulties in attracting and retaining new entrants to the dairy sector, exemplified by the comment from a Canadian veterinarian: "*we see a lot of the younger generation that's coming on to the farm that seem to really want to push the calf welfare issue*" (36). Whether future economic pressures play a role in facilitating improved surplus calf management, particularly when considering the opportunities for increased revenue from beef, remains to be seen. Regardless, change is not easy as stated by some Canadian farmers who participated in a focus group study where they emphasized that money is necessary to make on-farm changes and meet the must-haves of farms in 20 years (57).

The case for shifting away from regarding the surplus calf as a waste product of dairy systems is not confined to social and economic pressures. Multiple studies have reported that beef from the dairy herd has a lower carbon footprint compared to beef from traditional beef herds (58–61), making this form of beef production potentially very attractive, particularly in the context of climate change. This potential advantage of dairy beef is attributed to emissions from the breeder cow being allocated between the various products. In the case of dairy beef production, the dairy cow produces milk, meat, and calves, with emissions allocated among all three products compared to the beef suckler cows which only produce meat and calves (60, 61). This explanation suggests that improving the uptake of beef from the dairy herd could lead to improved land use efficiency, which will be required in order to meet future increases in food production (62).

Current Approaches to Achieving Change

There is little doubt that the dairy industry has some appetite for change, one only has to look at the structural changes that have occurred over the last 50 years (63). However, these changes have for the most part been driven by the pursuit for improved production efficiencies, such as increased milk production per cow through the adoption of improved genetics (64), scientific advances in ruminant nutrition [i.e., (65, 66)] and adoption of technologies to aid in health monitoring [see (67)]. When it comes to surplus calves, approaches to achieving change have largely focused on improving practices such as colostrum management (68), euthanasia practices (69) and transport standards (39), and increasing the adoption of technologies such as sex-sorted semen (4, 70).

Increased adoption of sex-sorted semen, which allows predetermination of calf sex with ∼90% reliability (70), will affect surplus calf management as it provides for more targeted breeding of replacement females. Advantages of sexed semen can include accelerated rates of genetic gain in the female herd (71) and reduced dystocia rates due to smaller female calves, although potential reductions in fertility can reduce the financial benefits associated with implementation (70). Most notably, the combined use of sexed semen to produce the required number of replacement females with beef crossbreeding over the remainder of the herd has the potential to improve the value of surplus calves (72, 73). Indeed, recent evidence suggests that the feedlot performance, carcass quality and yield of crossbred Jersey calves sired by beef breeds was improved compared to purebred Jersey calves (74). Undeniably, a focus on improving the technical feasibility of more sustainable surplus calf management practices is a fundamental requirement to achieving change. However, despite the widespread availability of these technical advancements, the problem of surplus calf management persists, suggesting that this approach alone may be insufficient.

Unique marketing angles have also been suggested as an approach to improving surplus calf management by increasing the financial returns of beef from the dairy herd. This may provide gains in niche markets; however, Appleby (75) notes that *"it is not reasonable to expect consumers to take day-by-day responsibility for animal welfare at the point of sale, any more than they are expected to do so for other issues of concern to society, such as pollution."* Whilst niche markets may offer a partial solution, it is unrealistic to expect this approach to act as a panacea.

Approaches to preserving trust in the dairy sector also faces a lack of consensus amongst stakeholders. The fact that many communities are increasingly disconnected from agriculture, has caused many within the industry to dismiss the general public as simply not knowledgeable (76). However, restricting the flow of information (often referred to as "ag-gag" laws) has been shown to be counterproductive, decreasing trust in farmers and leading to more negative perceptions of farm animal welfare standards (9).

Educating the public as a means to gain acceptance is another approach commonly argued by those within agriculture as a way of preserving trust [discussed by (36, 57)]. However, proponents of the education approach often fail to recognize that it will likely also highlight aspects that fail to resonate with societal values [e.g., zero grazing, cow calf separation reviewed by (10, 77, 78)]. This is compounded by the fact that animal welfare is often assessed by citizens not just in light of biological functioning, but also through the lenses of "naturalness" and affective states (i.e., the way the animals feel) (79).

Given that closing the doors or educating the public into understanding is unlikely to adequately address the threat of diminishing public trust in dairy production (45), how then should the industry proceed? Whilst technical solutions for improving surplus calf management are available and utilized to some extent, the persistence of the issue at a global level brings into question whether the problem must be viewed differently to those that are tackled solely through traditional scientific approaches targeted at refinement of existing practices.

Why the Status Quo May Be a Wicked Problem?

Despite the refinement efforts made to date, there remain few, if any, dairying countries that do not experience some form of challenge when it comes managing surplus calves. In short, the issue is yet to be completely "solved," despite our best efforts in research, development and extension.

The inherent division between the separate beef and dairy sectors present in many countries may play a role, at least to some degree, in hindering the development of sustainable solutions to the surplus dairy calf issue. Other challenges hindering progress may include commodity price volatility and inherent aversion to financial risk by many dairy producers (57), arguably resulting in current management practices continuing to place most emphasis on the path with least economic resistance. Possible differences in cultural attitudes to the perceived quality of dairy beef or veal both within the agricultural sector as well as amongst consumers may also play a role. Further, the concept of "barn blindness"—a lack of perception of problems on one's own farm where the abnormal is viewed as normal because it is seen every day (80)—may also contribute to a lack of widescale change. This barn blindness can occur at both a farm level, as well as an industry level; indeed, some practices become normalized by those working within the industry but are found abhorrent by others outside of the industry.

In further exploring the reasons for the persistence of the surplus calf challenge, framing the issue as a "wicked problem" may provide some insights. The term wicked problem was first coined by urban planners Rittel and Webber (81) as a way of describing problems which, in contrast to "tame problems," present a unique set of challenges as a result of their inherently complex and incendiary nature. In **Table 1** we show how common features of wicked problems can be related to the management of surplus dairy calves.

Developing a dairy industry where practices are more aligned with public values will likely be more socially sustainable (10); the question is what do these practices look like, are they economically viable, and who should be involved when discussing them?

Addressing Complex "Wicked Problems" (The Inclusion of Voice)

Given the complex nature of surplus calf management, gaining an understanding of, and accounting for the interests of, all stakeholders and reasons that motivate conflicts of interest between them is vital (50). This will require more interactive methods of communication that can provide for democratic, interactive, and multidirectional discussion sessions (87) that stretch across different disciplines and even across public, private and civic sector organizations (88).

When addressing wicked problems, it is widely recognized that relying solely on experts and advocates is not only insufficient (89), but can actually make tackling the issues more difficult (90). As pointed out by Weary et al. (10), some solutions (see above discussion on the modified cage for hens) developed by scientists fail to gain traction with the public because (a) they do not adequately address the societal concerns that motivated the original research and, (b) they do not adequately address the perceived constraints within the industry. According to Fung (91), non-professionals may be able to contribute to the development of innovative approaches and strategies precisely because they are free from the received but obsolete wisdom of professionals and the techniques that are embedded in their organizations and their procedures.

The importance of ensuring that surplus calf management practices are not only socially acceptable but also financially viable, means that it is vital that discussions include both industry, including the farmers, their trusted advisors (e.g., veterinarians, nutritionists) and other stakeholders along the supply chain (e.g., milk processors), and the general public, in their role as both citizens and consumers, as credible stakeholders. Weary and von Keyserlingk (45) emphasize the importance of two-way conversations with the public that include not just consumers who purchase dairy products but all citizens that provide a social license for the dairy industry to operate, including those that do not consume animal products but are interested in the issues and who

TABLE 1 | Key features of a "wicked problem" and how aspects of current surplus dairy calf management systems could be argued to meet each of the individual features that when taken together meet the criteria for a wicked problem.

Features assigned to wicked problems	Relation to surplus calf management
• They are **difficult to clearly define** (81) and **different stakeholders have different versions of what the problem is** (82).	The challenge of surplus calf management is difficult to distill into a clear problem definition, primarily because the components of the problem are many and varied. The problem could be defined as surplus calves being slaughtered early in life and treated differently to replacement females because they are of lower economic value (as is the case in most dairy regions). But why are they of low value? Is the problem one of genetics, nutrition, husbandry, market access and demands, human perceptions of value, industry attitudes or cultural norms? Additionally, different stakeholders will place different emphases on each of the potential components of the problem.
• They are often **not stable**; the problem, constraints and evidence involved in understanding the problem (e.g., legislation, scientific evidence, resources, political alliances) are frequently evolving. They also have many **interdependencies** and are often multi-causal (82).	Evolving and interdependent influences on the management of surplus calves include market incentives/disincentives, policy, legislation, commodity price fluctuations, land availability, scientific knowledge, and evolving community attitudes/values.
• They often include **internally conflicting goals** or objectives (82).	Internally conflicting goals include the desire to achieve financially viable growth rates through accelerated/lot feeding of dairy breed calves vs. rising public opposition to concentrated animal feeding operations (83); the advantages offered by increasing use of sexed semen (70) vs. the value placed by the public on the concept of "naturalness" (84, 85); the welfare impacts of transporting calves to rearing facilities vs. at-birth euthanasia which may not compromise welfare if performed effectively but is likely to be at odds with public values.
• They have **no immediate and no ultimate test of a solution**; the full consequences of a potential solution cannot be appraised until all the waves of repercussions have completely run out (81), **and measures introduced to address the problem may lead to unforeseen consequences elsewhere** (82).	The social, environmental, and economic consequences of any changes to surplus calf management will take time to become evident. For example, increasing the number of surplus calves reared for beef or used for veal production may fail to resonate with societal values for reasons associated with production methods (e.g., cow-calf separation); proposed solutions may have a detrimental financial impact on farmers in the short term; management changes may have unforeseen impacts on the environment, land use, food security etc.
• They have **no stopping rule**, as the perfect solution will likely never be achieved (81).	Given that the socio-cultural evolution of humans is ongoing (86), the question will likely not be whether the management of surplus calves becomes "good enough" to the point that it is "solved" but rather that practices will likely require continual review in order to ensure that they align with public values in perpetuity.
• They are **socially complex**, and it is social complexity rather than the technical complexity that overwhelms most current problem-solving and project management approaches (82).	The management of surplus calves involves a diverse range of stakeholders with varying frames of reference including dairy and beef farmers, calf growers/veal producers, transporters, feedlot operators, meat processors, milk processors, wholesale, retail, food service, exporters, policy makers, compliance etc. This level of social complexity is increased again by the addition of the general public as a credible stakeholder.
• They involve **changing the behavior** and/or gaining the commitment of individual citizens (82).	Changing the status quo of surplus calf management will not only involve changing the behavior of farmers, but of all stakeholders involved along the whole supply chain (i.e., from farm to plate).

influence corporate and government responses. Similarly in the mining sector, it has been recognized that genuine community engagement, participation and collaborative approaches to the development of strategies to mitigate negative impacts will likely create greater community trust and acceptance in the longer term (92).

Indeed, it is becoming increasingly clear that exclusion of certain voices (i.e., the lay public), despite their lack of connection to the industry, may not be sustainable in the long term; particularly given that the younger generations are predicted to contribute significantly to the debate on choices toward new food production practices and consumption patterns (93). In contrast, the inclusion of voice from both industry as well as citizens through public participation can act as a source of "trust" and "legitimacy" (i.e., that all those involved in the conversation trust those developing potential solutions and therefore see them as legitimate) and thus can act as a means of effecting change (94).

However, the inclusion of the voice of the citizen must not be merely tokenistic; Schuppli and Fraser (95) examined factors influencing the efficacy of animal ethics review committees and found that the inclusion of community members, usually as a single or pair among a panel of several experts, often lead to them feeling outnumbered or intimidated by the expert members and their voice was often not heard. This emphasizes the importance of attempting to ensure that the inclusion of voices from various stakeholders is at least in some way representative. Despite this, Fung (91) describes the challenges associated with achieving adequate representation amongst participating voices, including: whether important interests or perspectives are excluded; whether they possess the information and competence to make good judgements and decisions; and whether participants are responsive and accountable to those who do not participate. Whilst these challenges must be acknowledged, moving to include the voice of the lay stakeholder in at least some form is an as-yet underexplored frontier when it comes to addressing wicked problems in agriculture. Using these approaches to guide and build upon traditional approaches to research, development, and extension offers a promising domain in which to break new ground.

Driving ownership of the problem and buy-in for new approaches from farmers and wider industry is also vital as any initiatives are more likely to be successful when led by producers (96) and the associated allied industries who support the agriculture industry. This buy-in for new approaches must circumvent the traditional attitudes of industry-based stakeholders who have often characterized public concerns about farm animal welfare as symptomatic of a lack of knowledge about farming and have used one-way information vehicles to educate the public (76). The challenge is to help the dairy sector as a whole to see the opportunities that change may bring as opposed to supporting a way of doing business that may become an intractable problem.

In the case of surplus calves, "fixing" the problem must go beyond refining existing practices and improving profit margins. As Bos and Koerkamp (97) state, "*the old-fashioned idea that pure technological magic will do the job, no longer applies*". Instead, these authors argue that in order to make modern western animal production systems more sustainable, it is necessary to design systems that address multiple challenges at one time. It is not only profitability of alternative surplus calf systems that must be considered, but these types of approaches may also aid in identifying solutions for other complex issues such as animal welfare, farmer welfare, environmental impacts, and other aspects of social sustainability. Ideally, solving these issues is not done in isolation of one another as individual solutions may conflict with, or even negatively influence, the performance of other aspects of the system.

Further, when considering that human social evolution is a constant process (86), it is vital that systems for tackling complex issues such as surplus calf management are designed to accommodate and move with evolving societal values. Almost 15 years ago the Commonwealth of Australia (82) reported that any approach to tackling wicked problems will require: *"holistic, not partial or linear thinking; innovative and flexible approaches; the ability to work across agency boundaries; increasing understanding and stimulating debate on the application of the accountability framework; effectively engaging stakeholders and citizens in understanding the problem and identifying possible solutions; additional core skills such as communication and tolerating uncertainty and accepting the need for a long term focus."* We argue that identifying a sustainable path forward regarding the issue of surplus calves produced by the dairy industry will require approaches that embrace all of these attributes. Below we discuss the use of participatory methodologies that could be used as a starting point to engage in dialogue that includes representation from industry stakeholders as well as the public.

Examples of Participatory Methodologies

Whilst participatory methodologies vary based on who participates, they are all based on the concept that those involved co-create knowledge and make decisions together and it is their collective voice that is then linked with policy or public action (91). When it comes to the inclusion of the voice of the community, Gregory et al. (98) defines community engagement as the process of involving the community in the planning and development of policies and services by which they themselves are likely to be impacted. The three methods described in **Table 2** are examples that could be used to tackle the complex surplus calf management problem and were specifically chosen since they all provide for the inclusion of voice from all sides of the issue, including the lay public, with the overall aim of identifying more meaningful, sustainable outcomes.

In all three examples (see **Table 2**), the values and ideals of those not directly connected to an issue, but who are either affected by the issue or downstream recipients such as community members or consumers, are recognized as being of equal importance as the needs of experts or industry stakeholders in developing sustainable solutions to complex problems. It should be noted that this is in contrast to the relatively minor changes that normally follow the traditional process of getting feedback after a fundamental design had been completed by experts (that may include a representative of the humane movement (110), but not always i.e. (111) and then put forward for public comment [see process described by Canada's National Farm Animal Care Council (112)]). As Raman and Mohr (113) point out, it is not enough to simply measure social acceptance of a practice, but instead industries should aim to include all stakeholders in the co-construction of social license. Thus, engaging with all stakeholders, including the public, is a key step to ensuring that practices remain in step with evolving societal values.

Additionally, as in the case for laying hens, if the dairy industry implements solutions that fail to resonate with societal values, there is a great risk that any proposed changes may result in public disapproval as awareness of this issue grows, wasting immense resources by both the dairy industry as well as the research community. By engaging in social science research using some form of participatory methodology (see **Table 2**) that includes the public, we believe that the industry can minimize this challenge.

CONCLUSION: THE EVER-DISTANT HORIZON

Achieving widespread adoption of socially acceptable, financially viable, and environmentally sustainable alternatives to surplus calf management is an immediate requirement to ensure the continued viability of the dairy industry. However, as complex as this specific issue is, we also recognize [as have others; (103)] that it is unrealistic to expect that the challenge of ensuring dairy

TABLE 2 | Brief descriptions of three participatory methodologies and examples where they have been used to tackle complex problems.

Participatory methodology	Description	Examples of methodology in use
Deliberative forums	Deliberation is defined as the action of thinking carefully about something, especially in order to reach a decision (99). According to Gregory et al. (98), deliberative approaches to community engagement centre on involving the community in discussion and deliberation about issues, ideally leading to concrete proposals that can be adopted by policy makers. The process involves ordinary citizens being willing to tackle difficult, often value-laden problems. A key part of these types of forums is the recognition that participants will absorb educational background materials and engage in exchanges with others, who may have different perspectives, experiences, and reasons with one another and in doing so will develop their views and discover their interests (91). In contrast to the commonly-utilized focus group, Carcasson (90) emphasizes that deliberative engagement focuses on developing mutual understanding and genuine interaction across perspectives, which then provides a base to support the constant adjustment, negotiation, and creativity required to tackle wicked problems. These types of interactions do however require extensive community capacity and are indeed a cultural shift away from an over-reliance on either expert or adversarial processes.	The Irish Citizens' Assembly is an example of a deliberative forum [see Farrell et al. (100) for full description] where members of the assembly were regular citizens selected from the wider population and participated in facilitated roundtable discussions on a monthly basis. Presentations by advocacy groups and on occasions (notably when discussing abortion) personal testimonials by a number of women were also included. Together, the creation of two deliberative mini-publics in quick succession [The Irish Citizens' Assembly (2016–2018) and the early Convention on the Constitution (2012–2014)] played a significant role in supporting key referendums for constitutional change that followed [marriage equality in 2015 (101), and abortion in 2018 (102)]. In a dairy-specific example, participatory policy making was recently employed in the United Kingdom to enable groups of dairy producers to deliberate and develop an antimicrobial stewardship policy [see (103) for full description]. The authors noted that "the participatory process provided comprehensive learning for all involved and allowed for the integration of science and the producers' own knowledge and experience. The process led to the development of credible and practical recommendations designed to deliver real on-farm changes" (103).
Reflexive Interactive Design (RIO)	According to Bos and Koerkamp (97), the RIO approach (a Dutch acronym for Reflexive Interactive Design) was first proposed to aid the discussions surrounding agricultural issues that are viewed to be complex and value-laden. The approach recognizes that livestock production's historical focus on volume and cost-efficiency has increasingly been confronted with a series of self-generated risks and unwanted side effects [see also (104) for discussion on risks to sustainability arising from current dairy management practices in the US]. The RIO framework places equal focus on both technical and social challenges and seeks to redesign agricultural systems in ways that can overcome these constraints to be truly sustainable (97). According to the same authors, determining the fundamental needs of all actors that are involved in a system (including farmers, the general public and consumers as well as the animals themselves) and formulating them into a "Brief of Requirements" is a key starting point of this approach. Their aim is to then redesign systems that simultaneously speak to the needs of all the different actors, instead of weighing the pros and cons of the various interests against each other (97).	An example where RIO methodology was used is the Pork Opportunities project in the Netherlands (2008-2010) [see (105)]. Briefly, the aim was to redesign the pig husbandry system to "produce pork in a way that is good for People, Planet, Profit and Pigs." This project began with a system analysis that identified and assessed the needs of the pig, pig farmers, the environment and the consumer/citizen. Key challenges in the current pig production system were then identified as were possibilities for change. Design goals were formulated, key functions were identified and solutions to these functions were generated to fulfill the needs of all actors. A selection of these solutions was then combined to render new designs of pig husbandry systems. The RIO approach was also used by Romera et al. (106) to re-design sustainable dairy systems in New Zealand. The authors argued that this approach offered an opportunity for more profound reflexion within the dairy industry and is tailored to wicked problems and situations with apparent value conflicts. It first set out to develop desirable "ideal" systems; participants were actively encouraged to not focus on technical or economic feasibility. Only after completion of this phase were the participants then encouraged to focus on the feasibility of the concepts. Animals were considered as key actors alongside farmers as were the consumers and the New Zealand citizens; this latter aspect of the process was driven in large part by the recognition and acceptance by all involved that animals are sentient beings, whose lives could be profoundly affected by the designs if they were to be implemented.
Human Centred Design	Human Centred Design is rooted in fields such as ergonomics, computer science, and artificial intelligence (107). This approach also places priority on deeply respecting all views, recognizing that in order to develop creative, innovative solutions that are rooted in people's actual needs, the voices of all stakeholders must be included [see (108)]. The process involves three main phases: Inspiration, Ideation and Implementation, and is designed to help participants learn directly from each other, open themselves up to a breadth of creative possibilities, and then zero in on what is most desirable, feasible and viable for all actors involved [see (108)].	Human Centred Design has been used to address complex issues such as healthcare, and was utilized by The Best Babies Zone initiative, a multi-year project aimed at reducing inequities in infant mortality rates and enhancing overall population health in Oakland, California (109). As the authors describe, this approach was used to design solutions that addressed the deeply-rooted, complex social and economic conditions that are important drivers of health inequities in this region. A diverse team representing organizations from multiple sectors were invited to attend; stakeholders represented government, design, community, and economic development and individuals who worked in the neighbourhood. Collectively the goal was for all stakeholders to become familiar with the complexity of the situation in a context that deepened their understanding and empathy. Based on insights from working in the community, the team brainstormed over 100 concepts to address the design challenge and integrated community members' feedback at an early stage of the planning process.

animal management practices meet the needs of people, planet, profit and animals will be solved immediately and that issues hindering the sustainability of the dairy industry will be confined to the issue of surplus calves alone. There is little doubt that public scrutiny of dairy production practices will continue to increase and that this scrutiny will increasingly include challenges based on ethical grounds, including the current practice of managing surplus calves as an associated "dispensable" product of the dairy industry.

Short term measures of progress on surplus calf management will likely include improved beef market access by the dairy sector and a move away from early life slaughter. However, in addition to working on short term solutions, we encourage the industry to simultaneously begin working toward longer term solutions that will meet the future needs of the animals, the farmers who care for them, the wider agricultural sector, consumers as well as the citizens in the broader community. In doing so, related "contentious" issues such as cow-calf separation, confinement feeding (concentrated animal feeding operations), involuntary culling due to disease and lameness, and the welfare of cull cows will also need to be addressed.

The current challenge facing the global dairy industry regarding the fate of surplus calves demonstrates a clear and pressing need to engage in research that expands on the traditional focus on technical solutions by developing and evaluating participatory methodologies, enabling the dairy industry to address these ever-evolving, complex, "wicked" problems. This novel approach could potentially aid the dairy industry to clearly position itself as a leader in sustainable food production, rather than simply being reactive to issues as they arise; thereby assisting the industry in retaining its' social license to practice.

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AUTHOR CONTRIBUTIONS

SB and MvK both performed the literature searches and together wrote the review. All authors contributed equally to conceptualization.

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Factors Affecting the Welfare of Unweaned Dairy Calves Destined for Early Slaughter and Abattoir Animal-Based Indicators Reflecting Their Welfare On-Farm

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In many dairy industries, but particularly those that are pasture-based and have seasonal calving, "surplus calves," which are mostly male, are killed at a young age because they are of low value and it is not economically viable to raise them. Such calves are either killed on farm soon after birth or sent for slaughter at an abattoir. In countries where calves are sent for slaughter the age ranges from 3-4 days (New Zealand and Australia; "bobby calves") to 3-4 weeks (e.g., Ireland); they are not weaned. All calves are at the greatest risk of death in the 1st month of life but when combined with their low value, this makes surplus calves destined for early slaughter (i.e., <1 month of age) particularly vulnerable to poor welfare while on-farm. The welfare of these calves may also be compromised during transport and transit through markets and at the abattoir. There is growing recognition that feedback to farmers of results from animal-based indicators (ABI) of welfare (including health) collected prior to and after slaughter can protect animal welfare. Hence, the risk factors for poor on-farm, in-transit and at-abattoir calf welfare combined with an ante and post mortem (AM/PM) welfare assessment scheme specific to calves <1 month of age are outlined. This scheme would also provide an evidence base with which to identify farms on which such animals are more at risk of poor welfare. The following ABIs, at individual or batch level, are proposed: AM indicators include assessment of age (umbilical maturity), nutritional status (body condition, dehydration), behavioral status (general demeanor, posture, able to and stability while standing and moving, shivering, vocalizations, oral behaviors/cross-sucking, fearfulness, playing), and evidence of disease processes (locomotory ability [lameness], cleanliness/fecal soiling [scour], injuries hairless patches, swellings, wounds], dyspnoea/coughing, nasal/ocular discharge, navel swelling/discharge); PM measures include assessment of feeding adequacy (abomasal contents, milk in rumen, visceral fat reserves) and evidence of disease processes (omphalitis, GIT disorders, peritonitis, abscesses [internal and external], arthritis, septicaemia, and pneumonia). Based on similar models in other species, this information can be used in a positive feedback loop not only to protect and improve calf welfare but also to inform on-farm calf welfare management plans, support industry claims regarding animal welfare and benchmark welfare performance nationally and internationally.

Keywords: bull calf, welfare indicators, ante- mortem, post-mortem, meat inspection, health, pasture-based, slaughter

INTRODUCTION

In dairy industries worldwide, the focus on milk production means that male calves are surplus to requirements. Some female calves are also surplus to requirements as 60% of the milking herd can produce a sufficient number of replacement females (1). The fate of these surplus calves varies between countries depending on the system of production (calving pattern, breed used etc.) the calf price and consumer preference for veal [slaughter age 5–11 months, (2)] or beef [slaughter age >12 months, (2)] (3). The variation is such that in Germany, surplus calves from dual-purpose dairy cows are raised for beef (4) while in the Netherlands, France and Italy, the veal industry is the major outlet [(5) cited by (3)]. This is also the case for most calves produced in North America though calves are also killed soon after birth (6).

A recent review of animal welfare in pasture-based systems of milk production concluded that farm management is as important as the system of management (7), a concept which applies particularly to calf management. Indeed the early (<1 month old) slaughter of surplus calves is particularly associated with pasture-based systems of milk production, where calving is usually seasonal to match the start of grass growth. In such temperate dairying regions, the majority of calves are born in spring (northern hemisphere, e.g., Ireland) or in the autumn (southern hemisphere, e.g., New Zealand and Australia). Furthermore, calving often occurs over a very short timeframe of approximately 8 weeks where a "compact calving" pattern optimizes profitability of the system (8). The seasonality of calf births means that pasture-based production systems are generally incompatible with a veal industry based in the same country, as veal production relies on calf availability all-year-round. This means that such milk production systems face a particular challenge in finding an outlet for surplus calves. The main outlets are that calves are (1) reared for beef in the country of origin, (2) exported to a veal or intensive beef industry in another country or (3) they are killed early, either on-farm soon after birth or slaughtered at a licensed premises within 1 month of birth—(3). For slaughter calves, the age ranges from 3–4 days (New Zealand and Australia; "bobby calves") to 3–4 weeks (Ireland, other EU countries and the UK).

Ireland is an example of a country with an intensive pasture-based system of milk production with a seasonal calving pattern as described above. About 40% of all calves born in Irish dairy herds are reared for beef primarily in pasture-based systems of production, while almost 12% of dairy calves 180 k dairy calves [predominately male–out of approximately 1.6 m dairy cows; (9)] are shipped unweaned to the European continent for veal [or beef—(10)] production. Export of calves to a second country is a contentious practice with opponents arguing not to transport young unweaned animals over long distances because it poses major threats to their welfare (11). Indeed, there is scientific evidence to support the detrimental impact of long distance travel on the health and welfare of cattle of all ages (12, 13). In addition, Knowles et al. (14) reported that calves under 1 month of age are physiologically unable to adapt and therefore to cope with transport. The age at which the calves are transported (c. 3 weeks old) coincides with the decrease in maternal antibody and the immaturity of the humoral immune system (15) leaving them more susceptible to environmental infections. There are also concerns with calves' fate at the destination, particularly with veal, but also with intensive beef production, relating to feeding and housing practices and associated antimicrobial use (3, 10, 16). There is considerable room for improvement to calf transport and veal production systems and such changes might make these options for surplus calves more sustainable and ethically acceptable from a societal point of view (3).

In contrast, the ethical issues surrounding slaughter of unweaned calves are such that it is never likely to be acceptable to society (17). One of the most promising potential solutions to surplus calves in general involves use of sexed semen either to ensure the production of female replacements when using dairy genetics or to produce males from beef sires (18–20). Indigenous (rose) veal industries and systems in which calves stay with their dams could also play a role in reducing the need to slaughter calves (3). However, none represents a panacea and several are associated with considerable research gaps (21) as well as political and economic constraints. Hence, it is likely that slaughter of unweaned, mostly male, surplus calves will continue for some time. Given their young age as well as the societal and retail focus on this cohort of animals [e.g., (22)] it is crucial to protect their welfare during their short lives. The vulnerability of these animals to poor welfare was highlighted by a scandal involving cruel treatment of "bobby calves" in New Zealand in 2015 (23). Subsequently, legislation was passed to better protect bobby calves by ensuring a maximum duration of travel of 12 h (from August 2016) and that calves were slaughtered within 12 h of last feed (from Feb 2017) (22). Accordingly, the mortality rate at the abattoir prior to slaughter declined in New Zealand [(24, 25) cited by (26)]. This decline in pre-slaughter mortality rate also reflected education and extension efforts by various industry stakeholders in the New Zealand dairy industry (26). One such successful dairy industry initiative involved a checklist to assist farmers and hauliers in decision making regarding calves fitness for transport.

Checks relating to age (minimum of 4 days old), ability to stand, brightness/alertness of eyes and ears, presence of an ear tag, dryness of the navel, hoof hardness, fullness of the stomach and absence of scour (27). Such an animal-based welfare assessment is in line with recommendations of the European Food Safety Authority (EFSA) Panel on Animal Health and Welfare (28).

Ideally, regular comprehensive on-farm welfare assessments would help to protect the welfare of surplus calves while on-farm. However, such assessments are labor-intensive, time-consuming and run the risk of facilitating disease transmission (29). Many conditions that compromise calf welfare that occur on-farm can be assessed at the abattoir (30). Velarde and Dalmau (31) describe a Welfare Quality® assessment for pigs and cattle at the slaughterhouse. Such abattoir-based welfare assessments are not necessarily for use in routine veterinary surveillance (32). Therefore, there are recommendations to incorporate welfare indicators during meat inspection at abattoirs as a voluntary monitoring tool for animal health and welfare (33, 34).

EFSA recommends that animal-based indicators (ABI) be used when assessing welfare in the slaughterhouse (28). ABIs also inform on pre-slaughter handling and transport practices [e.g., (35)]. They are the most valid method of assessing animal welfare because the assessments are of the animals themselves, not their resources, which facilitates comparisons across all systems of husbandry (36). In recent years, numerous studies investigated ABI prior to (ante) and post (mortem) [AM/PM] slaughter in various species [(37–39) [pigs]; (40) [sheep], (41) [cull cows], (42) [cattle]]. Some authors validated specific PM ABIs as indicators of pig health and welfare on-farm [e.g., pig carcass tail lesions (34) and lung pathologies (43)]. Similarly, research on ABI in calves in the slaughterhouse focused on veal calves where PM evaluation of lung pathologies complemented on farm welfare assessments [e.g., (44, 45)]. While the value of necropsy findings from unweaned calves that die on farm is recognized [e.g., (46)] there are only two studies which looked at ABI PM in unweaned calves slaughtered early (26, 47). Both studies involved bobby calves as they were based in New Zealand. Meanwhile, a report of the New Zealand Ministry for Primary Industries (48) presented a systematic mapping review of ABI that could be used to assess the welfare of bobby calves in lairage at commercial abattoirs but these did not include ABI for measurement PM.

Currently, the only routinely collected data relating to the welfare of surplus, unweaned calves are mortality rate on-farm and pre-slaughter (dead or condemned/euthanised at the abattoir). Presumed cause of death, based on PM examination, in bobby calves that die or are condemned prior to slaughter is also recorded in New Zealand. We propose that standardized protocols to record ABI in the slaughterhouse could help to protect the welfare of surplus, unweaned calves destined for early slaughter.

Our main aim in this paper is to identify AM/PM ABI potentially relevant to the welfare (and health) of unweaned dairy calves (<1 month old) on-farm and in transit. This paper frames the issue of slaughtering unweaned calves around pasture-based dairy production systems with seasonal calving patterns such as in Ireland and New Zealand. However, the AM/PM scheme proposed herein could easily be adopted to other production systems disposing of surplus unweaned calves by means of slaughter. Further, we draw on findings from studies reporting slaughterhouse findings in unweaned, mostly "bobby," calves, studies relating market/auction (<1 month of age) and abattoir (<12 months)-based ABI findings in veal calves and PM findings for dairy calves that die on farm at all ages. As such, this concept could be extended to the slaughter of young cattle in general. Additionally, we outline how a calf AM/PM scheme could work in practice, elaborate on the associated benefits to dairy industries and make recommendations for research in this area. We also cite literature emanating from all production systems on calf mortality, and aspects of calf management with a focus on sex differences, of relevance to surplus, unweaned, calves destined for early slaughter. Our approach is narrative, this is not a systematic review. Hence, we marshall relevant literature to build the case for the need for an AM/PM scheme whereby salient papers are cited but other similar papers may not be.

ON-FARM MANAGEMENT AND MORTALITY RATES OF UNWEANED CALVES DESTINED FOR SLAUGHTER IN SEASONALLY CALVING PASTURE-BASED SYSTEMS

Ireland

Abolition of the European Union milk quota brought about significant sectoral changes in the dairy industries of member states. Ireland was one of the countries that saw the greatest increase in the size of the national herd (49). Larger herds means more calves born on dairy farms and recent research indicates that this is positively associated with the probability that calves are slaughtered early (50). Hence, expansion results in an increase in the number of unweaned calves sent for slaughter. In Ireland, expansion also resulted in a renewed focus on breeding for milk production characteristics (51). This combined with an initial increase in the proportion of producers using Jersey genetics (52). These breeding-related changes resulted in an increase in the number of dairy male calves with low beef, and at the extreme, no veal, characteristics, and therefore of very low economic value. Hence, in recent years Irish Animal Identification and Movement (AIM) bovine statistics indicate that a proportionately small number (c. 30 k in 2019) of predominately-male, unweaned dairy calves are slaughtered in Ireland each year [e.g., (9)]. Under EU legislation (Council Regulation (EC) 1/2005) it is illegal to transport calves <10 days old over distances >100 km in the EU so while these animals appear in the 0–6week old category in the AIM bovine statistics (9) they are generally 3–4 weeks old at slaughter.

New Zealand and Australia

In New Zealand and Australia, there are no opportunities to rear or to export surplus or "bobby" calves for veal. These calves are killed on-farm by farmers shortly after birth (53) or they are slaughtered at meat processing premises for human consumption or pet food, usually within the 1st week of life (26, 54). In New Zealand, ∼2.2 million calves aged between four and ∼7 days are slaughtered annually (26). These calves are at particular risk of welfare compromise, morbidity and mortality due to the very young age at which they are transported, mixed and held off feed prior to slaughter (14, 55, 56).

On-Farm Calf Mortality

Livestock mortality rates are a useful, though somewhat crude, indicator of animal welfare on farm (57–59). Numerous observational studies document on-farm mortality rates in dairy calves and young stock [e.g., (60–62)] and causes of death are well-defined [e.g., (46, 60, 63)]. In general, calves are at greatest mortality risk during the first 4 weeks of life, with diarrhea and respiratory disease being the most important reasons for death (58, 64, 65). Risk factors for young cattle mortality are widely studied (60, 66–69) and include sociological factors such as farmer attitude (50) or "blindness" (70) toward animal welfare.

Management of Male Compared to Female Calves on Farm

There is evidence of discrimination against male compared to female dairy calves in several areas (6, 48, 67, 71). In particular colostrum and post-colostrum feeding practices differ between males and females in many countries [Canada: (72, 73); United States; (71); New Zealand: (48); Ireland: (69) and UK: (74)]. This can be associated with differential rates of failure of passive transfer (FPT) of immunologlobulins between male and female calves (75, 76). Although a recent Irish study found no difference in rates of FPT between male and female calves on dairy farms (68). In another study, which investigated health outcomes in surplus dairy calves at auction in Canada, there was a protective effect of being a female calf on the odds of omphalitis and being generally unhealthy (77). These authors also surmised that female calves were associated with a higher sale price because there was a perception that they received better care on farm.

Mortality Rates of Male vs. Female Calves On-Farm

It is likely that different mortality outcomes reflect differential treatment of male and female calves on farm (57). Notwithstanding the biologically higher risk of mortality in males, higher than expected mortality rates in male compared to female dairy calves are widely reported [(78) [at the receiving veal farm]; (61) [first month of life at mortality odds ratio of 1.20]; (79) [first 48 h of life]; (80) [UK; between 21 and 90 days]]. Additionally, Hyde et al. (80) reported that the trend for males to have a disproportionally greater rate of mortality increased from 17.4% in 2011 to 26.16% in 2018. In Ireland, Ring et al. (81) showed generally higher odds of male calf deaths compared to females in both dairy and beef herds. However, in dairy herds the odds of male calves dying compared to females was 6.15 compared to 3.34 in beef herds. Findings from both of these studies suggest that in accordance with others (82, 83) higher mortality rates in males from the dairy herd mirror risk factors associated with economic value as well as biology. Interestingly Ring et al. (81) also showed general higher risks of mortality of calves in herds with Jersey genetics. This would seem consistent with the very low economic value of both male and non-replacement female Jersey calves (84). Irrespective of sex, calves from herds with calf mortality problems are likely to have greater risk of morbidity given the causal continuum between morbidity and mortality. Thus, young calves presented for slaughter from farms with high calf mortality problems are more likely to have ante and PM indicators of poor health and welfare.

PRE-SLAUGHTER MORTALITY IN SURPLUS, UNWEANED CALVES AND RELATED RISK FACTORS

Pre-slaughter mortality includes calves that do not survive the journey to the processor or their time in the lairage yards prior to slaughter or that are so seriously compromised that they are condemned (euthanised) on arrival (26, 47). Both these authors reported that the latter category composed two thirds of all pre-slaughter mortality. Risk factors for increased pre-slaughter calf mortality may act on the farm of origin, in transit or upon arrival in the abattoir. There are very few studies investigating mortality and associated risk factors in surplus calves prior to slaughter. Data on such animals can yield important insights on calf welfare because of associations with standards of calf management on-farm, in transit and at the abattoir [e.g., (26, 48)]. Hence, pre-slaughter mortality, particularly when combined with the associated PM examination results of animals that died (85), is an important indicator of calf welfare. However, a calf can suffer poor welfare before slaughter without dying so it can be a crude indicator of animal welfare status. Hence, there is a need for validated ABI relevant to calf health and welfare to understand the experiences of calves that survive to the point of slaughter. Another constraint to the usefulness of pre-slaughter mortality is its comparative rarity in slaughter calves. An Australian study reported a pre-slaughter mortality rate for bobby calves as 0.64% (86) which was similar to that reported in a New Zealand study conducted in 2011 [0.7% (47)]. Following the introduction of legislation protecting bobby calf welfare in New Zealand, the national pre-slaughter mortality rate declined from 0.25% in 2015 to 0.06% in 2017 (24, 25). Given that slaughter calves are older in countries governed by EU legislation, the pre-slaughter mortality rate is likely even lower though there are no data readily available to support this theory. However, while the mortality rate is extremely low, this does not obviate the need to reduce it further. Understanding and addressing the underlying risk factors in each stage of the supply chain: on-farm, during transport and in lairage at the slaughterhouse can help to achieve this.

Risks Associated With Management, Housing and Feeding of Calves on Farm

Calves slaughtered at 3–4 weeks of age are likely slightly better able to withstand the stresses of feed withdrawal, transport, movement through markets, lairage and slaughter than 3–4-day-old calves (87). However, the period on-farm when the welfare of these low value animals could be compromised is longer. Welfare concerns for dairy calves on farm are associated with housing, feeding and management practices (88). Apart from general calf management (e.g., nutrition, housing, etc.), management of ill-health can be a risk factor for poor calf welfare. This can be caused by mis-diagnosis and possibly incorrect therapy of a particular condition (e.g., sepsis) (89). But it can also mean that the problem was not recognized or that there was failure to treat (70). There are very few studies linking mortality of unweaned, surplus calves prior to slaughter with specific on-farm practices. The only on-farm risk factor identified by Boulton et al. (26) was time in the farm of origin's calving season which they suggest reflected farm-management related factors that change over the season. The severity of infectious disease in calves is influenced by management and hygiene practices (90) as well as immune status (91). Furthermore, disease transmission among infected calves may also be affected by management factors such as housing, group size and hygiene (92–94), which change over a farm's season (68, 70). Furthermore, research into the prevalence FPT of maternal antibodies in New Zealand dairy calves found that FPT was more prevalent in the middle compared to the early calving period (53). It is not routine practice to measure FPT on the vast majority of dairy farms internationally (70), hence farmers are not aware of the dynamics of this risk factor. The increase in FPT over the calving season observed by Cuttance et al. (53) may have contributed to the observed seasonal effect on risk of pre-slaughter mortality in the study of Boulton et al. (26).

Risks Associated With Transport and Lairage

Not surprisingly, and in line with most other classes of animals, there is a correlation between increasing transport distance (from farm to processor) and the correlated travel duration and calf mortality (26, 86, 95, 96). Transportation of young animals from the farm to the processor imposes stressors that affect their biochemical, hormonal and metabolic status (97). Loading and unloading (86, 98), novel human-animal contact (99), and the inability to lie down (96) are major stressors with negative effects on calf health and welfare resulting in increased mortality. The slaughter schedule is the main risk to calf welfare associated with the slaughter facility itself (26). Given that calves in lairage yards don't have access to feed this risk is directly associated with the amount of time elapsed since milk withdrawal whereby longer lairage times are associated with longer time off feed. Prolonged feed withdrawal negatively impacts on calf energy status (100). Additionally, although there is access to water in lairage yards calves may not consume this such that water loss and dehydration are also associated with prolonged feed withdrawal (101). Clearly, in order to reduce slaughter calf mortality and morbidity, transport distance/duration should be as short as possible.

REVIEW OF ANTE AND POST MORTEM ABI FINDINGS IN UNWEANED SLAUGHTER CALVES

Ante-Mortem Findings

There are only two recent studies specifically concerned with ABI findings in calves at the abattoir (26, 47, 48). In relation to AM findings, Thomas and Jordaan (47) reported some observations on calves that died pre-slaughter and which were subjected to PM examination. Boulton et al. (26) reported the most frequently recorded ABI as correlates with calf mortality prior to slaughter as weakness, recumbency, emaciation and dehydration. These authors also included behavioral measures related to posture and oral behaviors in their lairage inspection of bobby calves (48). They reported that welfare-related conditions affected 20% of calves and concluded that more calves with compromised welfare were recorded than would be registered officially.

In New Zealand, calves must not be moved off farm younger than 4 days of age. However, neonatal characteristics in such animals are commonly reported findings. For example, Thomas and Jordaan (47) observed "wet" umbilical cords in 25% of calves that died pre-slaughter. Similarly, Stafford et al. (102) classified over 4% of calves as "marginal" because of at least one of the following: wet umbilicus, hollow-sided, apparently immature, or weak and slow and unsteady on their feet. Studies conducted on unweaned calves presented for auction to the veal industry also report neonatal characteristics (12.3% of calves inspected) on the basis of wetness of the umbilical cord (77). At birth the umbilical cord is wet and though of variable length and diameter will be, on average, 15–25 mm thick (diameter) close to the base, (103). With age the cord dries [on average, by day 3, in all, by day 7; (104)] and shrivels from the distal end thus reducing diameter, e.g., 5–10 mm at 24–72 h old (83) and 10–15, 5–10 and 5–10 mm at one, 2 and 3 weeks of age (105). Cord dryness alone is a poor indicator of calf age (104). The cord finally detaches, on average, at 15–20 days old (103).

Findings from studies of young calves at veal auctions can help inform likely AM findings in unweaned slaughter calves. Both Marquou et al. (77) and Wilson et al. (106) report navel infection or omphalitis caused by opportunistic bacteria (107), as the main finding in such animals. Both studies also reported concerns with lightweight calves as these, and animals with navel infections, have reduced growth (108) and increased mortality (67) at veal farms.

Post-mortem ABI Findings in Unweaned Slaughter Calves

The value of necropsy findings from calves that die on farm in informing health management plans is well-recognized [e.g., (109)]. In slaughter animals, PM checks are primarily motivated by food safety (30) but meat inspection also provides an excellent opportunity to measure ABI of relevance to calf welfare [e.g., (44, 45)].

The most frequently recorded PM findings in calves that die (or are euthanised) pre-slaughter are digestive tract disorders and inflamed/infected umbilicus (omphalitis) (26, 47). Only Thomas and Jordaan (47) report recent findings from routine PM examinations of surplus calves. They found that omphalitis (54%) and septicaemia (37%) were the main causes of calf condemnation post-slaughter. This is in line with older studies performed in New Zealand (110, 111). However, Thomas and Jordaan (47) recorded proportionally more omphalitis and less

TABLE 1 | Morbidities recorded in dairy calves from 3 days to 3 months of age on 120 Irish dairy farms (n = 6,850) (70).

Level	%	Diarrhea	Respiratory disease	Navel ill
Herd	Min.	0	0	0
	Max.	12	27	6
	≥1 calf	89	42	53
Calf	%	7	2	2

TABLE 2 | Conditions most frequently diagnosed on *post-mortem* examinations of calves (0–5 months old) which died on Irish farms, (n = 1,219) (117).

Five most common conditions	0–1 month n = 609 (%)	Five most common conditions	1–5 months n = 610 (%)
Gastrointestinal infection	27.2	Respiratory infection	30.6
Systemic infection	19.4	Gastrointestinal infection	13.4
Respiratory infection	11.0	Gastrointestinal torsion/obstruction	9.4
Navel/joint ill	7.1	Systemic infection	9.1
Gastrointestinal torsion/ obstruction	6.9	Gastrointestinal ulcer/perforation/foreign body	6.1

pneumonia than these studies. They discuss that the younger age of calves in their study was likely responsible.

Omphalitis represents a major difference between PM findings of bobby calves and other classes/ages of calves. As mentioned above it is likely that the young age of these calves at slaughter is responsible such that infection has not yet traveled beyond the umbilicus and become systemic. In older calves, infections that originated in the umbilicus could be responsible for the systemic infections reported [i.e., septicaemia; (83, 112) or idiopathic peritonitis; (113)]. Additionally antibiotic usage is uncommon in bobby calves (48) compared to in calves destined for intensive beef rearing or veal systems (114–116) which could also explain the omphalitis-related pre-slaughter mortality and post-slaughter condemnations.

Thomas and Jordaan (47) describe how the few cases of pneumonia they recorded were considered typical of those caused by the aspiration of food material, probably during esophageal feeding, rather than the enzootic-form typically associated with calf pneumonia. The low incidence of enzootic pneumonia in bobby calves is in line with their young age (63, 117, 118). Pneumonia occurs at a much higher prevalence in all classes of older calves [dairy replacement heifers: (60, 63, 64), beef calves: (10, 118), veal calves: (83, 113, 114)].

In the absence of data on PM findings for older unweaned slaughter calves (i.e., in the EU/Irish context), we rely on data from two recent sources. O'Donovan (117) reported the main causes of on-farm mortality in calves, in various age categories, submitted to the six Irish government veterinary laboratories for diagnosis of the cause/s of death. While Mee (70) reported morbidities recorded in dairy calves from 3 days to 3 months of age on 120 Irish dairy farms (**Table 1**). The majority of deaths were due to infectious causes (**Table 2**). In line with findings for bobby calves (47) the main finding in calves 0–1 month of age was infection of the gastrointestinal tract. However, respiratory tract infections, though less common in calves in the 0–1 month age group compared to the 1–5 month age group (**Table 2**), were a more common cause of death than reported in the New Zealand studies. Though only 7% of calves were diagnosed with navel or joint ill, as discussed above, it cannot be discounted that the navel was the original point of infection in calves diagnosed with systemic infection (19.4%). The high proportion of farms with calves having navel ill further supports this theory [**Table 1**, (70)].

Hence, these data provide a good indicator of likely PM findings in slightly older though still unweaned, slaughter calves. On the basis of the findings outlined above we propose a range of ABI for potential recording at AM and PM examination in unweaned calves in the following sections.

ABATTOIR-BASED ABI RELEVANT TO CALF HEALTH AND WELFARE

Ante Mortem

Group Based Measurements

Inspection of calves at unloading could be on a batch-basis to identify problem cohorts for more detailed inspection. However, there are a number of behavioral ABI to measure at unloading which reflect not only fearfulness but also the efficiency and care with which calves are handled on arrival at the slaughterhouse (119, 120). Indeed slaughter plants are rarely designed with the behavioral needs of animals in mind (120). For young calves, unloading could be even more stressful than the journey itself (121). Ideally group-based behavioral indicators would be employed at this point such as number of falls, slips, jumps, balks, reversing, mounting and vocalizations (99, 121, 122). Unloading is a particularly useful opportunity to identify severely compromised calves such as those appearing very unsteady/lame, and falling frequently. Group-based behavioral observations can also be conducted in the lairage pens (48). In that report, observers viewed groups of calves from outside the pen using binoculars. They employed a detailed list of behavioral ABIs including group–(huddling and social play) and individually–based behaviors (oral behaviors, locomotory play, postures, head shaking or tilting). These measures could be useful on an *ad hoc* basis for specific welfare schemes/welfare assessments but would be logistically difficult for abattoir vets to conduct.

Human-animal relationship (HAR) tests measure calf fearfulness and reflect the way in which the calves were handled on farm (99) and in the abattoir (122, 123)]. Though measured on an individual calf basis (99, 124, 125) they could be conducted in the lairage pens and thus are considered as group (or pen) based observations.

Individual/Calf Based Measurements

The AM inspection is essentially a clinical examination of individual calves, preferably conducted by the lairage vet. As with all such examinations a systematic approach (where the same ABIs are evaluated in the same way in every calf) will glean a comprehensive picture of the animal's health and welfare status. It is also possible to conduct a systemic "walk-through" of the pen when carrying out the AM inspection of calves (48). Given the circumstances in which such an evaluation is conducted (large numbers of calves, limited space, time pressures), this is primarily a visual examination but with auxiliary examinations as indicated from the visual exam, e.g., palpation, temperature checking. Critical to the process is adequate lighting at the unloading dock and in the lairage. Each of the ABIs individually, but also collectively, inform judgement on whether, and to what degree, the calf's health and welfare is compromised. Thus, either an overall score could be assigned to each calf (e.g., normal/healthy or abnormal/unhealthy/condemned and euthanised) or only to those calves where poor welfare is recorded. Marquou et al. (77) assigned calves presented at auction for sale into veal production a general health score based on the summation of abnormal findings.

Hereunder we outline the main ABI to record in unweaned calves prior to slaughter with a brief explanation of their relevance to the overall health and welfare status of the calf. Examples of animal-based-indicators, their key features and published studies that used these indicators in a scoring system are shown in **Table 3**.

- Age/maturity (appearance of neonatal characteristics)

Clearly determining calf age is important from the point of view of compliance with codes of practice or legislation governing minimal ages at which calves can be moved off farm. While it is not possible to be precise about a calf's age, (even from birth certificates as calves may not be registered for days after birth) certain indicators can be used to estimate post-natal maturity. Very young calves may still be wet and can have difficulty standing (77) but establishing wetness of the umbilical cord is the main indicator of maturity. As a heuristic, calves with a wet cord are less than a week of age, those with a dry cord are likely to be more than 3 days old and those without a cord are likely to be more than 2 weeks old.

- General demeanor and posture

In the absence of obvious clinical anomalies, a calf's general demeanor can indicate the presence of an underlying illness, stress or pain. While standing, a calf showing good demeanor is alert/bright, interested in its surroundings and inquisitive. It should show a good suck reflex and be responsive (i.e., moves away or toward) to the approach of a human. Stafford et al. (102) described such calves as "strong, walking freely, round-sided, bright and alert." Such calves lie in sternal recumbence with their head held upright. In contrast, a calf with poor demeanor is dull and depressed, tilts its head downwards with drooped ears, and shows no interest in its surroundings, people or other calves. While lying such calves may tuck their head back on their shoulder or if in extreme pain, distress or illness will lie in lateral recumbence. They are either reluctant or unable to rise. A calf with abdominal pain or a thoracic disorder (e.g., pneumonia) may have a crouched posture with a humped back (kyphosis) while standing.

- Body condition

The body condition score (BCS) is an assessment of subcutaneous adipose reserves and therefore how well the calf was fed on-farm or the degree to which it has catabolised its fat reserves. This is best assessed by palpation of certain sites such as over the ribs, lumbar spinal processes and tail head. In a thin or emaciated calf which has catabolised its reserves there is less subcutaneous fat; a low BCS. Visual or palpation examination of the calf's abdomen to detect presence/absence of colostrum or milk/milk replacer in the gastrointestinal tract (sunken/hollow vs. full/rounded flanks) may support the findings of the BCS evaluation.

- Stability while standing

A healthy calf will maintain a standing position without obvious effort. A weak calf (e.g., due to under-feeding or diarrhea) or one with pain (e.g., due to a fracture) or hypothermia or with CNS abnormalities (e.g., cerebellar hypoplasia) may quiver/tremor while standing or shift legs uneasily.

- Shivering

If a calf is shivering (shaking slightly and uncontrollably) this suggests a degree of hypothermia (cold), which can be interpreted given the ambient conditions. Wet, small calves are at greater risk of hypothermia so coat condition also needs to be taken into account.

- Injuries and skin lesions

When visually inspecting a calf, injuries may sometimes be apparent such as swellings (e.g., over joints in the case of joint-ill or subcutaneous abscesses or haematoma possibly following injection or tagging), (**Figure 1**) wounds/abscesses (e.g., from sharp surfaces or handling), (**Figure 2**) or hairless patches (focal alopecia, e.g., on the perineum from prolonged scouring). The extent and degree of such lesions may relate to other findings in the calf. Boulton and colleagues (48) employed a scoring system for skin lesions for calves adapted from one devised by Jorgensen and colleagues (127) for horses.

- Locomotory ability/joint swelling

A healthy calf will move freely while a calf in pain or with limb joint infection (joint-ill) or limb abnormalities (e.g., contracted tendons) will limp exhibiting varying degrees of lameness or limit its voluntary movement.

- Cleanliness/fecal soiling

Depending on the type and cleanliness of the on-farm bedding or transport vehicle, calves should have a clean coat. Perineal soiling with watery or bloody feces indicates diarrhea (scour), (**Figure 3**) and perineal alopecia indicates chronic diarrhea. Visual observation of fecal consistency accurately correlates with reduced fecal dry matter content and diarrhea (73). Thomas and Jordaan (47) reported that the majority (96%) of calves

TABLE 3 | Examples of animal-based-indicators, their key features and published studies that used these indicators in a scoring system.

Animal-based indicator (ABI)	Key features of ABI	Example of study using this ABI in a scoring system
Age/maturity	Umbilical cord characteristics	Hides and Hannah (104)
Demeanour	Inquisitiveness, responsiveness, posture, suck reflex	Barry et al., (68)
Body condition	Subcutaneous adipose reserves, sunken/hollow flanks	Renaud et al., (67)
Stability	Unassisted standing/tremor	Barry et al., (68)
Shivering	Shaking slightly and uncontrollably	Bellows and Lammoglia (126)
Injuries	Skin lesions	Jorgensen et al., (127)
Locomotory ability	Lameness, joint swelling, contracted tendons	Renaud et al., (67)
Cleanliness	Faecal soiling of the hair coat	Barry et al., (68)
Dehydration	Enophthalmos, skin tenting	Renaud et al., (67)
Nasal/ocular discharge	Excess/abnormal discharge	Renaud et al., (67)
Respiration	Breathing characteristics	Ministry for Primary Industries (48)
Umbilical abnormalities	Umbilical heat/pain/swelling	Renaud et al., (67)
Body temperature	Rectal temperature	Mahendran et al., (128)

FIGURE 1 | Injection site swelling under the skin on the shoulder.

FIGURE 2 | Abscess under the skin in the neck of a young calf.

condemned due to digestive tract disorders (recorded PM) presented with severe diarrhea AM.

- Dehydration

The hydration status of a young calf should not be obvious unless the calf is dehydrated, as the calf will appear normal. However, dehydration is not uncommon in calves transported for long distances with an inadequate water supply. Dehydration (commonly due to diarrhea but also peritonitis and prolonged inadequate fluid intake) can be diagnosed visually by the degree of enophthalmos (recession of the eyeball into the eye socket), (**Figure 4**) skin tent test and capillary refill time (101). With the skin tent test the skin over the thorax is raised and the return time measured; <2 s indicates the calf is <5% dehydrated (normal) while >5 s indicates a calf is >10% dehydrated (obvious dehydration), (67).

- Nasal, ocular discharge

The presence of a nasal (**Figure 5**) and/or ocular discharge (**Figure 6**) (usually bilateral) indicates upper respiratory tract infection. Respiratory tract infections reflect both the infectious challenge from the calf's environment (e.g., poorly ventilated housing) and the livestock in a common air space (especially where there is overcrowding or older stock are present). The nature (e.g., nasal discharge–serous, cloudy, mucopurulent, purulent) and extent of the discharge may indicate the severity and chronicity of such infection. Rarely, nasal discharge with milk may indicate palatoschisis.

- Respiration

While the normal respiratory rate is approximately 10–30 bpm (129), this is affected by numerous factors such as recent exercise, transport, ambient temperature and time of day. Pathological factors which can elevate respiratory rate include lower respiratory tract disease and pain. Calves should not normally pant [>36 breathes per minute, counted over a 20 s

FIGURE 3 | Perineal fecal soiling in a calf with diarrhea.

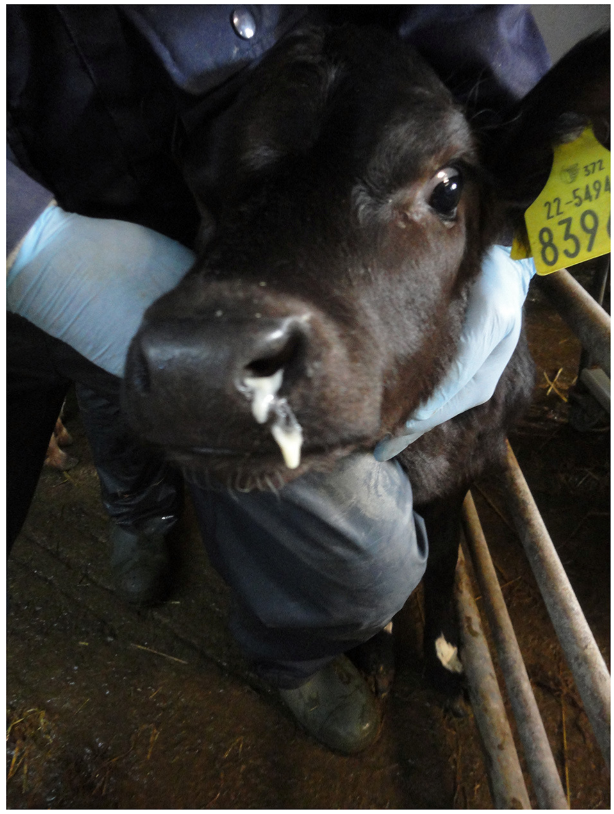

FIGURE 5 | Nasal discharge in a calf with respiratory tract infection.

FIGURE 4 | Enophthalmos (sunken eye) in a calf with dehydration.

FIGURE 6 | Ocular discharge in a calf.

period as per (48)] or spontaneously repeatedly cough (**Figure 7**) so the occurrence of either indicates respiratory compromise.

- Umbilical abnormalities

Common abnormalities of the umbilicus such as infection (navel-ill/omphalitis) and/or umbilical herniation are best detected by palpation (**Figure 8**) rather than just relying on observation.

- Rectal temperature

FIGURE 7 | Coughing calf with respiratory disease (Animal Health Ireland).

FIGURE 9 | Infection in and around the umbilicus (omphalitis).

FIGURE 8 | Infection of the umbilicus (navel ill).

In calves where visual inspection suggests an infectious process (e.g., navel-ill, joint-ill, pneumonia, diarrhea, etc.), (or possibly hypothermia), measurement of rectal temperature is warranted. In the normal young calf this will be <38.5°C (128) but, recent transport and exercise may elevate normal rectal temperature.

Following this systematic examination it is possible to establish if the calf is healthy, its approximate age, whether it has been adequately fed, and whether it is suffering from injuries, infections or congenital defects. Thus, each calf can be scored on its health and welfare status prior to slaughter.

Post-mortem

As with the AM inspection, the PM inspection is at the animal level. PM indicators may confirm findings from the AM indicators or add additional information about the calf's nutritional, infectious, injurious or developmental status not detectable from the AM evaluation.

Unlike a necropsy, where a more forensic approach is taken to investigate the carcass, abattoir carcass inspection is subject to the limitations of the conditions under which it is conducted. These include limited inspection time per carcass, the skin and musculoskeletal system separated from the viscera, a moving carcass or viscera line and no control over carcass opening and inability to collect confirmatory samples. Additionally any artifactual changes introduced by the method of killing and hanging the carcass need to be considered when evaluating the carcass for abnormalities.

Salient ABI detectable at PM calf inspection, their links to farm management and relevance for calf welfare are outlined hereunder.

- Umbilical disorders

Omphalitis is an infection of the umbilicus (**Figure 9**) that may be localized to the umbilicus or track up along the umbilical arteries to the bladder and pelvis or along the umbilical vein to the liver causing secondary site infectious foci. This has serious welfare implications for the affected calf due to chronic pain and resultant ill thrift. There are numerous on-farm risk factors for such infections, including umbilical antisepsis, colostrum management and feeding practices (and associated passive transfer) and general hygiene practices (93, 94).

- Lung disorders

Pneumonia and pleurisy are the most common visible lesions in calves with lung disorders (**Figure 10**). These reflect inadequate diagnosis and/or therapy of respiratory disease, usually on a group basis as well as a myriad of on-farm calf management and housing practices (44, 83, 130). Where pulmonary lesions are detected at PM inspection it is likely there are other sub-clinically affected calves in the same environment also with compromised welfare.

- Abomasal contents and disorders

Incision of the abomasum (subject to abattoir meat inspection SOPs) reveals how recently the calf was fed and what it was fed. Normally the abomasum should contain variably formed rennin curd and whey (**Figure 11**) though there may be evidence of oral electrolyte administration (depending on the color of

FIGURE 10 | Pneumonia and pleurisy in a calf with respiratory infection.

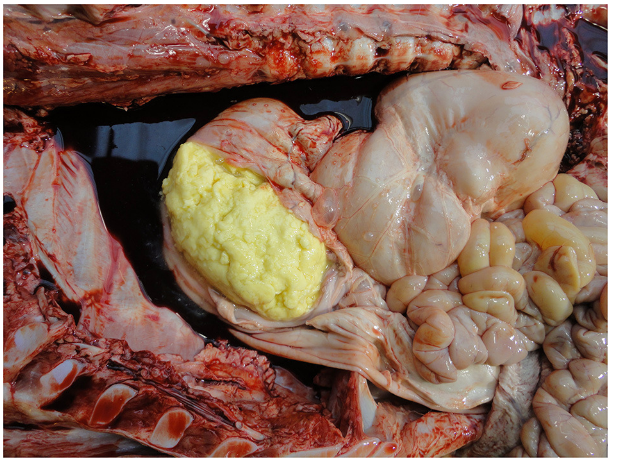

FIGURE 11 | Well-formed curd in the abomasum of a young calf.

the electrolyte product). The latter reflects recent therapy for dehydration, e.g., calf diarrhea. Given that the median time for complete abomasal emptying is 1.5 days (131), an empty abomasum suggests the calf was not fed recently. While absence of abomasal curd may rarely reflect abomasal dysfunction resulting in failure of curd to form (132) or the use of non-clotting (usually whey-based) milk replacers (133), whey would still be present if the calf was fed recently. Post-mortem examination alone cannot distinguish between these underlying causes, but the absence of curd prompts questions about the feeding practices used on-farm. Inspection of the abomasum can also reveal mucosal pathologies (oedema, hemorrhages, and ulceration of varying degrees including penetrative with localized or generalized peritonitis). Bedding material may be found in the abomasum from about a week of age and occasionally hair balls (tricholiths), abomasal bloat, or torsion may be found in older calves. Abomasal disorders in young calves are a reflection of both suboptimal feeding management (particularly with automatic milk/milk replacer feeders) and poor hygiene of the calf's feeding environment (134).

- Intestinal contents and disorders

Enteritis is the most common lesion found in the calf's intestines though congenital defects (e.g., intestinal or anal atresia or stenosis) are found occasionally. Enteritis is visible as fluid-filled contents with variable congestion of the intestinal serosa and mucosa and enlargement of the intestinal lymph nodes. Thomas and Jordaan (47) reported that the majority (96%) of calves that died pre-slaughter and were diagnosed with digestive tract disorders (usually without macroscopic enteritis) PM presented with severe diarrhea on arrival at the slaughterhouse. Calf diarrhea (enteritis) is caused by infections (e.g., cryptosporidia, coccidia, rotavirus, etc.) the calf picks up from its environment, and its inability to protect itself against these common agents (i.e., its immune status). Thus, the presence of enteritis reflects both inadequate colostrum management and/or an excessive infectious challenge in the calf's environment. Enteritis is a painful, debilitating condition causing ill thrift and seriously compromising calf welfare.

- Fat reserves

Fat reserves can be assessed from the perirenal, epicardial, mesenteric, intrapelvic (brown fat—required for non-shivering thermogenesis) and subcutaneous (white fat) deposits. In cases of catabolism, reserves may be visibly depleted from about 2 weeks of age indicating either under-feeding and/or a debilitating process, e.g., infection. Fat color varies with breed, e.g., more yellow in Jerseys (135).

- Rumen contents and disorders

In younger calves, the presence of milk in the rumen is cause for concern (47). Milk in the rumen of calves <1 month old reflects failure of the esophageal groove to close properly and to deliver milk directly into the abomasum. Some calves have a poorly functioning esophageal groove (136), potentially explaining this finding, but feeding of the calves via an esophageal feeder [as described by Chapman et al. (137)] prior to transport to the abattoir may also cause this to occur. In some calves ("rumen drinkers") an excessive, acidic/sweet smelling, milk volume is present in the rumen. This is found in calves which are repeatedly and/or over-fed using an oro-gastric feeder ("stomach tube") such as when they fail to suck adequately.

- Peritonitis

Infection of the abdominal peritoneum is usually secondary to a primary infectious focus elsewhere, e.g., umbilicus or liver or it may be part of a generalized infection, e.g., sepsis. It may be localized or extensive depending on the chronicity and severity of the infection and can vary from serous to fibrinous to purulent (**Figure 12**). Detection of such severe pathology at the PM inspection reflects inadequate management of diagnosis and therapy. Peritonitis is a painful condition indicating severe welfare compromise.

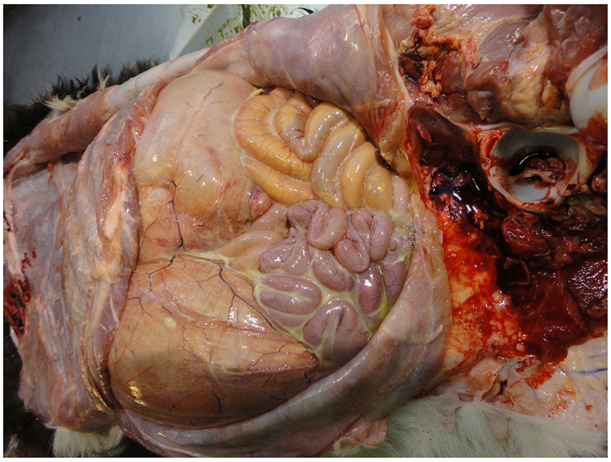

FIGURE 12 | Purulent peritonitis in the abdomen of a calf.

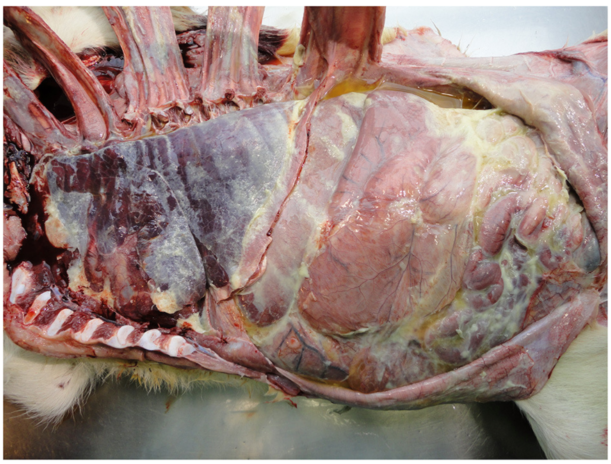

FIGURE 13 | Sepsis affecting the thorax and abdomen of a calf.

FIGURE 14 | Joint ill causing swelling of the carpus in a young calf.

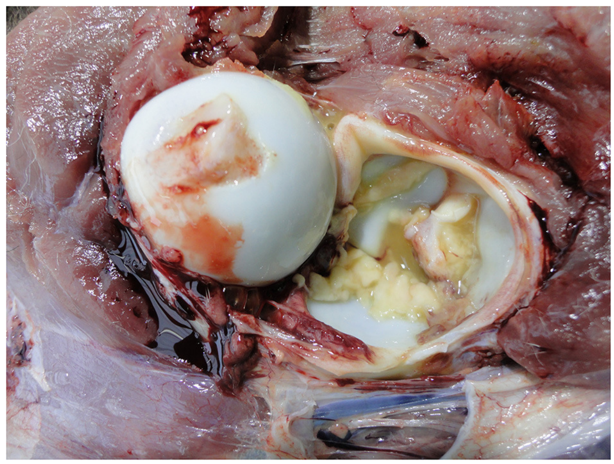

FIGURE 15 | Infection in the hip joint (arthritis) in a calf.

- Septicaemia

Infection that has spread to multiple organs (sepsis) may be detectable from the congested appearance of these organs (e.g., lungs, liver, intestines, spleen, kidneys), and associated lymph nodes and the presence of fibrin deposits (**Figure 13**). The presence of sepsis at PM inspection reflects overwhelming infectious challenge from the calf's environment and/or compromised immune status and severely compromised welfare.

- Arthritis

As arthritis is an extremely painful condition (138) it reduces calf welfare. It most commonly reflects poor environmental hygiene and/or poor perinatal umbilical/colostral management and consequent joint infection by opportunistic environmental pathogens. It can also be caused by the presence of specific primary pathogens, e.g., Mycoplasma bovis, in the herd (139) which may be transferred to calves through colostrum, waste milk or environmental contamination. Relying on detection of lameness and joint swelling in the live animal underestimates the presence of arthritis in young calves (47). However, arthritis cannot be detected PM unless joints are routinely incised, except in cases with obvious joint swelling, discharge or other signs of infection. While these signs may be obvious in lower limb joints (**Figure 14**) they may be more difficult to detect in the upper limb (**Figure 15**) and spinal joints. Thomas and Jordaan (47) found that arthritis most commonly affected the tarsal joints.

- Fractures

Fractures are rare in young calves but can occur following traumotocia or postparturient accidents in the ribs, limbs or mandible. They may occur on-farm or during transport where they may reflect unsuitable transport conditions or mis-handling. They obviously seriously impair calf welfare.

- Abscesses

Foci of infection (abscesses) may occur in any organ internally or externally. Externally, they are likely to result from trauma, poor injection or tagging technique or umbilical infections. Internally, they may result from systemic infections or localized infections, e.g., in the liver or lungs or in the neck from esophageal rupture following faulty oro-esophageal feeding technique. While internal abscessation is not possible to diagnose specifically, affected calves may show signs of non-specific ill-thrift with poor body condition. Where multiple calves in a batch have abscesses at the same site, e.g., injection site in the neck, this indicates poor technique with resultant localized pain and reduced welfare.

CALF AM/PM WELFARE SCHEME

Validation of ABIs

None of the ABIs outlined above are validated for use in a routine AM/PM scheme for surplus, unweaned calves. Indeed, validity is arguably the most important consideration, such that the chosen ABI reflect calf welfare on farm, during transport and pre-slaughter as intended [(31, 140)]. It is also important that the ABIs are repeatable in terms of producing the same result for repeated observations of the same animal by the same and different observers. For example, Teixeira et al. (141) found a significant effect of meat inspector shift on reasons for carcass condemnation. Standardized recording systems can help such as the calf health scoring chart developed by The University of Madison-Wisconsin School of Veterinary Medicine (https://www.vetmed.wisc.edu/fapm/svm-dairy-apps/calf-health-scorer-chs/) which several authors employed for calves at veal auctions [e.g., (67, 84)]. The associated APP allows scoring of clinical signs on a four-point scale related to respiratory disease (142), diarrhea (143), and navel and joint inflammation (144). As all of these are relevant to slaughter calves, it could be modified for AM use.

Importantly, the ABIs also need to produce consistently reliable results across observations of different animals and they need to be feasible in terms of speed and cost (145). Clearly, they should not compromise normal operating procedures and in this respect consultation with stakeholders is critical (146). Other practical considerations such as the degree of automation of the abattoir, the line speed, and the amount of variation in the training and experience of the veterinary inspectors are also important.

Feedback of Data

Ultimately, data collected on ABI relevant to calf welfare in the abattoir whether as part of routine veterinary surveillance or by more comprehensive welfare audits should be provided to farmers so that they can benchmark themselves against their peers and to inform animal management plans (33). Toward this end, education of farmers on calf care was identified as a critical finding of a recent needs analysis of male dairy calf marketing (106). By providing farmers with better access to their own data, animal welfare is improved (147, 148). The latter authors found that benchmarking encouraged farmers to make changes to their calf management practices by identifying areas needing attention and promoting discussion about best practices. However, abattoir-based findings on calf welfare are also of interest to cattle veterinarians who play a central role in improving youngstock management on-farm through effective communication of best practice recommendations (149)]. In addition, one needs to be cognisant of the possible divergence in opinion between farmers and stakeholders regarding prioritization of animal welfare issues (150). Other relevant stakeholders include national governmental and non-governmental public-good animal health and welfare organizations, quality assurance schemes and/or retailer groups. This raises issues about confidentiality and data sharing which can be contentious. Ultimately, national benchmark data on findings need to be generated and disseminated to demonstrate temporal and regional trends in progress toward improved ABIs included in the AM/PM calf welfare scheme.

CONCLUSIONS

The most important outcome from this review is the proposal, for the first time, of an abattoir-based AM/PM calf welfare scheme. This scheme in conjunction with a positive feedback loop would ensure critical calf welfare-associated information is communicated to on-farm decision makers and off-farm key stakeholders with the common purpose of improving the welfare of surplus dairy calves destined for early slaughter. This proposal is set within the unique concerns regarding the welfare of surplus dairy calves internationally and the context of existing similar schemes in other species. Such schemes can be used to identify and remediate farms with poor animal welfare and provide real-time and trending industry benchmark data on animal welfare, critical to quality assurance schemes. An abattoir-based AM/PM calf welfare scheme will ultimately provide the evidence-base to protect and enhance dairy industry's reputation amongst increasingly animal welfare-conscious consumers.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

LB and JM participated equally in the conception, writing and refining of this paper.

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Exploring the Opinions of Irish Dairy Farmers Regarding Male Dairy Calves

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Background: There has been very little previous research in Ireland on the farmers' opinions regarding calf welfare issues. Calf welfare, particularly for male dairy calves, has assumed greater importance in Ireland in recent years due, in part, to an increase in the number of dairy cattle over the past decade. The objective of this study was to explore dairy farmers' views on a broad range of issues related to the expansion in the dairy herd.

Methods: A survey was developed to capture the views of farmers regarding male dairy calves. The majority of questions were quantitative, and a final open-ended question collected qualitative data. The survey was distributed to ∼2,900 dairy farmers via text message and 881 responses were received.

Results: The sample was composed almost entirely of dairy farmers, although ∼20% also had a beef enterprise on their farm. Fifty eight percent of the farmers were concerned with the increase in the number of male dairy calves in recent years. The EU's abolition of milk quotas, the profitability of dairy farming compared to other farm types, and guidance from farm advisors were the three highest ranked drivers behind the increase in the number of male dairy calves. The three highest ranked options for managing the number of male dairy calves were to increase exports, encourage greater use of sexed semen, and improve the beef merit of these calves. Eighty five percent of respondents stated that individual farmers had responsibility for making changes to the number of male dairy calves. The main themes arising from analysis of the responses to the open-ended question, seeking any additional comments, were breed, beef price, live exports, and sexed semen.

Conclusions: Dairy farmers recognized the responsibility they have for making changes in respect of male dairy calves, and many demonstrated a willingness to make changes in this regard. The important role of other stakeholders, particularly suckler (system where reared from calf to beef) farmers, in rearing male dairy calves for beef production was also recognized. However, the issues of who bears the risks and costs associated with greater integration will have to be carefully considered.

Keywords: calf welfare, dairy farmers, male calves, qualitative research, Ireland

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INTRODUCTION

Since 2015, with the abolition of milk quotas in the European Union, there has been considerable expansion in the Irish dairy industry (1). The Irish Department of Agriculture had, in anticipation of the abolition of quotas, targeted a 50% growth in milk production in the strategy document Food Harvest 2020 (2), which a range of key stakeholders from across the agricultural sector helped inform. Regarding the increase in the national herd, the number of dairy cows in Ireland increased by 27% between 2013 and 2018 (3). As a consequence of the increased dairy cow numbers, there are increased numbers of male and female dairy bred beef animals coming onto the market. The issue of how to manage male dairy calves has been controversial in several countries, particularly where these young animals are euthanised, and has received prominent media attention (4).

Looking comparatively at how other countries manage male dairy calves, New Zealand and Australia do not have well-established industries for raising these calves, leading to the majority being transported long distances to be slaughtered within days of birth (5). For example, the significant increase in New Zealand dairy production since 1990 (6) led to a focus on traits for dairy productivity. This resulted in the male progeny from such cows, particularly Jersey and Jersey/Holstein-Friesian cross, having inferior beef characteristics, with the majority of these calves being slaughtered (7). The Irish dairy industry has modeled itself on New Zealand's pasture-based production system (8). In Europe and North America, the majority of male dairy calves contribute to the red meat industry (9), but the move to New Zealand type genetics in Ireland has led to increased numbers of calves with inferior beef characteristics, which beef farmers have difficulty in making a reasonable economic margin on.

Ireland differs from most other European Union countries; most Irish dairy farms are pasture based with spring calving (10, 11). As a consequence, there is a seasonal surplus of male dairy calves born on Irish dairy farms each year. A significant outlet for these calves is export to continental Europe, where there are well-established veal industries (12). Maintaining access to these export markets is a priority for Irish farm organizations, in order to maintain competition in the domestic beef market. However, the issue of live exports is of concern to the EU, with an EU parliament committee currently looking at animal welfare during transport. Therefore, like in Australia and New Zealand, surplus male dairy calves are a challenge for the Irish dairy industry (13).

While the present study does not directly address the welfare of male dairy calves, the increased number of male dairy calves in Ireland has the potential to result in welfare issues over the coming years if these animals are not managed in an appropriate manner. Driessen (14) recognized how the voices of farmers have been largely absent from debates on animal welfare and environmental concerns. Before specific new policies are introduced it is important to include stakeholders who will be responsible for their implementation in the process (15). By seeking the views of Irish farmers, this study aims to include farmers in the policy development process, which is particularly important given the inclusion of actors in policy development can lead to greater welfare compliance (16). For example, in Ireland, when suckler farmers were included in designing welfare initiatives the resulting initiatives were more practical and relevant (17). Regarding specific themes that have emerged from researching farmers' views on animal welfare, Cornish et al. (18) described how farmers' perceptions of animal welfare can be grouped into two categories; those concerned with the physical health and productivity of animals (focus on achieving economic results) and those concerned by broader aspects of well-being including the ability of animals to express natural behaviors (focus on moral and ethical concerns). There have been several studies examining dairy farmer's perspectives on welfare of dairy cattle in other jurisdictions, for example Sumner et al. (19) in Canada, Wolf et al. (20) in USA, and Vetouli et al. (21) in Norway and Sweden (specifically regarding organic dairy calves, which connected good welfare with the concept of naturalness). The US study demonstrated how farmers believe they are the actors with the most influence on calf welfare, followed by veterinarians, while the Canadian study highlighted the importance of farmer-veterinarian interaction for dairy cattle welfare. However, relatively little is known about Irish farmers' perspectives on animal welfare as Irish farmers' views on animal welfare are rarely sought, even though farmers "are the ones actually able to improve animal welfare" (22). Ventura et al. (23) found that veterinary practitioners believe farmers are the most important stakeholder in the improvement of animal welfare. Despite the importance of the farmer's role in improving welfare, very few previous studies have sought Irish farmers' views on how male dairy calves should be managed and this study aims to fill a gap in the existing literature. Given this dearth of knowledge, the objective of this study was to gather information on the perspectives of Irish dairy farmers regarding the issue of male dairy calves and on their preferred potential policy responses to manage the number of male calves. The availability of farmers' views on these issues may help inform future Departmental strategy on the management of male dairy calves.

METHODS

Survey Development

A self-completion survey using the *SurveyMonkey* software package was created by the One Health Scientific Support (OHSS) team within the Irish Department of Agriculture, Food and the Marine (DAFM), with expertise in social science, veterinary, epidemiology and animal science backgrounds. The topics chosen were based on the project proposal that the OHSS received from the Animal Welfare division of DAFM, which had set out the key issues the Animal Welfare division wanted examined. Input was also provided by senior official veterinarians with responsibility for animal health and welfare policies. This collaboration took place during face-to-face and remote meetings. Various drafts of the survey were circulated to the relevant stakeholders (veterinary and administrative staff within DAFM), and changes were made following constructive feedback.

Survey Design

In total, there were nineteen questions to be answered. An information section was presented at the outset, assuring potential participants that their anonymity would be protected and that their participation was voluntary, and the first question then asked respondents if they consented to participate in the study. Seventeen quantitative questions, comprising multiple choice and ranking style questions, were included in the survey. Where multiple responses were available the order of the options was randomized to minimize responder bias. In the ranking style questions, the participants had to rank each of the options; with 1 being what they felt the most important factor was. The method used for scoring these responses was to assign a reverse score, i.e., in a question with seven options the most important factor, ranked by a farmer at number 1, was given a score of 7. The weighted average was then used to determine the rankings. It was made compulsory to provide a response to each question before one could progress to answering the next question. Section breaks were also used, in conjunction with automatic skipping, to bring respondents to the end of the survey when they had completed all questions of relevance to their demographic cohort.

The final question was an open-ended question, asking participants to provide any further thoughts they had in a free text field; "Please provide any additional comments or suggestions you may have in the box below." Qualitative research asks participants "to describe their experiences in ways that are meaningful to them" (24). Although the findings of such research cannot be generalized to other contexts, this method helps provide a greater understanding of certain issues, through the unique perspective of the participants. While the current survey did not allow for the collection of qualitative data in the same way as an interview or focus group, our rationale for incorporating a free text question to this survey was to help improve DAFM's understanding of dairy farmers' opinions on these topics. The final question afforded farmers an opportunity for their voices to be heard in an unprompted manner and not in response to direct questioning. This coincides with the aim of this paper to include the views of farmers in policy development. A list of the questions asked, and available responses, is available in **Additional File 1** in Supplementary Information.

Data Collection

There are ∼18,000 dairy farmers in Ireland (25). The OHSS team issued a link to the survey using text messages to a sample of ∼ 2,900 farmers, derived from a nationwide database of dairy famers held by the organization Animal Health Ireland on January 21st, 2020. This method of distribution was chosen in order to reach a wide audience of dairy farmers from all around Ireland. In previous research links have been distributed to online surveys of Irish farmers, for example Meunier et al. (26). Two text message reminders were subsequently issued and, by the closing date of February 10th, 2020, a total of 881 responses had been received. This would suggest a response rate of ∼30%, but it is not possible to determine an accurate response rate given the possibility that recipients of the text message may have forwarded it to friends and family to complete. Overall, 98.6% (869) of the 881 respondents consented to participate in the study.

Data Analysis

SurveyMonkey aided the presentation of the results of the quantitative questions (Q2–Q18), generating tables and graphs presenting the results of each question; the output file is available in **Additional File 2** in Supplementary Information. SurveyMonkey was used to generate rating scales for ranking style questions, as in previous research including Sayers et al. (27). Regarding the qualitative question, a total of 402 responses were received (representing 46.2% of the respondents who had consented to participate in the study). The first step in the analysis of these responses was to identify any unusable replies, for example, where the respondent had indicated that they had no further comment. Sixteen responses were removed at this stage, leaving 386 substantive responses for further analysis, amounting to a total word count of almost 13,000 words.

The next step was for the lead author to read through each of the individual responses and assign a tag, or multiple tags where appropriate, categorizing the responses as falling under specific themes. The coding was done manually, with the aid of Microsoft Excel. There were no *a priori* assumptions of what themes would arise. An inductive coding approach was used; the codes applied to the responses were single words or short phrases that represented the meaning behind the content of the response. Multiple codes could be applied to longer responses where several different issues were raised. The responses were categorized following a careful reading of all of the responses on multiple occasions and the responses were subsequently rechecked multiple times by the lead author to ensure that the correct codes had been applied to each response. The responses were then grouped by the themes that were coded in order to determine the most frequently mentioned topics.

There is evidently a strong subjective element to any such categorization exercise as judgment calls frequently have to be made in deciding what theme most accurately represents the content of the response (28). It is not claimed that the list of themes used to categorize the qualitative responses is an exhaustive one, rather the themes cover those topics which could be clearly defined, and which arose in multiple responses. One hundred and twelve of the responses referred, in whole or partially, to issues that could not be categorized clearly within these chosen themes. In this paper only the most common themes will be presented and discussed. Select, representative quotes will be used to demonstrate the attitudes of the dairy farmers. The principles governing the choice of quote were to use a quote that "is illustrative of the point the writer is making about the data, it is reasonably succinct, and it is representative of the patterns in data" (29).

QUANTITATIVE RESULTS

Completion

Six hundred and seventy two respondents (78% of those who consented to participate) completed all seventeen quantitative questions.

TABLE 1 | Demographic results.

	Frequency	%
FARM TYPE		
Dairy	693	80.1
Beef	4	0.5
Dairy & Beef	163	18.8
Other	5	0.6
AGE		
18–24	23	2.7
25–34	79	9.1
35–44	233	26.9
45–54	283	32.7
55–64	191	22.1
65+	56	6.5
PROVINCE		
Connacht	36	4.2
Leinster	223	25.8
Munster	544	62.9
Ulster	62	7.2
WORK PATTERN		
Full-time	814	94.1
Part-time	51	5.9

Demographics

As seen in **Table 1**, the vast majority of participants had a dairy element to their farm enterprise. Over 60% of the respondents were aged over 45 years. Approximately 90% of the respondents were from Munster and Leinster. Ninety four percent of participants identified as being full time farmers.

Attitudes to Number of Male Dairy Calves

Fifty eight percent of participants stated that they were concerned about the large number of male dairy calves in recent years. An interesting observation regarding this question was that 184 participants (21% of those who had consented to take part) dropped out of the survey at this juncture, without providing a response. Lack of engagement in studies of welfare issues has been observed previously. In Butler et al. (30), some potential participants believed that assessing the welfare of horses was a pointless exercise and refused to participate in the study.

Regarding potential drivers of the increase in number of male dairy calves, the abolition of milk quotas (5.71), the profitability of dairy farming compared to other farm types (5.37) and guidance from farm advisors (4.25) were the three highest ranked factors. DAFM strategy (2.82) was viewed to be the least important driver. Increasing calf exports (5.85), encouraging greater use of sexed semen (5.66), and improving beef merit (5.1) were identified as being the most effective options in managing the number of male dairy calves. The two least popular options were the reintroduction of quotas (3.11) and rearing these calves for beef on their own farms (3.49). The subsequent question asked farmers to rank their preferred policy options in the scenario that live exports were to cease. The ranked order of the policy options, aside from the now removed "increasing calf exports" option, remained the same; encouraging greater use of sexed semen (5.13), improving beef merit (4.62), and try to establish an Irish veal industry (4.55) were the three highest ranked options. Regarding responsibility for making changes to the number of male dairy calves, 85% of participants stated that individual farmers had responsibility in this area. Teagasc, a state agency responsible for agricultural research and advice (70%), and DAFM (51%) were the two organizations farmers identified as having most responsibility for making changes to the number of male dairy calves. Please see **Additional File 2** for a more detailed breakdown of these results.

Herd Statistics

Calf Accommodation

87.5% of farmers indicated that they had sufficient calf accommodation.

Number of Cows

The vast majority of the farmers had between 50 and 200 dairy cows on their farm (77%), with very few having <50 (8%) or more than 500 cows (2%).

Breed

Friesian (74%) and Holstein (60%) were the two most frequently used breeds on these dairy farms. Five percent of the farmers used pure bred Jersey cows, but a quarter had cross bred dairy cows in their herd, which included Jersey cross animals.

Management of Male Dairy Calves

Purpose

Sixty eight percent of farmers believed that their male dairy calves are a product worthy of selling in their own right, while 32% of respondents felt that the main purpose of their male dairy calves was just to get the cow to produce milk.

Current Management

For this question, it was possible for farmers to select multiple options. Fifty one percent of the farmers sell their male dairy calves via a mart (live animal market), 49% sell directly to a dealer (a person who buys the animals and sells them immediately again to another client) or exporter (a person who buys animals to export them), while 24% rear the male calves for beef themselves. In respect of the 24% of farmers who selected the "other" option, most specified that they sold directly to other farmers. Only 1% of farmers indicated that they use contract rearing for their male dairy calves.

Willingness to Pay for Contract Rearing

Contract rearing refers to the practice whereby calves are moved to another farm for a different farmer to rear them in return for an agreed payment. The dairy farmers retain ownership and by using contract rearing they can free up labor, accommodation facilities, and grazing land, allowing them to focus on their dairy enterprise activities. Seventy percent disagreed with the statement "I am willing to pay for contract rearing for my male dairy calves," indicating an unwillingness to pay for male calves to be contract reared.

Please see **Additional File 2** for detailed statistical results of quantitative portion of survey.

QUALITATIVE RESULTS

This section aims to present the results of the final, open-ended question of the survey. This question gave respondents a chance to voice any further opinions they had on the topics of calf welfare and male dairy calves. The responses were categorized into themes and the main themes emerging from the analysis are presented here.

Breed ($n = 84$)

This theme covers responses that referred to the breed of cattle in general, or to specific named breeds. Regarding specific breeds, Jersey/Jersey cross cattle were mentioned the most often ($n = 51$). The issue of personal responsibility came up frequently in conjunction with breed; "*I think every farmer should be responsible for their own calves and if they want to cross breed (i.e. Jersey) they should not be making that calf someone else's problem.*" There was a perception that all dairy farmers are being tarnished by the negative views of Jersey/cross bred calves, best seen in the following quotes: (i) "*Dairy bull calf covers all breeds but the issue with the dairy bull is not with all breeds probably only one*"; (ii) "*Jersey and jersey cross calves have given all dairy calves a bad reputation.*" Solutions suggested by farmers included initiatives aimed at discouraging the use of these breeds, placing a levy on these animals, only using sexed semen for these breeds, ranging to severe outright bans on the use of Jersey artificial insemination straws.

Many farmers suggested other breeds as a better alternative for dairy farmers. Friesians/Holstein-Friesians ($n = 18$) were the second most commonly mentioned breeds. Specifically relating to the welfare of the animals, it was suggested that "*Friesian Holsteins have some chance of having some kind of life.*" Several farmers suggested that the issues with male dairy calves are a recent occurrence associated with a change in the breeds being used on dairy farms; "*When there was almost all British/Holstein Friesian cows there was no problem with bull calves from dairy herds.*" Some respondents suggested that dual purpose animals, which have value for both beef and dairy farmers, should be used instead, with Fleckvieh and Montbéliarde being mentioned in this regard.

Beef Price ($n = 57$)

This theme covers responses where the price of beef received from factories was mentioned by farmers. The following quote is representative of the vast majority of these responses; "*The main problem is the price the factories are giving for quality beef.*" Some farmers claimed that if there was a reasonable price available at factories there would be no problem with male dairy calves. Farmers felt that a better price at the factory would act as an incentive for beef farmers to rear dairy calves for beef production; "*If the beef price was at a fair level (€4 per kg plus) there would be plenty of part time farmers who would be delighted to bring these cattle to finish.*" €4 per kilogram was mentioned several times as representing a fair price for beef.

Sexed Semen ($n = 53$)

This theme covers responses where farmers mentioned the cost or efficacy of sexed semen. Farmers wrote about the need for better research into the use of sexed semen to improve conception rates and reduce cost. Given the higher cost associated with sexed semen several farmers suggested incentives should be offered by DAFM to make it more accessible. The need for a sexed semen lab in Ireland was also mentioned on numerous occasions; "*sexed semen should be produced here in Ireland to improve quality instead of going to the UK, with all that movement quality is comprised.*" The issue of using sexed semen was emphasized for farmers using Jersey/Jersey cross breeds "*Anyone using extreme milk genetics e.g. Jersey, should use sexed semen to reduce the volume of poor quality dairy males diluting the beef market.*"

Live Exports ($n = 51$)

This theme covers responses where farmers spoke about the live export of male dairy calves from Ireland. Farmers stressed the importance of the continued availability of live exports as an outlet for dairy calves: "*All the talk of ban on exports is bad news for Ireland. We have to have export markets at calf level and older stock too otherwise there will be too many stock in the country.*" These farmers demonstrated an awareness of the consequences if live exports ceased to be option; "*If live exports go, we will have a very serious situation.*" Problems relating to capacity on ships and lairage abroad were raised as issues requiring serious governmental attention. The topic of exports was frequently mentioned in combination with references to demand for veal in other EU countries, particularly the Netherlands.

Beef Merit ($n = 49$)

This theme covers responses where farmers mentioned the beef merit, or lack thereof, of animals coming from the dairy herd. Farmers recognized the importance of considering the beef merit of dairy calves in addition to their dairy traits; "*Every calf born must also be considered a beef animal as well as a dairy animal.*" The problems with the beef merit of Jersey/Jersey cross calves were raised; "*they lack beef qualities such as bigger carcasses and muscle production*". Some farmers were willing to slightly reduce the productivity of their dairy enterprise by placing greater emphasis on beef traits; "*give more value to beef side of cow with perhaps a small sacrifice in milk solids output so produce male calves people want.*"

Welfare ($n = 44$)

This theme covers responses where farmers mentioned animal welfare in general or specifically wrote about the welfare of male dairy calves. Most farmers who spoke about welfare expressed very strong sentiments in favor of protecting the welfare of all animals; "*livestock should not be treated simply as 'business inventory'. These are living and breathing animals and must be treated with the compassion and respect that they deserve.*" Farmers were supportive of very severe penalties if other farmers were found to be treating their animals poorly; "*Where actual animal welfare breaches occur they should be investigated and when breaches are detected they should be severely punished and published.*"

There were very few references to killing dairy calves, only thirteen were in favor of euthanasia, at least in certain circumstances: "*This study has not addressed the real elephant in the room. Bull calves are an unwanted by-product of dairying - they are relatively worthless. Why wasn't controlled, humane, culling at birth an option?*" Seven were against euthanasia in any circumstances "*Any person deliberately killing male beef calves should have their herd number cancelled by Dept of Agriculture.*"

Organizations

DAFM ($n = 32$, Including References to Minister for Agriculture)

While there were a small number of negative comments aimed at DAFM, mainly regarding beef price, the majority of comments spoke about the role of DAFM in providing a solution to the issues regarding the large number of male dairy calves; "*Farmers desperately need the Dept of Ag to protect us from the mess.*" The need for DAFM to set out a clear, long-term dairy strategy was raised; "*the department have to produce a proper long term plan for the industry, currently farms are making long term investments, then suddenly the rules change and just because there is a grant we are expected to change over night.*" The roles of DAFM in maintaining export markets and monitoring calf welfare on farm were also mentioned.

Teagasc ($n = 28$)

There was a widespread perception that farmers are now suffering the consequences of the advice they had received; "*Teagasc encouraged expansion without considering male dairy calves. Now we have to deal with the consequences of crossbreeding jerseys.*" Advice from the cooperatives ($n = 7$) were also mentioned in some of these comments attempting to explain how the current situation arose. Many of the farmers who mentioned Teagasc identified Teagasc's responsibility for providing solutions going forward; "*Need Teagasc to drive research and knowledge transfer on rearing dairy bred beef*".

Bord Bia ($n = 11$)

Farmers referred to Bord Bia's crucial role in identifying new export markets and maintaining exist export markets.

Farm Type ($n = 17$)

This theme covers responses which mentioned different farm enterprise types, particularly suckler farming. Dairy farmers spoke about the important role suckler farmers could have in rearing their male dairy calves, with some expressing a willingness to give these calves away for free. Farmers also felt that the beef from male dairy calves would be of similar quality to beef currently produced by suckler farmers; "*the male dairy calf is as good in terms of quality of meat as suckler counterparts.*" Coinciding with the results in the quantitative questions very few farmers spoke of the usefulness of contract rearing as a means of managing male dairy calves. Several responses referred to competition or potential conflict between dairy and beef farmers in Ireland; "*Don't force a profitable dairy sector subsidize a loss-making beef industry either by paying for contract rearing or forcing the use of beef straws.*"

Other

A small number of farmers spoke about a range of other topics including, *inter alia*, the expansion in the dairy herd, the reintroduction of quotas, domestic veal production, environmental concerns, and media coverage. These will not be examined in this paper.

DISCUSSION

To the authors' knowledge, this is the first survey to study Irish dairy farmers' attitudes to the issue of male dairy calves. Selection of suitable sires, the more widespread use of sexed semen, live exports, and the integration of male dairy calves into beef finishing systems were found to be the main strategies in addressing the issue.

Breed

While the most common theme arising in the free text responses related to breed, especially Jersey and Jersey cross cattle; the herd statistics of the cohort surveyed indicated that only a minority of dairy farms have these breeds in their herd. It is difficult to reconcile the difference between the perception of how significant a problem these breeds represent and the fact that they represent a small, declining, proportion of the national herd (31). The sustained focus on the issue in the agricultural media (32) and the poor beef characteristics of these breeds may help to explain why it arose so frequently in responses in this survey. This is not a uniquely Irish concern, with media, particularly online news sources, in New Zealand regularly raising the issue of male dairy calves (33, 34).

Responsibility

A minority of farmers questioned the strategic direction of the industry and the advice provided to farmers by Teagasc and milk processors. Very few respondents mentioned the responsibility of organizations in making changes regarding male dairy calves. Rather, many farmers mentioned the role of farmers in bringing about changes. The link between personal responsibility and behavioral change has long been recognized in public policy (35). Furthermore, given Ventura et al. (23) recognized the central role of farmers in improving animal welfare, it was encouraging that, when asked to select all stakeholders responsible for the making changes to the number of male dairy calves, the most commonly selected response (by 85% of respondents) was the individual farmer. Dolan et al. [(36), p. 71] described how personal responsibility and government involvement in changing behavior are not mutually exclusive; "government may spark initial changes that lead to reinforcing behaviors that manifest personal responsibility." This coincides with research literature on nudging behavior (37).

The interaction of breed and farmer responsibility in the free text responses was another interesting finding; the implication being that if farmers decide to have cross bred (particularly Jersey) animals in their dairy herd then they should also be responsible for managing any consequences of this decision. The concept of personal responsibility also arose in respect of beef merit with some farmers displaying a willingness to reduce dairy productivity in order to ensure that male calves from their herds would be able to be reared for beef. A small number of farmers also described how they would be willing to contribute toward the cost of establishing a sexed semen lab in Ireland. All of these findings serve to demonstrate the willingness of some Irish dairy farmers to accept personal responsibility and their openness to making changes which could ameliorate the situation. This will be crucial to the success of any future strategy, as the people responsible for implementing the strategy must be motivated to change (38). Dwane et al. (17) demonstrated that when the farmers were motivated to change their behavior, in that study using financial incentives, welfare improved and certain new welfare practices were expected to continue into the future. It is also worth acknowledging that, while farmers ranked themselves as the stakeholder most responsible for making changes to the number of male dairy calves, other administrative changes may be required to help and support farmers making changes to their behavior in this regard.

Live Exports

The issue of live exports is somewhat contentious and has been the subject of recent discussions in the Irish Parliament (39). While farmers demonstrated an awareness of the possible consequences if live exports were to cease to be available as an outlet, very few farmers indicated an awareness that such a scenario could occur in the short to medium term. Risks to the continued availability of live exports due to welfare concerns or adverse media coverage causing reputational damage were not identified by many farmers. The possibility of a ban on live exports is a real one, given recent suggestions that live exports from England and Wales may be banned in what would be a first for European nations (40). A recent study from Wilson et al. (41) surveyed the existing research, which suggests a 12-h maximum transport time for young calves and that rest stops may provide little benefit; these findings will be problematic for Irish live exports given the destination for calves is continental Europe.

Welfare

Much like Kauppinen et al. (22), the Irish farmers who mentioned welfare in their responses were against practices that would cause negative effects on an animal's welfare. The responses mentioning welfare did not just cover farmers who were critical of other farmers who abuse or mistreatment animals; a smaller number of farmers recognized the importance of actively treating animals well in terms of taking steps to ensure that male calves had proper housing and were well-fed before leaving their farm. This is indicative of empathy toward the animals in their herd, which Balzani and Hanlon (16) indentified as the foundation of farmers' opinions on animal welfare and their ability to meet the needs of their animals. The majority of responses were general in nature, condemning any mistreatment of animals; there were very few mentions of specific negative welfare behaviors or actions farmers could take to improve welfare. It is important to be aware of farmers' attitudes to welfare, given Dwane et al. (17) described how mismatches between farmers' attitudes and welfare strategies can result in non-compliance or even adversely effect animal welfare. In light of their finding, perhaps more in-depth examination of welfare practices on Irish dairy farms could be conducted in future research, ideally through interviews with farmers. This has been done previously in other countries, for example in Horseman et al. (42), investigating lameness in dairy cattle using interviews with farmers in the United Kingdom, and in Tucker et al. (43), where NZ dairy farmers identified a range of welfare issues. While recent research has examined public perceptions of animal welfare and dairy calf rearing (44), there is a dearth of studies examining farmers' views on the specific issue of male dairy calf welfare.

Greater Integration

This section encompasses the responses related to beef merit and farm type in the results. While only a small number of farmers specifically made reference to the difficulty of reconciling the two sectors, a divide between beef and dairy farmers would be a significant obstacle to any measures aiming to develop greater dairy-beef integration. In terms of reducing the number of unwanted male dairy calves, there were many encouraging qualitative responses; such as those farmers who indicated a willingness to use sexed semen, especially if it was made more effective in terms of conception rates and accessible in terms of cost, and those farmers showing an awareness of the need to improve the beef merit of dairy animals, even if this would adversely impact milk production. These developments, if introduced, would still take several years to have a significant impact on the large number of male dairy calves in Ireland. While the benefits of using sexed semen have long been recognized (45), sexed semen usage has not yet become widespread. De Vries et al. (46) had anticipated that widespread usage would become common over the following decade, but this has not materialized as envisaged. In the interim, alternative ways for managing male dairy calves need to be considered. While the possibility of dairy farmers rearing male dairy calves for beef production on their own farms was not viewed as an effective option in the survey, one quarter of the dairy farmers still indicated that they currently rear male dairy calves for beef on their own farms.

Improving the beef merit of calves from the dairy herd in order to improve suitability for beef production, identified as a potential solution in New Zealand (47), will be an important step for greater dairy beef integration. Given the potential negative health and behavioral impact of transporting animals long distances to veal farm (48), alternative calf management strategies which allow for male dairy calves to be raised for beef in Ireland would have welfare benefits. A solution may have emerged from the free text question, where many farmers identified the potentially important role for other farm enterprise types, particularly suckler farmers, in rearing male dairy calves for beef production. However, the issues of who bears the risk and costs associated with greater integration will have to be carefully considered, as demonstrated in the following quote from a dairy farmer "*Presumably the dairy farmer bears the risk on the bull calf right through to slaughter or sale. Making this a mandatory requirement would be a massive shift in the system design so that the whole industry is mobilized. It's full Integration of the dairy/beef system in Ireland.*"

It is worth acknowledging the crucial value of the information obtained from these farmers' opinions on male dairy calves, which may help inform future policy solutions. Following the analysis carried out on the results of this survey, and discussions with the relevant stakeholders as part of the calf stakeholder group (comprising the main governmental, semi-state, farmer representative, and private organizations from across the Irish agricultural sector), it is clear that the barriers to better dairy-beef integration need to be examined in greater detail. This study has focused almost entirely on a sample of Irish dairy farmers. In this regard, the next logical step is to examine the views of a large sample of Irish beef farmers on potential solutions to the issue of the large number of male dairy calves in Ireland, to ensure that their unique perspectives are adequately considered before considering any changes to existing policy. Further qualitative research, such as interviews, with dairy farmers examining the themes arising from this study in greater detail may also provide further insight into these issues.

CONCLUSIONS

To the knowledge of the authors, this is one of the first times Irish farmers have been surveyed on the welfare of male dairy calves. The estimated response rate of 30% is high for studies of this kind and indicates a high level of engagement. The respondents recognized that the primary responsibility for the welfare of dairy calves rested with the farmers themselves. While live exports were considered the main outlet for such calves, the wider use of sexed semen to ensure cross bred calves were female and the use of sires with more beefy characteristics were considered as potential solutions. However, poor beef price was considered a contributory factor which impacted disproportionately on dairy breed beef production.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

RD conceived the idea of the paper, suggested questions for the survey, and provided observations on the results. MB reviewed the survey questions and provided observations on the results. AC and AB contributed to the design of the survey, redrafted the report of the results, and assisted with the literature review. JM assisted with the study design, analyzed the quantitative and qualitative data, presented the results to the calf stakeholder forum, and drafted this manuscript. DB oversaw the entire project and contributed to each stage from survey design through to the drafting of this manuscript. All authors read and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2021.635565/full#supplementary-material

Additional File 1 | Survey questions.

Additional File 2 | Summary data for quantitative responses.

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Pecking Behavior in Conventional Layer Hybrids and Dual-Purpose Hens Throughout the Laying Period

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To avoid the killing of surplus male layer chickens, dual-purpose hybrids are suggested as an alternative approach. These strains may offer additional advantages compared to conventional laying hens, for instance, a lower tendency to develop injurious pecking behavior. The aim of this study was to assess the behavior, with focus on pecking behavior, of conventional layers (Lohmann Brown plus, LB+) and dual-purpose hens (Lohmann Dual, LD). About 1,845 hens per strain with intact beaks were housed in four stable compartments in aviary systems. Video-based scan sampling of general behaviors and continuous observations of pecking behavior were carried out between 25 and 69 weeks of life. With the exception of "dustbathing" and "scratching," hybrid × time during the laying period affected all of the observed general behaviors [$F_{(2,\ 89)} = 3.92$–10.81, $P < 0.001$–0.05]. With increasing age, the LB+ hens performed more general pecking, more locomotion and less comfort and sitting behavior. General pecking and comfort behavior did not change over time in the LD hens, whereas inactive behaviors increased with age. During continuous observations, a significant hybrid x period interaction was found for all forms of pecking behavior [$F_{(2,\ 89)} = 4.55$–14.80, $P < 0.001$–0.05]. The LB+ hens showed particularly more severe feather pecking (SFP), which increased with age. In contrast, SFP remained exceptionally low in the LD hens throughout production. Therefore, dual-purpose hybrids should be considered as an alternative to both avoid the killing of surplus male chickens and the development of SFP in laying hen production.

Keywords: laying hen, aviary, behavior, welfare, feather pecking

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INTRODUCTION

Killing male day-old chickens from layer strains directly after hatch is a common practice all over the world. These chickens are not suitable for economic meat production due to the genetically determined negative correlation between fattening and reproductive performance (1). This led to the selection of specialized hybrid strains for either meat production (broiler hybrids) or egg production (layer hybrids). In broiler hybrids, both sexes are used for meat production. However, as male layer hybrids do not lay eggs, they are usually killed at day-old. This practice raises strong socio-ethical—and in some European countries—also legal concerns (2). Thus, in recent years, different approaches to avoid this practice have been developed (3). A dual-purpose concept that consists of housing hens for egg production and keeping roosters for meat production, is one solution to deal with the problem of surplus male chickens of very specialized hybrid strains. According to a public survey, dual-purpose chickens seem to be one of the preferred alternatives (4). Other approaches include different methods of in-ovo sex determination, with discharging eggs with male embryos at a preferably early stage of incubation and only hatching female chickens (2, 3). In other cases, the male offspring of conventional, high-yielding layers are reared without economic profit. Their meat is mainly processed for convenience food and the costs of rearing are usually subsided by a higher price for the eggs from such concepts (2). However, these concepts do not address additional challenges in the context of animal welfare in modern laying hen husbandry. For instance, the frequent occurrence of abnormal behaviors, such as injurious pecking (5, 6). In this respect, the use of dual-purpose hens may also provide advantages compared to conventional layers, as they seem to show a lower tendency to develop injurious pecking behavior (6).

By the term "injurious pecking," several behaviors are summarized, which are all directed at conspecifics and lead to physical damage. Feather pecking (FP) is a form of injurious pecking with multifactorial origins, posing a serious welfare threat to current laying hen husbandry (5, 7, 8). This undesirable behavior impairs the health and welfare of the animals as it causes pain in the receiver and is a sign of stress in the offending bird (9). FP refers to non-aggressive pecking, and is directed mainly at the bird's back, tail, and vent area (5, 10). Different forms of FP can be distinguished depending on the forces of the pecks, and whether feathers are completely removed or not (11). A distinction between severe feather pecking (SFP) and gentle feather pecking (GFP) is suggested, as SFP causes most of the feather damage to the recipient bird (10). SFP is characterized by forceful pecks that result in feathers being pulled out, accompanied by a reaction of the recipient bird. In contrast, GFP normally does not result in feather loss or a reaction from the receiver (5). Nevertheless, GFP may develop into SFP, which itself can turn into tissue pecking and cannibalism as soon as denuded areas occur on the hens' bodies (11). In contrast, cannibalistic behavior that is directed at the vent or the toe of a conspecific often occurs irrespectively of FP in hens with intact plumage cover (11–13). Moreover, feather pecking must be distinguished from aggressive pecking (AP), as the latter occurs due to a different underlying motivation (5). AP is regarded as a normal dominance behavior to establish social hierarchies. It is mainly directed at the birds' head and neck, and usually does not result in severe feather damage (5, 11). More recent research suggests that FP behavior is an over-expression of social exploration (7). However, FP has also been considered as redirected foraging behavior (14). In this respect, the inhibition of environmental pecking (EP) at the ground or other surfaces in the barn may cause a redirection of pecking at the bodies of conspecifics (14, 15). Besides foraging, which includes EP and scratching, there are other, more general behaviors that influence or are influenced by FP behavior. Similarly to foraging, dustbathing behavior includes phases of EP. FP has also been associated with locomotion behavior. Hens selected for high levels of FP traveled longer distances (16) and showed higher levels of general locomotor activity (17) than birds selected for low FP activity. Comfort behavior is seen as a behavioral priority in laying hens (18) and its presence or absence can provide more general indications of the welfare status of a flock.

The likelihood of developing injurious pecking is influenced by many parameters such as resource-related factors. Resource-related factors may include the presence of dustbathing and foraging material, the arrangement of perches, the stocking density and the total amount of space provided (19–23). Thus, the prevention of abnormal behaviors seems mainly related to an optimization of husbandry and management conditions (8, 24). However, a correlation between FP and the genetic background of the hens was also previously described (7, 25, 26). Observational on-farm studies showed that the prevalence of feather damage varied among different commercial high-yielding layer strains (27, 28). Furthermore, a divergent phenotypic selection on FP behavior led to the high- and low FP chicken lines, which are used in fundamental research (26, 29). It was also possible to identify quantitative trait loci for FP behavior by using methods of molecular genetics (30). To date, little is known about the prevalence and the development of injurious pecking behavior in dual-purpose hens. In a previous longitudinal study, the plumage and integument condition of dual-purpose hens and conventional layer hybrids was comparatively assessed by a visual scoring method, indicating that severe feather loss and skin injuries were only present in the conventional layers but not in the dual-purpose hens (6). However, this research did not include behavioral results to support differences in actual FP activity between the two hybrids. Although feather loss and injuries are valid indicators for pecking behavior in laying hens (10), differences in plumage and integument condition might also be due to strain differences in feather quality or resource use causing more or less abrasion. So far, evidence that FP activity is higher in conventional layers compared to dual-purpose hens is only found in the functional area of the nest boxes (31). Thus, it is not known whether and to which extent the behavior, particularly injurious pecking behavior, differs between the two hybrid strains in other parts of the housing system.

The aim of the present study was to compare the pecking behavior and general behaviors potentially related to pecking behavior of conventional layer hybrids (Lohmann Brown plus, LB+) and dual-purpose hens (Lohmann Dual, LD) throughout the laying period (25–69 weeks of age). Based on previous research on feather loss and injuries, we hypothesized that the LD hens would show less injurious pecking behavior than the LB+ hens. Furthermore, we expected that within both hybrid strains, general behaviors and pecking behavior would be affected by age.

MATERIALS AND METHODS

Animals and Husbandry

The present study involved a total of 3,690 Lohman Brown plus (LB+, conventional layer hybrid) and Lohman Dual (LD, dual-purpose hybrid) hens, all of them with untrimmed beaks. From day-old to 19 weeks of age, all LB+ and LD chickens were reared on a commercial farm in Northern Germany. The chickens were kept in the same house in one separate pen per hybrid (10 pullets/ m^2). In both pens, the birds had unrestricted access to nipple drinkers (one nipple every 13 pullets), perches at different heights (35–95 cm above the floor, 30 m perching space/pen), wood shavings on the floor, and two straw bales. A commercial diet was provided *ad libitum* in pan feeders on elevated tiers (one feeder every 35 pullets). Wood shavings and straw bales were available in both pens on arrival of the chicks from the hatchery. A good litter quality (dry and flaky, easy to move with foot) was maintained in both pens during the entire rearing phase. All housing and management conditions were kept the same for the two hybrids (**Supplementary Material**) and the same caretaker looked after all pullets. Behavioral observations were not carried out during rearing. However, feather loss and injuries, which indicate feather pecking and cannibalism, were not observed in the LB+ and the LD pullets (**Supplementary Material**). At 19 weeks of age, the birds were transported to the research farm of the University of Veterinary Medicine, Hannover, Germany, where they were kept until the birds were 71 weeks of age. Again, both hybrids were subjected to the same standard housing and management conditions (32). The hens were housed in two stable compartments per hybrid (about 920 hens per compartment, 9 hens/m^2) (31). Each compartment was equipped with six sections of an aviary system (Natura Nova 270, Big Dutchman, Vechta, Germany; total height: 200 cm) (33). The aviary was equipped with eight perches at four different heights (33–103 cm above a grid tier of 65 cm height) offering about 17 cm perching space per hen (33). In addition, the hens had access to linear feeding throughs (12.5 cm per hen), nipple drinkers (one nipple every 6.4 hens) and colony nest boxes (0.008 m^2 per hen). On the floor, beneath and on both sides of the aviary, the hens had access to a scratching area with sawdust litter. Alfalfa bales suspended in hay nets served as standard enrichment material (about one bale every 200 hens). The light regime started with 10L:14D (week 19) and was gradually extended until 14L:10D (week 25). At 45 weeks, the light regime was increased to 16L:8D and maintained until the end of the laying period. At first signs of feather pecking or cannibalism additional measures, for instance pecking blocks, were placed in all stable compartments following a gradual emergency scheme (34). Detailed information on the emergency scheme, the measures being taken and general production data were reported by Giersberg et al. (6, 34).

Behavioral Observations and Data Collection

For video-based data recordings, four cameras (EverFocus EQ610e, EverFocus Electronics Corp., Taipei, Taiwan) connected to a hard-drive recorder (EverFocus ECOR 264-9X1, EverFocus ElectronicsCorp., Taipei, Taiwan) were installed (one camera per stable compartment). Data were recorded for 1 day per week at three times (25th−30th, 43rd−48th, and 64th−69th week of life) during the laying period. These observation times were chosen based on a previous study (6), in which the onset of plumage loss around week 25, first injuries and severe plumage loss around week 43, and an exacerbation of the damage until the end of the laying period in the LB+ hens indicated the occurrence of FP behavior of varying severity over time. In the present study, 4 days per time period were evaluated to compare the behavior of the LB+ hens with that of the LD hens. In the morning and in the afternoon of each day, the hens were observed for a period of 30 min each (10:00–10:30 h and 15:00–15:30 h). An overview of the behavioral observations performed at different times during the laying period is provided in **Table 1**. The observed area in each of the four stable compartments measured 1.17 × 1.20 m (length × width) and was located approximately in the middle of the respective compartment. The observed area was regarded representative for the stable compartment, as it included a part of the aviary and of the scratching area, which contained all resources such as litter, feeding through and perches. For an overview of general behaviors, the number of hens performing a certain behavior (ethogram **Table 2**) was determined using instantaneous scan sampling with a sampling interval of 2 min. Behaviors were interpreted as exclusive events, i.e., each animal was assigned one behavior per scan. When a hen for instance performed comfort behavior, it was not noted whether it occurred in a standing or in sitting position. Location was also not considered separately, i.e., it was not registered whether a hen was standing on a perch, on the tier of the aviary or in the scratching area. Before each scan, the total number of hens present in the observed area was counted. Furthermore, the pecking behavior was recorded in detail by determining the number of pecking bouts for each hen in the observed areas by continuous observations (ethogram **Table 3**). Repeated pecks at the same conspecific or object were counted as one bout. A bout ended when pecking was stopped for 4 s or when pecking was interrupted by another behavior. All general behavior scans were conducted by one observer; continuous observations of pecking behavior were carried out by two observers. Both observers were trained prior to the evaluation of the videos. Due to phenotypic differences between LB+ (brown feathered) and LD hens (white feathered), the observers were not blinded to hybrid strain.

TABLE 1 | Overview of behavioral observations performed at different times during the laying period.

Parameter	Animal age (week of life)	Period	Observation time (one day/week)
General behavior scans (scan sampling)	25, 26, 29, 30	1	30 min morning (10:00–10:30 h) 30 min afternoon (15:00–15:30 h) Sample interval: 2 min
	43, 44, 47, 48	2	
	64, 65, 68, 69	3	
Pecking behavior (continuous observations)	25, 26, 29, 30	1	30 min morning (10:00–10:30 h) 30 min afternoon (15:00–15:30 h)
	43, 44, 47, 48	2	
	64, 65, 68, 69	3	

Statistical Analysis

All statistical analyses were performed using the software SPSS Statistics (version 26, IBM, Armonk; NY, USA). To account for the varying number of birds in the observed area at each general behavior scan, data were expressed as proportion of hens performing distinct behaviors. Pecking behaviors in the continuous observations were calculated as bouts per hen and observation interval. The normality of the data was examined using histograms including the Gaussian distribution curve. The Levene procedure was applied to test for homogeneity

TABLE 2 | Ethogram of general behavior scans [(31) and (35), modified].

Behavior	Description
Pecking behavior (Peck)	Pecking at conspecifics, ground or objects.
Comfort behavior (Comf)	Includes preening, body shake, wing flap, leg and wing stretch, and tail wag.
Dust bathing (DB)	Manipulation of substrate with the wings, feet, tail, and/or beak while lying in the litter with some or all feathers fluffed.
Scratching (Scra)	Bird standing and scratching repeatedly the litter with one or two feet in a backward movement.
Locomotion (Loc)	Taking at least two consecutive steps.
Stand	Bird is upright and standing on its feet with fully extended legs.
Sit	Bird is upright with its body touching the ground.

TABLE 3 | Ethogram of continuous observations of pecking behavior [(31) modified].

Pecking behavior	Description
Vent Pecking (VP)	Pecks directed to the vent of a conspecific.
Severe Feather Pecking (SFP)	Forceful pecks, sometimes with feathers being pulled out and with the recipient bird moving away.
Gentle Feather Pecking (GFP)	Careful pecks, not resulting in feathers being pulled out and usually without reaction from the recipient bird.
Aggressive Pecking (AP)	Severe and fast, directed mainly at the head and given in a downward direction.
Environmental Pecking (EP)	Pecks directed at any surface, includes ground pecking and object pecking.

of variance. To build generalized linear mixed models, data were structured by hybrid × stable compartment (subject) and observation period × week as repeated measures. The models consisted of behaviors of the general behavior scans and continuous observations as target variables, the fixed effects of hybrid, period, the interaction between hybrid and period, and daytime, and the random effect of stable compartment within hybrid. All models were fitted with a normal probability distribution and a log link function, except for environmental pecking, for which an identity link function was applied. For the continuous observations, observer was added as a fixed effect. Fixed effects with $P > 0.1$ (i.e., observer) were excluded in the final models by means of a backward regression procedure. Since vent pecking was not observed at all, it was excluded from statistical analyses. *Post-hoc* pairwise comparisons were adjusted by Bonferroni correction. P-values < 0.05 were interpreted to be significant.

RESULTS

General Behavior Scans

The proportions of LB+ and LD hens showing the different behaviors, the interaction between hybrid and period, and the effects of hybrid, period and daytime are summarized in **Table 4**. There was a significant hybrid x period interaction for the proportion of hens pecking [$F_{(2, 89)} = 6.45$, $P < 0.01$], showing comfort behavior [$F_{(2, 89)} = 6.52$, $P < 0.01$] and locomotion [$F_{(2, 89)} = 9.67$, $P < 0.001$], and standing [$F_{(2, 89)} = 3.92$, $P < 0.05$] and sitting [$F_{(2, 89)} = 10.81$, $P < 0.001$]. Pairwise comparison showed that LB+ hens pecked more than LD hens during all periods [$F_{(1, 89)} = 4.33–19.18$, $P < 0.001–< 0.05$]. Within hybrid, a larger proportion of LB+ hens pecked in period 2 and 3 compared to period 1 [$F_{(2, 89)} = 7.04$, $P < 0.001$], whereas there was no difference over time in the LD hens. LD hens showed more comfort behavior than LB+ hens in period 3 [$F_{(1, 89)} = 7.00$, $P < 0.01$]. Within the LB+ strain, comfort behavior occurred to a larger extent in period 1 compared to period 2 and 3 [$F_{(2, 89)} = 6.05$, $P < 0.01$], whereas no such effect was found within the LD strain. A larger proportion of LD hens compared to LB+ hens showed locomotion in period 1 [$F_{(1, 89)} = 5.84$, $P < 0.05$]. Within hybrid, LB+ hens performed more locomotion behavior in period 3 than during the first two observation periods [$F_{(2, 89)} = 3.61$, $P < 0.05$], whereas in the LD hens, locomotion decreased over time [$F_{(2, 89)} = 11.19$, $P < 0.001$]. More LB+ than LD hens were observed standing in period 2 and 3 [$F_{(1, 89)} = 4.44$ and 3.89, $P < 0.05$]. LD hens showed more standing in period 1 than during the remaining observation periods [$F_{(2, 89)} = 5.11$, $P < 0.05$] but no difference was found within the LB+ strain. A larger proportion of LD compared to LB+ hens was sitting in period 2 and 3 [$F_{(1, 89)} = 76.50$ and 179.84, $P < 0.001$]. Within hybrid, LB+ hens showed more sitting behavior in period 1 compared to period 3 [$F_{(2, 89)} = 3.35$, $P < 0.05$], whereas sitting behavior increased throughout the laying period in the LD hens [$F_{(2, 89)} = 74.38$, $P < 0.001$]. Dustbathing and scratching were affected by the main effect of period (i.e., the hens' age) but not by the interaction between hybrid and period. Dustbathing behavior increased over time [$F_{(2, 89)} = 7.95$, $P < 0.01$], whereas scratching decreased [$F_{(2, 89)} = 65.95$, $P < 0.001$] in both hybrids. Daytime affected all observed behaviors, except locomotion. More hens performed comfort behavior, standing and sitting in the morning than in the afternoon [$F_{(1, 89)} = 8.01–15.60$, $P < 0.001–< 0.01$]. In contrast, pecking, dustbathing, and scratching occurred more often in the afternoon [$F_{(1, 89)} = 17.59–47.04$, $P < 0.001$].

Pecking Behavior

A significant hybrid x period interaction was found for the number of severe feather pecking (SFP) [$F_{(2, 89)} = 6.12$, $P < 0.01$] and gentle feather pecking (GFP) events [$F_{(2, 89)} = 4.55$, $P < 0.05$]. Pairwise comparison showed that, while SFP was low in both hybrids during period 1, LB+ hens performed more SFP compared to LD hens in period 2 and 3 [$F_{(1, 89)} = 29.08$ and 21.99, $P < 0.001$]. Within hybrid, an increase of SFP throughout the laying period was observed in the LB+ hens [$F_{(2, 89)} = 17.82$, $P < 0.001$] but not in the LD hens (**Figure 1A**). There was no difference in GFP between the two hybrids. Within the LB+ strain, more GFP was found in period 3 compared to period 1 and 2 [$F_{(2, 89)} = 10.78$, $P < 0.001$]. In contrast, LD hens showed a peak of GFP in period 2, which was significant compared with period 1 and 3 [$F_{(2, 89)} = 5.23$, $P < 0.01$; **Figure 1B**]. A significant hybrid x period interaction was also found for the number of aggressive pecking (AP) [$F_{(2, 89)} = 14.80$, $P < 0.001$] and environmental pecking (EP) bouts [$F_{(2, 89)} = 11.18$, $P < 0.001$]. In period 1,

TABLE 4 | Proportions of conventional layer (LB+) and dual-purpose (LD) hybrids performing distinct behaviors at three times during the laying period (1: 25th–30th, 2: 43rd–48th, 3: 64th–69th week of life) and the day (morning/afternoon).

Behavior	Hybrid	Period			Daytime		$P_{hybrid \times period}$	P_{hybrid}	P_{period}	$P_{daytime}$
		1	2	3	Morning	Afternoon				
Peck	LB+	38.94	45.55	44.01	33.05	38.27	<0.01	<0.001	ns	<0.001
	LD	30.69	28.74	26.05						
Comf	LB+	16.09	12.29	11.08	15.57	13.13	<0.01	ns	ns	<0.01
	LD	12.60	15.03	19.00						
DB	LB+	0.50	1.17	1.20	0.55	2.95	ns	ns	<0.01	<0.001
	LD	1.02	3.03	3.70						
Scra	LB+	3.38	1.27	0.82	1.44	2.83	ns	ns	<0.001	<0.001
	LD	4.40	1.33	1.61						
Loc	LB+	12.57	12.70	15.27	15.10	14.41	<0.001	ns	<0.01	ns
	LD	20.70	14.43	12.87						
Stand	LB+	24.02	23.83	26.05	24.18	20.45	<0.05	ns	<0.05	<0.001
	LD	23.69	17.83	18.49						
Sit	LB+	4.41	3.11	1.76	10.09	7.87	<0.001	<0.001	<0.05	<0.01
	LD	7.02	19.59	17.98						

LD hens performed more AP compared to LB+ hens [$F_{(1, 89)} = 20.22$, $P < 0.001$], there was no difference between hybrids in period 2, and in period 3, LB+ hens showed more AP than LD hens [$F_{(1, 89)} = 29.66$, $P < 0.001$]. Consequently, AP within the LB+ strain increased throughout the laying period [$F_{(2, 89)} = 36.81$, $P < 0.001$], whereas there was no difference within the LD strain (**Figure 2A**). Pairwise comparison of EP showed that LD hens were engaged in this behavior to a higher extent than LB+ hens in period 1 [$F_{(1, 89)} = 4.63$, $P < 0.05$] but no difference between hybrids was detected during period 2 and 3. EP in the LD strain decreased from period 1 to period 2 and 3 [$F_{(2, 89)} = 14.69$, $P < 0.001$], whereas there was no difference in EP over time within the LB+ strain (**Figure 2B**). All pecking behavior, except for gentle feather pecking, was affected by daytime [$F_{(1, 89)} = 5.23–46.07$, $P < 0.001–< 0.05$] with more pecking being observed in the afternoon than in the morning.

DISCUSSION

The aim of the present investigations was to comparatively assess the behavior with focus on pecking behavior of conventional layer (LB+) and dual-purpose (LD) hybrids during the entire laying period. Therefore, video-based behavioral observations (general behavior scans and continuous observations) were carried out. As expected, most of the observed behaviors, including pecking behavior, were affected by an interaction of hybrid strain and age. In general, the LB+ hens performed more pecking behavior, particularly severe feather pecking (SFP), which increased with age. In contrast, SFP remained exceptionally low in the LD hens throughout the production period. It is important to note that in this study, the hens were observed during the entire laying period (here: 44 weeks) and in a semi-commercial setting. As the social context, the management procedures and the housing system the hens were subjected to can be regarded as representative for many laying farms in Europe, the present results may be applicable to practice directly. On the other hand, however, such a setting only allows for investigating a limited number of groups of animals (here: two stable compartments per hybrid strain). A further limitation of the present study is that the birds were kept in only one pen per hybrid strain during the rearing phase. Environmental factors during rearing, such as the provision or absence of litter, can affect the occurrence of FP behavior during the laying period (36). However, confounding of hybrid strain and rearing environment was kept to a minimum, as both rearing pens were located in the same building, and housing and management conditions, for instance type and quality of litter, were the same for both hybrids.

The general behavior scans of the present study revealed that during all observation periods, the LB+ hens pecked more than the LD hens and within hybrid, pecking behavior of the LB+ hens increased with age. In the LD hens, no difference over time was found. These results are in line with the findings of a previous study by Giersberg et al. (31) on behaviors of LB+ and LD hens in the nest. In this functional area of the barn, more LB+ than LD hens performed total pecking behavior, which was, similar to the present study, defined as the sum of different types of pecking behaviors (SFP, GFP, AP, and EP) (31). Therefore, LD hens seem to be consistently less engaged in pecking activities compared to LB+ hens throughout the laying period. However, due to the different underlying etiology and the resulting consequences of pecking behaviors, it is important to distinguish between different types of pecking behaviors (5), particularly with regard to practical prevention or intervention strategies. Environmental pecking (EP), for instance is characterized by pecks at the ground or objects and is seen as a natural behavior in the context of foraging (37). In contrast, SFP can be regarded as a damaging abnormal behavior, which indicates reduced welfare in both the recipient and the offending bird (5, 9). Therefore, continuous

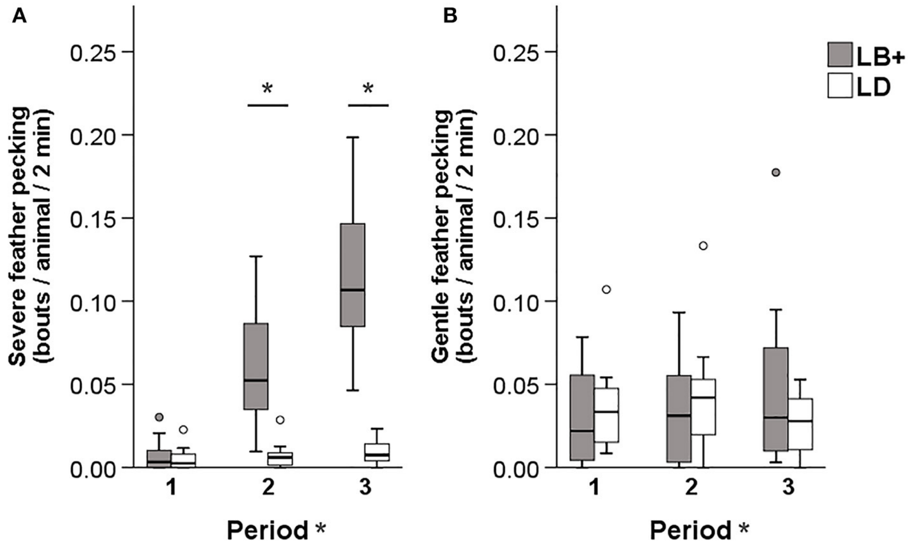

FIGURE 1 | Pecking behavior in conventional layer (LB+) and dual-purpose (LD) hybrids at three times during the laying period (1: 25th−30th, 2: 43rd−48th, 3: 64th−69th week of life). **(A)** Severe feather pecking, **(B)** gentle feather pecking. *Between bars denotes an effect of hybrid ($P < 0.05$). *After "Period" denotes an effect of period ($P < 0.05$). Both for severe feather pecking and gentle feather pecking a hybrid × period interaction was found ($P < 0.05$).

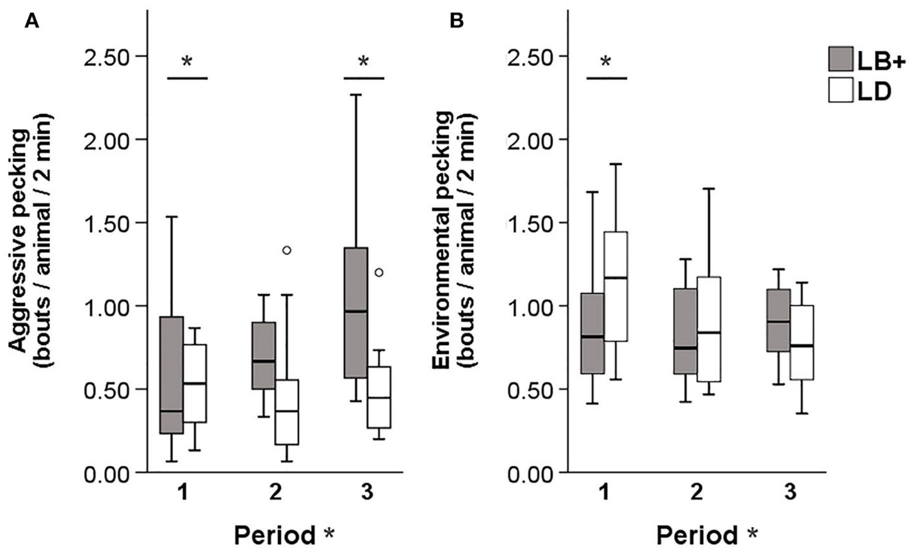

FIGURE 2 | Pecking behavior in conventional layer (LB+) and dual-purpose (LD) hybrids at three times during the laying period (1: 25th−30th, 2: 43rd−48th, 3: 64th−69th week of life). **(A)** Aggressive pecking, **(B)** environmental pecking. *Between bars denotes an effect of hybrid ($P < 0.05$). *After "Period" denotes an effect of period ($P < 0.05$). Both for aggressive pecking and environmental pecking a hybrid × period interaction was found ($P < 0.05$).

observations were carried out in the present study to determine which type of pecking behavior dominates in the respective hybrid. From the second observation period (43rd−48th week of life) onwards, the LB+ hens performed more SFP compared to the LD hens and within hybrid, an increase of SFP throughout the laying period was observed in the LB+ hens. This confirms the results of Giersberg et al. (6, 34) who found severe feather loss and skin lesions on body regions predisposed to pecking damage in LB+ but not in LD hens. In addition, both the observed increase of SFP within the LB+ strain and the constantly low levels of this behavior within the LD strain reflect the time course of plumage loss assessed by Giersberg et al. (6). The plumage quality of LB+ hens deteriorated with age, whereas this was not the case in LD hens (6). Thus, the present study confirms the assumption that plumage and integument condition are valid indicators for actual SFP behavior, both in conventional layers—as shown previously by Bilčík and Keeling (10)—and in dual-purpose hybrids.

There was no difference between hybrids regarding GFP behavior. Similar results were obtained by van der Eijk et al. (38) when comparing conventional layers with lines that were divergently selected for FP behavior. Hens selected for high FP behavior performed more SFP than hens selected for low FP and unselected control birds, whereas lines did not differ in GFP behavior at adult ages (38). Interpretation of age effects on GFP within hybrid strains remains difficult, as previous studies show ambiguous results. In one study, GFP behavior was inconsistent over time within layer line (38), whereas in another study, GFP decreased with increasing age (39). Thus, a consistent time course of GFP to which the present results could be compared has not been described in the literature. During the first observation period, the LD hens showed more AP compared to the LB+ hens. Within the LD strain, AP behavior remained constant, whereas it increased in the LB+ strain. This lead to a reverse effect of hybrid at the end of the laying period with the LB+ hens showing more AP than the LD hens. The same pattern was found when observing conventional layers and dual-purpose hens in the nest (31). Although AP and SFP result from different underlying motivations (5), it may sometimes be difficult to exactly distinguish between these two behaviors during video observations. In the present study, only pecks given in a downward direction and directed at the head were counted as AP, whereas forceful pecks against the neck and other body parts were recorded as SFP. In video images it may sometimes be difficult to draw a clear line between the different body parts, particularly the head and the neck. This might to some extent explain the increase of SFP and AP with age in the LB+ hens. In addition, the presence of AP behavior in the LD strain further confirms the previous findings regarding plumage condition: feather loss in this strain was only found on the head/neck region (6), which is indicative for AP (10). Similar to AP, the LD hens showed more EP than the LB+ at the beginning of the laying period. Within hybrid strains, EP decreased over time in the LD hens but remained constant in the LB+ hens. As EP is part of the natural foraging and exploration behavior of laying hens (37), these differences are difficult to explain.

However, regarding the other behaviors assessed during the general behavior scans, differences in activity were found, which may also be related to the different types of pecking behavior. For locomotion behavior, a significant hybrid × period interaction was found. Over time, locomotion increased in the LB+ hens, whereas this behavior decreased in the LD hens. In a previous study, a link between activity and FP was identified, with birds performing high levels of FP showing higher levels of locomotion activity compared to birds that perform low levels of FP (16). Furthermore, a larger proportion of LD compared to LB+ hens were observed in a sitting position in period 2 and 3, whilst LB+ showed more sitting in period 1. These findings are inverse to the results on locomotion behavior. The differences in the activity between the LD and LB+ hens over time may be related to their different genetic background. As dual-purpose chickens have a rather compact morphology (33), and they are also breed for meat production, a certain resemblance to broiler chickens can be assumed (40). Behavioral differences between broiler and layer strains may be based in their locomotor ability with layers being more active than broilers (41). Surprisingly, a previous study found that LD hens weighed about 5% less than LB+ hens at 34 weeks of age (33). However, this seemed to be compensated for, as no weight differences were observed between the two hybrids at the end of the laying period (70 weeks of age) (34). In addition, LD hens had about 7% larger body widths and shorter legs compared to LB+ hens (33). This may result in a different relation between body mass and skeletal system, which may lead to an altered locomotor ability in the LD hens. Therefore, the above mentioned decrease of EP behavior in the LD hens may also be due to a general decrease in locomotion and foraging behavior over time.

Concerning comfort behavior, a significant difference between hybrids was found in period 3 with LD hens showing more comfort behavior than LB+ hens. In the LB+ strain, comfort behavior decreased over time. Comfort behavior is a behavioral priority of laying hens with direct effects to animal welfare (18). As feather pecking is a sign of stress, it can be assumed that LB+ hens became agitated with increasing age and hence, comfort behavior decreased. Dustbathing and scratching behavior did not differ between the two hybrid strains. However, it should be noted that these behaviors occurred rarely in both hybrids, which might have overshadowed statistically significant effects.

Daytime effects were found for all observed behaviors, except for locomotion. Comfort behavior, standing and sitting occurred to a larger extent in the morning, while pecking, dust bathing, and scratching were seen more frequently in the afternoon. Laying hens show native circadian patterns of behavior that include egg laying in the morning and dust bathing in the afternoon (42). This is in line with a previous study by Giersberg et al. (31), in which a larger number of LB+ and LD hens stayed in the nests during the first 6 h of the light phase. A diurnal rhythm was also shown for FP behavior, which occurred mainly between 8 and 14 h after lights on (43). Similarly, all pecking behavior observed in the present study, except for GFP, was affected by daytime. In both hybrids, more pecking was observed in the afternoon than in the morning. The present findings reflect the diurnal rhythm of laying hens found previously, with less time spent resting and more time spent performing active behaviors in the afternoon (44).

Housing and management conditions were kept the same for both hybrid strains during the rearing and the laying period. Therefore, behavioral differences, particularly regarding FP, can be likely explained by the genetic differences of the LB+ and LD hens. A genetic background of the development of FP behavior has been suggested in many previous investigations [reviewed by Rodenburg et al. and Channing et al. (5, 44)]. As mentioned earlier, a divergent selection on FP behavior formed the high- and the low FP chicken lines, which are used in fundamental behavioral and physiological research (16, 17, 26, 29, 38). However, it is not clear to which extent those FP traits are present in different commercially available layer hybrids and breeds. In one experiment, conventional layer hybrids (ISA brown) showed more injurious pecking than purebred New Hampshire hens (45). In another experiment, a higher prevalence of FP behavior was found in purebred hens of the Danish landrace compared to two conventional hybrid strains (ISA brown and Lohman selected leghorn) (45). Plumage color seems to be a further genetically determined trait associated with the propensity to develop FP. White hens were less prone to FP than pigmented hens (46, 47). Plumage color might have accounted to a certain extent for the observed hybrid differences in FP in the present study, as the LB+ hens had brown feathers and the LD hens were white. By comparing the LD hens to white feathered conventional layer hybrids in future research, effects of plumage coloration and other strain characteristics could be disentangled.

The present study provides basic information on behavior in general and on different forms of pecking behavior in particular of dual-purpose hens housed in a semi-commercial aviary system. It highlights the behavioral differences between these hens and conventional layer hybrids. As dual-purpose hens show less injurious pecking behavior, they can be kept largely unproblematically with untrimmed beaks and under standard management conditions in loose housing systems. The absence of abnormal behaviors in these hens indicates that they may experience higher levels of welfare than conventional layer hybrids under the given conditions. This major benefit of dual-purpose hybrids should be taken into account when considering alternative approaches to avoid the killing of surplus male animals in laying hen production. Future research should investigate to which extent the present results can be generalized for other commercial farms with slightly different management procedures and housing systems. Further studies are required to investigate whether the observed behavioral benefits are specific for the dual-purpose strain used here or whether they can be reproduced with other dual-purpose hybrids or breeds.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because the experiments comply with the requirements of the ethical guidelines of the International Society of Applied Ethology (48). All animals were housed according to EU (49) and national law (50, 51). In compliance with European Directive 2010/63/EU Article 1 5.v(f) (52), the present study did not imply any invasive procedure or treatment to the hens.

AUTHOR CONTRIBUTIONS

MG, BS, and NK designed the experiments. LR, IZ, and MG performed the data assessment. LR and MG analyzed and interpreted the data, and wrote the paper. BS and NK helped to interpret the results and edited the manuscript. All authors read and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2021.660400/full#supplementary-material

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REVIEW
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A Review of Beef Production Systems for the Sustainable Use of Surplus Male Dairy-Origin Calves Within the UK

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The UK dairy herd is predominantly of the Holstein-Friesian (HF) breed, with a major emphasis placed on milk yield. Subsequently, following years of continued single-trait selection, the beef production potential of dairy bred calves has declined. Thus, male HF calves are commonly seen as a by-product of the dairy industry. Limited markets, perceived low economic value and high rearing costs mean that these surplus calves are often euthanised shortly after birth or exported to the EU for further production. Welfare concerns have been raised regarding both euthanasia and long distance transportation of these calves. Furthermore, total UK beef consumption increased by 8.5% from 2009 to 2019. Thus, in light of this growing demand, beef from the dairy herd could be better utilized within the UK. Therefore, the potential for these calves to be used in a sustainable, cost-effective beef production system with high welfare standards within the UK requires investigation. Thus, the aim of this review was to evaluate both steer and bull beef production systems, examining the impact on performance, health, welfare, and economic potential to enable a sustainable farming practice, while meeting UK market requirements. The principal conclusions from this review indicate that there is the potential for these calves to be used in UK based production systems and meet market requirements. Of the steer production systems, a 24 month system appears to achieve a balance between input costs, growth from pasture and carcass output, albeit the literature is undecided on the optimum system. The situation is similar for bull beef production systems, high input systems do achieve the greatest gain in the shortest period of time, however, these systems are not sustainable in volatile markets with fluctuating concentrate prices. Thus, again the inclusion of a grazing period, may increase the resilience of these systems. Furthermore, production systems incorporating a period at pasture are seen to have animal welfare benefits. The main welfare concern for surplus dairy bred calves is often poor colostrum management at birth. While in steer systems, consideration needs to be given to welfare regarding castration, with the negative impacts being minimized by completing this procedure soon after birth.

Keywords: Holstein, steer, bull, concentrates, welfare, high input, low input, pasture

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INTRODUCTION

Currently the UK dairy herd consists of 1.867 million cows (1) and is predominantly of the Holstein-Friesian (HF) breed. The main focus of the HF breed is maximizing milk yield and subsequently, following years of continued single-trait selection (2), annual milk yield per cow has increased by 14.1% in the 10 year period to 2018 (3). However, this has had a detrimental effect on other traits (e.g. functional traits, reproduction and health) and thus the beef production potential of dairy bred calves has declined, particularly in terms of carcass conformation (4, 5). Therefore, male HF calves are commonly seen as a by-product of the dairy industry (6, 7) due to limited markets and perceived low economic value (8). As a result the neonatal care of these surplus male calves is often inferior to that which heifer calves receive. Heifer calves are seen as the future of the dairy herd, and therefore, are often given priority to ensure their future productivity (9). Thus, dairy bred bull calves are at a greater risk of not receiving a sufficient quantity of quality colostrum within 24 h of birth, resulting in increased risk of failure of passive transfer (FPT) of antibodies (10). High levels of pre-wean mortality are associated with FPT, in addition to increased morbidity post-weaning, and reduced live weight gain (LWG) (11, 12).

Euthanasia soon after birth is occasionally used as a means of removing these calves from the herd, for example, in 2018 it was reported that 15% of male dairy sired calves were euthanised at birth in Great Britain (13). The high labor requirement associated with rearing, together with high rearing costs, which have been reported at £195.19 per calf from birth to weaning, mean there is little economic incentive to rear these calves when the monetary return is minimal (14, 15). This is a problem that exists worldwide. For example in New Zealand and Australia, surplus dairy calves are referred to as bobby calves and it is estimated that 2.2 million bobby calves are slaughtered for meat processing between 4 and 7 days of age in New Zealand each year (16). In the UK an alternative outlet for a large number of male dairy calves is the export market to the EU for further production such as intensive veal or bull beef. For example, in Northern Ireland a 3 year average of 19,863 calves of under 42 days of age were exported to the EU from 2015 to 2017. The vast majority of these were exported to Spain (17), where they may be finished as bull beef for the domestic market, or further exported as store cattle to non-EU countries (18). This is considered a valuable market for the industry and vastly reduces the need for euthanasia (17, 19). The live export of cattle goes beyond the UK and is a common occurrence across Europe, for example in 2017 the intra-EU live cattle trade consisted of over 3.86 million cattle, 53% of which were intended for immediate slaughter. While live cattle exported from the EU to non-EU countries was estimated to be 0.80 million cattle in 2017 (20). Unsurprisingly, animal welfare and ethical considerations have been raised regarding such live animal exports. Concerns such as journey times, animals not being given rest periods, overcrowding and poor provision of feed and water have all been highlighted (21). Research has shown that long-haul transport with deprivation of food and water can result in an increased heart rate together with implications for liver function (22). In contrast Grigor et al. (23) reported that there was no major detrimental welfare impact when calves were transported under good conditions with access to feed, water, milk replacer, although the authors did suggest that there was some negative impact on calf health status post transport. Within the UK the exporting of live animals is regulated under the Welfare of Animals (Transport) Order 2006 (24). Inspections are conducted regularly and compliance rates within the UK are reported to be high. For example in 2015 and 2016 the mean non-compliance rate for cattle was 0.06% (17). Nevertheless, live exports have received a great deal of media attention, with calls for this practice to be banned (21). Furthermore, as a result of Brexit, the UK government may now have the opportunity to impose a ban on live animal exports. Alternatively, live exports may become more heavily regulated or see additional challenges associated with market or trade agreements for transporting animals across borders (25). However, the true impact that Brexit will have is yet to be determined. In addition, the environmental impact of transporting live animals such long distances has raised concerns, with one study showing that it is more environmentally sustainable, due to reduced CO_2 and NO_x emissions, to produce and slaughter lambs in their country of origin and export the carcasses, rather than operating live exports (26).

By definition in the UK, veal is meat from bovine animals slaughtered under 8 months of age. Whereas, beef is from bovine animals slaughtered over 8 months of age (27). However, in the UK the market for veal meat is small, with only 143,000 calves being slaughtered for veal in 2018 (28). Furthermore, public awareness of the product is limited and perceptions are often influenced by welfare concerns such as slaughter age (29). Therefore, the potential for these calves to be used in a sustainable, cost-effective beef production system with high welfare standards [regulated under the Welfare of Farmed Animals Regulations 2007 (30)] within their country of origin requires investigation. Here we review the literature, including examples from our own research, on the beef potential of these surplus male calves. This includes an evaluation of different production systems examining the animal performance and economic potential to enable a sustainable farming practice, while meeting the market requirements of the UK beef industry. In addition, the animal health and welfare implications are also evaluated.

STEER BEEF PRODUCTION

Of the prime beef (cattle produced for the sole purpose of beef production) slaughtered in the UK in 2019, 50.9% were steers, while only 9.6% were young bulls, while the remaining 39.5% were heifers (31). A 24 months steer system, where cattle spend two seasons at pasture and are slaughtered following an indoor finishing period (32, 33), is thought to be a relatively low cost system, that gains a high proportion of growth from pasture (34). For example, Murphy et al. (35) reported HF steers growing at 0.80 and 0.93 kg/d during their first and second season at grass, respectively. These steers were finished indoors on *ad* *libitum* grass silage, supplemented with 5 kg dry matter (DM) of concentrate per head daily, achieving a slaughter weight, carcass weight and fat classification (on a 15 point scale) of 603 kg, 307 kg and 7.86, respectively. Similar levels of performance were achieved by McNamee et al. (36) with a LWG of 0.92 kg/d during the second grazing season and 1.45 kg/d during the finishing period [concentrates fed at 67% of dry matter intake (DMI) during finishing]. A summary of the key findings on steer finishing performance from published literature are presented in **Table 1** however, the literature assessing Holstein steer production systems is relatively limited.

Alternative production systems for steers involve earlier finishing, usually off pasture at the end of the second grazing season. Keane and Moloney (37) compared two early (∼20 months) finishing strategies to the traditional 24 months system. The authors reported that finishing steers early lead to insufficient carcass weights and fat cover; while, *ad libitum* concentrates during the finishing period of the early strategy proved to be uneconomical. Thus, the most successful of the three systems was deemed to be the 24 months system when the grazing period was followed by a 3 months *ad libitum* finishing period; this system resulted in a lower concentrate intake per kg live weight (LW) than early *ad libitum* finishing (37). Murphy et al. (38), conducted a similar study and also found fat cover to be lower in a 21 months pasture finishing systems compared to a 24 months system. The reduced fat deposition at 21 months may be a limitation of implementing this system with the HF breed, due to their later maturing nature. Thus, a 21 months system may be more suitable for early maturing × dairy bred cattle such as Aberdeen Angus (37). Murphy et al. (38) also reported that slaughtering at 21 months following either a 60 or 120 days 5 kgDM concentrate supplementation period produced similar carcass weights of 275 and 276 kg, respectively, in comparison to 308 kg for a 24 months system (also offered 5 kgDM concentrate supplementation during indoor finishing). However, in contrast to Keane and Moloney (37) and Murphy et al. (38) reported that a 21 months system with a 60 days concentrate finishing period at pasture resulted in the greatest net profit margin (€55/head), while the 24 months steer system actually resulted in a net loss (–€29/head). Murphy et al. (38) took into consideration the additional land charge associated with keeping 24 months steers for an additional 3 months. The authors reported that the additional carcass gain achieved during this time was not sufficient to sustain the additional costs associated with land and feed. With feed costs accounting for a substantial proportion (75%) of the variable costs in beef production (39), it is important that a balance is reached between production costs and carcass output. Overall, the literature indicates that carcass output, concentrate costs, and stocking rate will largely determine the most economical steer beef production system. The environmental impact of a shorter steer system has also been considered. In the case of Murphy et al. (38) finishing steers at pasture with 60 days of concentrates resulted in an 11% reduction in GHG emissions per kg beef produced compared to a 24 months system. Yet, when the unit of measure is changed to GHG emissions per hectare that of the 21 months system is greater due to the greater stocking rate associated with the shorter production cycle.

TABLE 1 | Summary of key published research[a] addressing the effect of finishing diet on steer performance.

Finishing diet	Slaughter age (months)	Finishing LWG (kg/d)	Slaughter weight (kg)	Carcass weight (kg)	Breed	References
Pasture only for 94 days	21	0.82	496	244	Holstein-Friesian, Aberdeen Angus × Holstein-Friesian & Belgian Blue × Holstein-Friesian[c]	(37)
Pasture only for 94 days then silage + *ad libitum* concentrates for 98 days	24	1.33	627	329	Holstein-Friesian, Aberdeen Angus × Holstein-Friesian & Belgian Blue × Holstein-Friesian[c]	(37)
Pasture + 5 kgDM/d concentrate for 60 days	21	0.90	535	275	Holstein-Friesian	(38)
Pasture + 5 kgDM/d concentrates for 68 days	21	1.11	535	277	Holstein-Friesian	(35)
Pasture + 5 kgDM/d concentrate for 110 days	21	0.99	537	276	Holstein-Friesian	(38)
Silage + 5 kgDM/d concentrate for 92 days	24	0.97	603	307	Holstein-Friesian	(35)
Silage + 5 kgDM/d concentrate for 92 days	24	0.91	612	308	Holstein-Friesian	(38)
Total mixed ration of 0.67 concentrates and 0.33 silage (on a DM basis)[b]	25	1.45	594	289	Holstein-Friesian, Norwegian Red × Holstein-Friesian & Jersey × Holstein-Friesian[c]	(36)
Silage + *ad libitum* concentrate for 94 days	21	1.49	551	287	Holstein-Friesian, Aberdeen Angus × Holstein-Friesian & Belgian Blue × Holstein-Friesian[c]	(37)

LWG, live weight gain; DM, dry matter.
[a] *Treatments or studies were steers have been slaughtered over 30 months of age have not been included.*
[b] *Finishing duration not reported.*
[c] *These studies only reported the main effects of breed and production system.*
The databases used in this literature search were Web of Science, Scopus, and Google Scholar.

UK steer market requirements dictate a maximum age of 30 months. However, the literature on Holstein steer systems largely focuses on slaughtering cattle at 21 and 24 months, and thus does not consider more extensive systems. Keane and Allen (40) compared an extensive (29 months) system to a conventional (24 months) system with Charolais × Friesian steers. Due to the study design, cattle were slaughtered at a target live weight and thus, carcass weights were consistent across the two systems. Interestingly, the authors summarized the inputs and outputs of the two systems, reporting that the extensive system had a greater gross profit margin per head [156 vs. 34 European Currency Unit (ECU)] and per hectare (229 vs. 71 ECU) than the conventional system. The lower production costs associated with the reduced concentrate intake in the extensive system was the main contributing factor (40). Thus, extensive production systems may have some merit as a Holstein beef system. However, from an environmental perspective further increasing the age at slaughter would be expected to result in a greater GHG output per head and per kg beef (35). With recent Net-Zero Carbon targets outlined, the livestock sector will have to consider both the economic and environmental sustainability of its production systems going forward (41).

BULL BEEF PRODUCTION

Characteristically, bulls have a much higher growth rate potential and improved feed efficiency than steers (6, 42, 43). Under UK market requirements, bulls are to be slaughtered under 16 months of age, with research demonstrating that the slaughter age of bulls will directly impact on a number of meat eating qualities (44). Bulls slaughtered outside of market specification will be subject to reduction in the price paid per kg carcass. These market requirements create both challenges and opportunities for bull beef production. In order to achieve desired carcass weights at 16 months, there is little room for setbacks in LWG during the production cycle (45). Bearing in mind that male dairy bred calves often have an inferior health status (10), this can result in longer term indirect effects associated with reduced lung function, feed efficiency and LWG (46). Therefore, ensuring target weights are achieved throughout the production system can often be a challenge for producers. One potential advantage of the current market requirements is that the shorter production cycle for bull beef results in a faster throughput of cattle on farm. This is particularly advantageous where the availability of land or housing are limiting factors. Furthermore, a 16 months bull beef system has been reported to result in lower greenhouse gas emissions, than a steer system, due to slaughtering animals at a younger age (35, 47). However, if the bull beef system relies on imported feed this can substantially increase greenhouse gas emissions in comparison to one which uses nationally or home grown feedstuffs (48). The key findings from published bull beef research are summarized in **Table 2** and these will be discussed in the following three sub-sections.

High Input Bull Beef Production Systems

Bull beef production is traditionally an intensive *ad libitum* concentrate, indoor system (6, 53). *Ad libitum* feeding has the potential to lead to superior weight gains by supporting the genetic potential of the animal. Supplementing concentrates at 95% of DMI from 3 months of age until slaughter has been shown to result in a mean LWG of 1.33 kg/d, with bulls reaching target slaughter weight (550 kgLW) at 14 months of age (6). Rutherford et al. (50) offered housed autumn born Holstein bulls *ad libitum* concentrates from 6 months until slaughter at 15.5 months and achieved a mean LWG of 1.39 kg and carcass weight of 313.3 kg. These results are in agreement with previous *ad libitum* studies (49, 51) and show the potential for bulls to achieve a high level of performance when offered an intensive diet.

The literature has also explored the effect of *ad libitum* concentrates at grass. Rutherford et al. (50) offered bulls *ad libitum* concentrates at grass during the summer followed by a housed *ad libitum* finishing period. This system resulted in a 1.44 kg/d LWG and 314.5 kg carcass weight at 15.5 months. Similarly, Moloney et al. (51) slaughtered bulls at ∼12 months of age, following a 6 months period of *ad libitum* concentrates at grass achieving a LWG and carcass weight of 1.31 kg/d and 245.6 kg, respectively. The lighter carcass weight here, being a result of the younger age at slaughter. It was also reported that total concentrate intake did not differ between bulls that were housed or grazed with *ad libitum* concentrates (50). Furthermore, in both studies meat quality parameters were unaffected by *ad libitum* production system (50, 51). Although the forage component of the diet differed, both production systems were heavily dependent on concentrates and thus the energy dense diet resulted in sufficient muscle and liver glycogen stores for anaerobic glycolysis to occur post-mortem (54, 55).

One limitation of an *ad libitum* concentrate system, is that it often results in a high cost of production due to the high input nature of the diet. For example, total concentrate consumption from *ad libitum* production systems has been reported at 2.13 tDM (6) and 2.34 tDM (50) during the study period. This therefore creates a system that is subject to fluctuating concentrate prices and beef market volatility (34) and thus profit margins can vary substantially from year to year. In addition, a high input, housed system, may also raise animal health and welfare concerns which are discussed in section Effect of Beef Production System on Health and Welfare.

Housed Low Input Bull Beef Production Systems

When combined with good quality silage, moderate (56) or no (57) concentrate supplementation can support high levels of performance. Moving away from offering *ad libitum* concentrates and therefore, reducing the dependence on them, has the potential to lessen the cost of production. Kirkland et al. (5) offered concentrates at 50% of DMI (mean of 3.87 kgDM/d) from 6 to 16 months of age; achieving a LWG of 1.14 kg/d carcass weight of 278.8 kg. During the 249 d experimental period, total concentrate intake equated to 1.14 tDM (5); considerably lower than that of *ad libitum* fed bulls (6, 50).

Manni et al. (52) achieved a LWG of 1.16 kg/d from Finnish Ayrshire bulls when supplementing concentrates at 42% DMI. While a concentrate inclusion rate of 23% DMI resulted in

TABLE 2 | Summary of key published research[a] addressing the effect of production system on bull performance and concentrate intake.

Growing diet	Growing LWG (kg/d)	Finishing diet	Slaughter age (months)	Finishing LWG (kg/d)	Slaughter weight (kg)	Carcass weight (kg)	Total concentrates[b] (kgDM)	Breed	References
Pasture	1.11	Straw + *ad libitum* concentrates for 69 days	14	1.21	455	238	–	Danish Friesian	(49)
Pasture (autumn born bulls)	0.72	Silage + *ad libitum* concentrates for 191 days	15.5	1.61	581	291	1,700	Holstein	(50)
Pasture	0.90	Straw + *ad libitum* barley based concentrate for 209 days	15	1.56	546	283	1,673	Holstein-Friesian	(45)
Pasture (spring born bulls)	0.66	Silage + *ad libitum* concentrates for 209 days	15.5	1.38	510	258	1,440	Holstein	(50)
Pasture + 1 kgDM/d concentrates	0.87	Silage + *ad libitum* concentrates for 200 days	15	1.56	542	280	1,602	Holstein-Friesian	(35)
Pasture + 2 kgFW/d concentrates (autumn born bulls)	0.99	Silage + *ad libitum* concentrates for 191 days	15.5	1.48	575	295	1,790	Holstein	(50)
Pasture + 2 kgFW/d concentrates (spring born bulls)	0.87	Silage + *ad libitum* concentrates for 209 days	15.5	1.43	548	281	1,840	Holstein	(50)
Pasture + 3 kgDM/d barley + maize based concentrate	1.10	Straw + *ad libitum* barley based concentrate with rumen protected fat for 209 days	15	1.40	552	281	1,866	Holstein-Friesian	(45)
Pasture + 3 kgDM/d barley based concentrate	1.07	Straw + *ad libitum* barley + maize based concentrate for 209 days	15	1.47	554	288	1,578	Holstein-Friesian	(45)
Pasture + 3 kgDM/d barley based concentrate	0.96	Straw + *ad libitum* barley based concentrate for 209 days	15	1.55	572	296	1,774	Holstein-Friesian	(45)
Pasture + *ad libitum* concentrates (autumn born bulls)	1.38	Silage + *ad libitum* concentrates for 191 days	15.5	1.46	615	315	2,350	Holstein	(50)
Pasture + *ad libitum* concentrates (spring born bulls)	1.27	Silage + *ad libitum* concentrates for 209 days	15.5	1.28	579	296	2,330	Holstein	(50)
Silage + *ad libitum* concentrates (autumn born bulls)	1.58	Silage + *ad libitum* concentrates for 191 days	15.5	1.29	600	313	2,240	Holstein	(50)
Silage + *ad libitum* concentrates (spring born bulls)	1.34	Silage + *ad libitum* concentrates for 209 days	15.5	1.22	579	296	2,200	Holstein	(50)
–	–	Pasture + *ad libitum* concentrates for 180 days	12	1.31	473	246	–	Holstein-Friesian	(51)
–	–	Silage + low concentrate level (decreasing) for 438 days	16	1.02	539	278	665	Finnish Ayrshire	(52)
–	–	Silage + low concentrate level (constant) for 424 days	16	1.11	558	285	640	Finnish Ayrshire	(52)
–	–	Silage + low concentrate level (increasing) for 440 days	16	1.05	554	291	677	Finnish Ayrshire	(52)
–	–	50:50 silage:concentrate for 308 days	16	1.14	545	279	1,191	Norwegian Red & Holstein-Friesian[c]	(5)

(Continued)

TABLE 2 | Continued

Growing diet	Growing LWG (kg/d)	Finishing diet	Slaughter age (months)	Finishing LWG (kg/d)	Slaughter weight (kg)	Carcass weight (kg)	Total concentrates[b] (kgDM)	Breed	References
–	–	Silage + high concentrate level (decreasing) for 402 days	16	1.16	552	290	1,193	Finnish Ayrshire	(52)
–	–	Silage + high concentrate level (constant) for 404 days	16	1.16	558	297	1,187	Finnish Ayrshire	(52)
–	–	Silage + high concentrate level (increasing) for 409 days	16	1.16	565	299	1,116	Finnish Ayrshire	(52)
–	–	Straw + *ad libitum* concentrates for 135 days	8	1.32	300	155	624	Holstein	(6)
–	–	Straw + *ad libitum* concentrates for 177 days	9.5	1.27	350	179	876	Holstein	(6)
–	–	Straw + *ad libitum* concentrates for 180 days	12	1.24	541	235	–	Holstein-Friesian	(51)
–	–	Straw + *ad libitum* concentrates for 197 days	10	1.39	400	211	1,111	Holstein	(6)
–	–	Straw + *ad libitum* concentrates for 239 days	11.5	1.36	450	237	1,429	Holstein	(6)
–	–	Straw + *ad libitum* concentrates for 285 days	13	1.31	500	265	1,779	Holstein	(6)
–	–	Straw + *ad libitum* concentrates for 322 days	14	1.33	550	294	2,131	Holstein	(6)

LWG, live weight gain; DM, dry matter.
[a] Treatments or studies were bulls have been slaughtered over 16 months of age have not been included.
[b] The amount reported here is the total concentrates fed over the full duration of each study.
[c] This study only reported the main effects of breed and production system.
The databases used in this literature search were Web of Science, Scopus, and Google Scholar.

a slightly lower LWG of 1.11 kg/d. The lower concentrate also meant that these bulls required an additional 20 days to reach target slaughter weight. Even though both groups were slaughtered at the same LW (558 kg), differences were observed in carcass fatness, with the bulls on the higher concentrate inclusion rate being fatter. This indicates that the greater proportion of metabolisable energy in the diet from concentrates, not only supported a greater LWG but resulted in increased fat deposition (52), which as previously stated can have a detrimental effect on feed efficiency (58). However, fat cover is considered an important component of meat eating quality, as intramuscular fat can lead to increased flavor and tenderness of the meat (59).

Research has also investigated finishing dairy bulls up to 20 months of age. Under the current UK market requirements, these systems would not produce beef that is within market specification, however, some interesting trends were reported that could be used to inform a 16 months system. Although increasing slaughter age often results in a heavier carcass weight, growth rates have been shown to slow in the final months prior to slaughter. This was evident in the study conducted by Kirkland et al. (5) where increasing slaughter age from 16 to 20 months resulted in an increased LW at slaughter of 111 kg. However, growth rates were compromised during this additional 4 months of finishing. Bulls slaughtered at 20 months had a mean LWG of 1.14 kg/d up to 16 months of age; following this, mean LWG decreased to 0.88 kg/d; a substantial 30% reduction (5). This trend had previously been reported (60, 61) and reflects the sigmoidal growth curve of cattle (62).

Grazed Bull Beef Production Systems

Profitability in a dairy-origin beef production system is reported to be determined by two main factors; carcass output per hectare and the proportion of grazed grass in the diet (63). Grazed grass is known to be the cheapest form of feed for ruminant production (33, 64). Thus, the inclusion of a grazing period during the production system, may have the potential to reduce production costs considerably. However, managing cattle in a rotational pasture system can be more labor intensive than a housed system, particularly if the grazing infrastructure is suboptimal. The most suitable time for a grazing period in bull beef production is during the grower period, to allow for an indoor finishing period so that carcass traits are not compromised.

A LWG from grass of 0.72 and 0.80 kg/d have been reported during a 203 and 134 d grazing period, respectively for HF bulls (65). Therkildsen et al. (49) observed a greater LWG of 1.1 kg/d from grass for Danish Friesian bulls from 7 to 12 months of age. However, this was still 37% lower than that of housed *ad libitum* concentrate bulls. Supplementing concentrates during the grazing period may aid in maintaining a greater level of performance. Offering bulls 2 kg/d concentrates while at grass has been shown to support a LWG of 0.99 kg/d for autumn born bulls and 0.87 kg/d for spring born bulls. This was greater than that achieved from grass alone in the same study; 0.72 kg/d for autumn born bulls and 0.66 kg/d for spring born bulls (50).

Herbage quality (45) and pre-grazing height (66) are said to be two of the main factors influencing the LWG achievable from grass. Reducing sward-surface height from 10.0 to 6.5 cm resulted in 0.33 kg/d reduction in LWG in Continental × Friesian bulls (66). In addition, grazing weaned Friesian (FR) bulls on herb-legume swards has been reported to result in greater performance in comparison to grazing pasture or pasture with concentrate supplementation (67). However, this study focused purely on the summer grazing period, and thus it is unknown as to whether the live weight advantage continued throughout the finishing period. Therefore, the literature is limited on the effect of different pasture types in Holstein bull beef production systems from post-weaning to slaughter, thus this is an area that warrants further research.

One of the challenges of grazing is that a post-turnout LW loss can occur when calves are turned out to pasture. In the case of Steen and Kilpatrick (66) this resulted in a reduction in LW of up to 15 kg over a period of 2 weeks. This reduces the efficiency and LWG achieved from grass, as the period of loss and subsequent recovery time result in a period of unproductiveness. However, the extent of this can be reduced if cattle are fed a high forage diet pre-turnout, as opposed to having a high level of concentrate supplementation (68) and grazing and weather conditions are good at turnout. Other problems can arise with bulls at pasture, particularly if weather conditions are not optimal. Bulls are renowned for agonistic and sexual behavior (69), and being generally more unsettled that steers. The likelihood of which is amplified if conditions are wet, bulls are grazed in large groups or have a lack of shelter in a paddock grazing system (70). This can lead to increased poaching and a reduction in the grazable area. Thus, early housing of bulls in the autumn can reduce setbacks in LWG (65) and sward damage. Adverse grazing conditions were thought to be largely responsible for the poor LWG (0.58 kg/d) of bulls during the grazing season observed by McNamee et al. (36). Keane and Fallon (65) reported that bulls housed in early September were of better body condition than those housed in late November. This was confirmed by a reduction in mean LWG from grass of 0.08 kg/d when the grazing season was extended. Considering the relatively short duration for finishing following a summer grazing period (particularly for autumn born bulls) it is vital that a balance is reached between maximizing the inclusion of grass in the diet and LW performance.

Once housed, the level of concentrate feeding during the finishing period must be carefully considered. Depending on the length of the grazing period; bulls are likely to be considerably lighter than if they had been housed on an *ad libitum* system (6, 49, 50, 65). Thus, in order to ensure carcass weight is not substantially compromised, the aim should be to maximize carcass gain during the subsequent finishing period. Where concentrate supplementation is not offered during the grazing period, a finishing period of at least 200 days is said to be required (71).

Following a grazing period, Rutherford et al. (50) offered autumn born bulls *ad libitum* concentrates during finishing, achieving a LWG of 1.32 kg/d and carcass weight of 291.3 kg, which was 22 kg less than that achieved by lifetime *ad libitum* bulls. Thus, it was suggested that these bulls expressed compensatory growth during the finishing period (72). Furthermore, Rutherford et al. (50) reported similar carcass weights between bulls offered 0 and 2 kg/d concentrates at grass during the grower period. This was in agreement with Murphy et al. (45) who also reported similar finishing LWGs and carcass weights for bulls supplemented and unsupplemented at grass. Furthermore, mean carcass fat classification did not differ between these groups. Yet when the authors considered the proportion of bulls in each treatment that achieved the target fat classification, those that had received 3 kg/d concentrates at grass, were proportionately 40% more likely to reach target fat classification than those unsupplemented (45).

Keane and Fallon (65) evaluated three levels of concentrate feeding (3, 6 kg/d and *ad libitum*) for finishing HF bulls following a grazing period. A*d libitum* concentrate feeding achieved a mean LWG of 1.36 kg/d; leading to a LW at slaughter of 610 kg. These bulls obtained a carcass weight of 338 kg, and fat classification of 3.2 following a mean finishing period of 225 days. Whereas, those on 3 kg/d concentrates had a LWG of 0.91 kg/d, and LW at slaughter of 514 kg. Slaughter traits such as dressing proportion, carcass conformation, fat classification were also reduced as a result of the lighter slaughter weight (65). Although not specified, it is estimated that these bulls were approaching 18 months at slaughter, and thus alterations would need to be made to meet current market requirements.

The finishing diet must take into account the total feed input, the duration of finishing and the desired level of carcass finish. Keane and Fallon (65) concluded that commencing a finishing period at 300 kgLW following a grazing period, would require 1.9 tDM of concentrates and 0.2 tDM of silage over a 7 months period when concentrates were supplemented *ad libitum*, to achieve a carcass weight of 320 kg. A further 1.5 months of finishing was required when concentrates were supplemented at 6 kgDM/d; equalling a total concentrate intake during the finishing period of 1.3 tDM along with a 1.1 tDM silage intake. Thus, a balance between feed input and length of finishing period needs to be considered when identifying the optimum production system for bull beef. This will largely be determined by the age and weight of the bulls at the start of the finishing period. If carcass weights are to be lighter as a result of including a grazing period, then a lower cost of production must be guaranteed. Rutherford et al. (50) demonstrated that the inclusion of a grazing period could reduce total concentrate usage by 890 kg in spring born bulls compared to a housed *ad libitum* concentrate system, thus substantially reducing production costs. Therefore, although careful management is required to ensure market requirements are achieved (45), the literature does suggest that the inclusion of a grazing period in a bull beef system is a potential method of operating a sustainable bull beef production system.

EFFECT OF BEEF PRODUCTION SYSTEM ON HEALTH AND WELFARE

One of the main welfare concerns in a steer production system is the age and method of castration. Castration is well-known to cause pain and elicit a stress response, illustrated by a rise in plasma cortisol concentration and changes in calf behavior (73). Furthermore, neurohormonal and electroencephalographic stress responses to castration have been shown to be age-specific (74). Therefore, the method and age of castration of calves is controlled under UK legislation [the Protection of Animals (Anesthetic) Act 1954 and the Veterinary Surgeons Act 1966] (75), in order to minimize the negative impact on animal welfare. For example, the use of rubber ring castration can only be completed up to 7 days of age, whereas for calves up to 2 months of age, bloodless castration (crushing the spermatic cords) is the recommended method. After 2 months of age castration should be carried out be a veterinary surgeon (75). From a production perspective, it is recommended that calves are castrated at birth or close to birth, as live weight loss increases quadratically as the age of castration increases, regardless of the method used (76).

Behavioral freedom is an important component of animal welfare, and pasture based production systems are perceived to offer this to a greater extent than continuously housed systems (77). Research in dairy cows has shown that cows at pasture will spend a greater amount of time lying (78) and feeding (79) than those housed. Furthermore, bulls that have been housed throughout their lifetime have been observed to be more aggressive toward humans and one another, compared to those that have been at pasture (66). Therefore, a pasture based steer system or bull beef system with the inclusion of a grazing period, would be considered best in providing behavioral freedom for beef cattle, as this way cattle spend a lesser proportion of their lifetime housed. However, the handling and feeding of bulls at pasture can be a potential safety risk for the farmer, and thus care must be taken when carrying out these tasks. In contrast, the use of well-designed housing and handling facilities, make feeding and routine procedures such as weighing easier and safer to complete in a housed system. Yet regardless of whether bulls are produced indoors or at pasture there will always be an increased safety risk when working with bulls as opposed to steers.

Another consideration of continuously housed beef systems is the impact on lameness. Lameness has a multifactorial and complex etiology (77), and research on beef production systems has largely focused on the impacts of different floor surfaces (concrete, rubber, and straw) in housed systems (80, 81). Slatted concrete flooring has been documented to be a contributing factor, increase the incidence and severity of sole hemorrhages in dairy bred calves in comparison to straw bedding (80). Yet little is known about the impacts of a fully housed beef system in comparison to a pasture based beef system.

Subacute ruminal acidosis (SARA) is a common nutritional disease in beef production, which can have a considerable detrimental effect on animal health, welfare, and performance (82–84). The primary cause of SARA is the consumption of excessive amounts of rapidly fermentable carbohydrates in conjunction with inadequate fiber (85); resulting in an increased accumulation of organic acids within the rumen. The effects of which are compounded if the rumen environment is not sufficiently adapted to concentrate feeding (85). Thus, SARA is a health risk of intensive production systems, such as an *ad libitum* concentrate bull beef systems, or those where an appropriate transition period is not adhered to at the beginning of the finishing period. Liver abscesses are often a secondary outcome of SARA, and may result in a further reduction in DMI, LWG, feed efficiency and carcass yield (86). However, in the case of

Rutherford et al. (50) bull beef production system had no impact on the post-mortem incidence of liver abscesses, thus indicating that with the appropriate management, this can be avoided.

Other parameters such as clinical pneumonia incidence, together with the post-mortem incidence of pneumonia and pericarditis have also been considered and found to be unaffected by production system (50). Similarly, Manni et al. (87) also reported no clinical signs of disease during a bull beef production system study in Finland.

Bulls are reported to be more susceptible to stress than steers (88). Thus, pre-slaughter stressors associated with handling, re-grouping, transportation, and lairage (89, 90) should be minimized in order to reduce the risk to both animal welfare and meat quality (91, 92). Through the use of rumen temperature boluses, Rutherford et al. (93) demonstrated that bulls that displayed stress induced hyperthermia during the pre-slaughter phase also had the poorest meat quality. Suboptimal meat quality can result in a substantial cost to the red meat industry (94), thus bull beef systems may require better pre-slaughter management than that of steer systems.

The literature on beef production systems rarely evaluates the impacts on animal health and/or welfare, as the primary focus of these studies are intakes, performance, and carcass characteristics. Thus, direct comparisons of the welfare of beef production systems are particularly limited within the scientific literature. Therefore, future research evaluating these systems should involve a much wider assessment, beyond simply the impacts on animal productivity.

CONCLUSION

This review demonstrates that there is the potential for surplus male dairy bred calves to be used in UK beef production and meet market requirements. Whether the system implemented involves steers or bulls is something that will vary from farm to farm. Profitability is highly subject to fluctuations in calf, concentrate and beef price, while a high carcass output per hectare combined with a low total concentrate intake, have been shown to be key measures within a production system that can be farmer managed to maximize the sustainability of a production system (34, 35). Thus, it would be expected that the most suitable systems are those that achieve a high proportion of growth from pasture, such as a 24 months steer system, or a bull beef system that involves a grazing period.

A number of health and welfare challenges associated with beef production systems were highlighted within this review. However, the castration of calves is regulated within the UK, while health issues such as SARA can be prevented with appropriate nutritional management. Thus, these are challenges that can be overcome and do not raise the same welfare concerns as the current methods of exporting or euthanising surplus calves.

The issue of surplus male dairy calves may also be addressed *via* breeding programmes within the UK dairy herd. The increased use of sexed semen for targeted breeding of dairy replacements (95), now means that more beef genetics are being used within dairy herds (96). Beef sired dairy calves are well-known to have improved carcass gain and carcass characteristics while also having a lower DMI than their dairy sired counterparts (97) and thus are better suited for beef production.

Beef from the dairy herd has also been shown to have significantly less GHG emissions than that from the suckler herd (35, 98) and therefore from an environmental perspective surplus male calves should be utilized to their full potential within the UK. However, one consideration of using surplus dairy bred calves in UK beef production is to ensure that this additional beef production would not flood the market and drive prices down. However, the UK produces beef to some of the highest welfare standards in the world, in addition to a large proportion of beef being grass fed (33), and thus the marketing potential of this product should assist in sourcing and expanding markets.

AUTHOR CONTRIBUTIONS

NR: writing—original draft preparation. NR, GA, and FL: writing—review and editing. All authors: contributed to the article and approved the submitted version.

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Impact of Nematode Infections on Non-specific and Vaccine-Induced Humoral Immunity in Dual-Purpose or Layer-Type Chicken Genotypes

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Nematode infections may induce immune-modulatory effects and influence host-immune responses to other pathogens. The aim of the study was to investigate whether a mixed nematode-infection influences non-specific and vaccine-induced humoral immunity against Newcastle Disease Virus (NDV), Infectious Bronchitis Virus (IBV), and Avian Metapneumovirus (AMPV) in already vaccinated hens of a dual-purpose (Lohmann Dual, LD) or a layer genotype (Lohmann Brown Plus; LB). Until 17 weeks-of-age, LD ($n = 70$) and LB ($n = 109$) hens were vaccinated against major bacterial and viral diseases and coccidiosis. At 24 weeks-of-age, the hens received either a placebo or an oral inoculation of 1,000 infectious eggs of *A. galli* and *H. gallinarum*. Plasma total immunoglobulin (Ig) isotypes (IgY, IgM, IgA) levels and vaccine-induced antibody titers against NDV, IBV, and AMPV were determined from 2 to 18 weeks post-infection (wpi). Infections had no suppressing effect on total Ig isotypes IgY, IgM, and IgA as well as on vaccine-induced antibody titers against NDV, IBV, and AMPV ($P > 0.05$). Overall, LB hens had higher levels of IgY, IgM, and IgA than those of LD hens ($P < 0.05$). There were no differences between IBV titers of the two genotypes ($P > 0.05$). Independent of infection status of the hens, NDV titers were higher in LB hens than in LD hens at wpi 2 ($P < 0.05$), but not in following weeks ($P > 0.05$). Uninfected LD hens had lower AMPV titers than their infected counterparts at 6 and 14 wpi ($P < 0.05$). Regardless of nematode infection, LD hens revealed a higher risk of responding weak to vaccination against NDV (odds ratio = 5.45; $P = 0.021$) and AMPV (odds ratio = 13.99, $P < 0.001$) than did LB hens ($P > 0.05$). We conclude that nematode infections have no adverse effects on non-specific and vaccine-induced humoral immunity in either genotype. LB hens have higher levels of total immunoglobulin isotypes than LD hens. Except for IBV, vaccine-induced humoral immune responses show a dependency on genotype. Dual-purpose hens show lower responsiveness to vaccinations against NDV and AMPV, possibly due to factors associated with increased body fat reserves in this genotype.

Keywords: ascarids, animal health, alternative to culling, host genetic background, immunity, vaccination

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INTRODUCTION

Modern chicken genotypes that are used for commercial egg or meat production have been genetically selected for one-way production mode only, i.e., egg or meat production. This is mainly because of the strong genetic antagonism between reproduction and growth traits in chickens (1). In other words, because egg production is a sex-dependent phenotype for which layer genotypes are strongly selected for, poor growth performance and efficiency of male birds of the layer lines are not competitive to that of meat-type chickens. As a consequence in many countries, male birds are killed as day-old-birds for economic reasons (2, 3). The killing of day-old birds has however lead to extensive debates in Europe (4, 5), and alternatives to culling of the male birds of layer lines are currently being extensively explored. As reviewed by Krautwald-Junghanns et al. (6), in-ovo sexing techniques have a great potential to be used as a tool. However, an automatized and commercially viable use of in-ovo sex determination techniques is not widely available yet. One of the available potential alternatives to culling of male birds is the reintegration of the so-called dual-purpose genotypes in production systems in order to use female birds for egg production, while counterpart males are used for meat production (1, 6). Recent studies have clearly demonstrated that the use of dual-purpose genotypes is associated with compromises of both egg and meat production (7–9). Despite the lower performance of dual-purpose genotypes as compared to specialized layer or meat-type genotypes, their implementation in farming systems might nevertheless contribute to the mitigation of high-performance associated health and welfare problems in both broilers and laying hens (10, 11). Furthermore, dual-purpose genotypes may need lower protein levels in their diets, implying a smaller dependency on the highly nutrient dense diets for high performance birds (12, 13). Whether dual-purpose genotypes have improved health and welfare associated traits remain largely unknown.

From the most recent studies focusing on the comparison of both male and female birds of a dual-purpose genotype with commercial meat or layer-type chickens, we draw the main conclusion that high performing chickens are less tolerant to nematode infections (8, 9). Resistance to nematode infections, however, depends on both host genotype as well as on the nematode species involved in the mixed infections (8, 9). We focused on nematode infections as they constitute a concrete problem in the field, particularly in non-cage housing systems (14–17). The most commonly encountered nematodes are *Heterakis gallinarum* followed by *Ascaridia galli* (14, 15, 18, 19). Helminth infections may modulate the immune system, which may interfere with the immune response to other pathogens in the same host (20). Thus, there have been discussions on whether helminth-infected chickens are more vulnerable to infections with intra-cellular pathogens, including viruses and bacteria. Chicken's immune system deals with intracellular (e.g., viruses) and extracellular (e.g., nematodes) pathogens mainly through the Th1- and Th2-type immune responses, respectively (21, 22). This implies that nematode-infected chickens may be more vulnerable to intracellular pathogens. A critical argument supporting this hypothesis came from a study by Degen et al. (21) who demonstrated that Th-1 and Th2-type immune responses maybe traded off in chickens infected with Newcastle Disease Virus (NDV) or *A. galli*, respectively. In line with this, naturally helminth-infected local hens that received an anthelmintic treatment showed higher antibody titers following vaccination against NDV than their non-treated helminth-infected counterparts (23). A more recent study by Pleidrup et al. (20) demonstrated that chickens infected with *A. galli* exhibited impaired humoral and cell-mediated immune responses after vaccination against NDV.

To our knowledge, it is unknown whether vaccine-induced humoral immunity to viral pathogens are hampered in nematode-infected hens that are routinely vaccinated during the growing period. Because host-animal performance level is associated with tolerance to nematode infections in chickens (8, 9), nematode-infected chickens with high or lower performance levels may mount different immune responses to vaccinations against other pathogens. Therefore, the aim of this study was to investigate the effects of nematode-infection on vaccine-induced specific humoral- immunity against viral pathogens, including NDV, Infectious Bronchitis Virus (IBV) and Avian Metapneumovirus (AMVP), as well as on total immunoglobulin isotypes in routinely vaccinated hens of high or lower performing genotypes. A dual-purpose genotype with lower laying performance was particularly included in the study in order to further investigate whether such genotypes have different health-associated properties than hens of high performing genotypes.

MATERIALS AND METHODS

Ethics Statement

Ethical approval of the experiment was obtained from the relevant state ethics committees for animal experimentations (Lower Saxony State Office for Consumer Protection and Food Safety, Germany, Permission no.: 33.19-42502-05-15A594; Mecklenburg-Western Pomerania State Office for Agriculture, Food Safety, and Fisheries, Germany; permission no.: 7221.3-1-080/16). The experiment was conducted in accordance with animal welfare rules (animal care and handling, stunning, necropsies) and all sampling procedures were performed by trained/authorized staff. Experimental infection procedures were in line with the relevant guidelines of the World Association for the Advancement of Veterinary Parasitology for Poultry (24).

Hens and Vaccination Program

The study included samples from a total of 179 hens of two genotypes, namely Lohmann Brown Plus (LB; $n = 109$) and Lohmann Dual (LD; $n = 70$). During the growing period (17 weeks), the hens were subjected to a conventional vaccination program that included immunization against major bacterial and viral diseases as well as coccidiosis at recommended ages (**Table 1**). Except for vaccinations at d0, all vaccinations were applied at the Farm for Education and Research in Ruthe, University of Veterinary Medicine Hannover. Vaccinations were performed as recommended by the manufacturers. During the

TABLE 1 | Summary of the conventional vaccination program applied to Lohmann Brown Plus and Lohmann Dual hens during growing period (17 weeks).

Age, d	Vaccination against
0	MDV + IBD + IBV
1	*Salmonella enteritidis* + *S. typhimurium*
7	Coccidiosis
24	NDV
30*	IBV
44	NDV
50	*Salmonella enteritidis* + *S. typhimurium*
57	*Mycoplasma gallisepticum*
63	Avian pneumovirus-ART (AMPV)
72	IBV
78	NDV
85	Avian encephalomyelitis
113	*Salmonella enteritidis* + *S. typhimurium*
119	IBV + NDV + EDS + ART (AMPV)

MDV, Marek's Disease Virus; IBD, Infectious Bursal Disease; IBV, Infectious Bronchitis Virus; NDV, Newcastle Disease Virus; ART, Avian pneumovirus—ART (i.e., AMPV: Avian Metapneumovirus); EDS, Egg Drop Syndrome.

**originally planned for d16, but post-poned to d30.*

growing period in which the vaccination program was also applied, the birds of the two genotypes were raised under same husbandry conditions in separate housing units of the same facility. Following the last vaccinations, the pullets were transported to the Experimental Poultry Facility of Leibniz Institute for Farm Animal Biology (FBN) at around of 17 weeks of age.

Experimental Design, Nematode Infection, and Environmental Conditions

The experimental design of the study was a 3-factorial arrangement of treatments with nematode infection (infected vs. control), host genotype (LB vs. LD), and time as weeks post-infection (wpi 2–18). Following the arrival of the pullets at the FBN, all birds of each genotype were given individual wing-tags, and were randomly allocated to one of 12 pens in two adjacent rooms, each equipped with 6 pens, in the same facility. After the entry into the laying phase (i.e., laying rate >50%), all hens in the first room (i.e., 3 pens per genotype) were experimentally infected with embryonated eggs of two nematodes (see below for infection procedures), while all the hens in 6 pens (i.e., 3 pens per genotype) of the second room were kept as uninfected controls. Number of hens per genotype in each pen varied from 6 to 23 hens with a fixed stock density of maximum 6 hens per m^2.

An experimental (co-)infection with *A. galli* and *H. gallinarum* was induced when the hens were 24-wk old. Nematode eggs used as the infection material were collected from worms of naturally infected free-range chickens. Incubation conditions for embryonation of the nematode eggs and the preparation of the final infection inoculum have been described in detail elsewhere (25). The percentage of incubated, fully embryonated eggs considered infectious was determined (26). On the day of infection, separately incubated eggs of *A. galli* and *H. gallinarum* were merged to a final dosage of 0.4 ml/hen containing a total of 1,000 embryonated eggs of the two species in equal proportions (1:1, i.e., 500 eggs per worm species). All hens in the first room were given a single infection dose orally by using a 5-cm esophageal cannula. Starting from 2 weeks post-infection (wpi), i.e., at the age of 26 weeks, infected and uninfected hens of both genotypes were randomly collected from each pen and necropsied at timed intervals (i.e., 2, 4, 6, 10, 14, and 18 wpi) to quantify infection intensity with either nematode. The length of the infection experiment (18 weeks) was planned to assess hens' responses to both primary (experimental) and subsequently occurring natural re-infections. Total number of hens necropsied at each wpi ranged from 29 to 34. Infection intensity (i.e., worm burdens) with either nematode was quantified as described earlier (9). In brief, the small intestine was opened longitudinally and the intestinal content was washed through a sieve (36 µm) under running water to collect mature and immature stages of *A. galli* from the intestinal lumen. The tissue-associated *A. galli* larvae were recovered by using a modified EDTA (10 mM EDTA, 0.9% NaCl)-incubation method for digesting intestinal tissue overnight at 40°C, followed by sieving (25, 27, 28). *H. gallinarum* was harvested from the caecal lumen contents only as described for *A. galli* from the small intestine. The caecal tissue and lumen contents were flushed under running water through a sieve (20 µm) to isolate immature and mature *H. gallinarum*. Worms of both species collected from each chicken were then counted using a stereo microscope.

In the pre-experimental period (24 weeks), the hens were kept in helminth-free conditions. During the experimental period, the hens received no vaccinations or medical treatments, including anthelminthics. During the experimental period, the hens were fed a commercial laying-hen diet that contained 11.2 MJ metabolizable energy, 170 g crude protein and 3.6 g Calcium per kg feed (i.e., as-fed basis). Feed and water were offered for *ad libitum* intake. Lighting and temperature regimes were as suggested by the breeding company. The hens were kept under floor husbandry conditions using wood shavings as litter material. Litter was not removed until the end of the experiment.

Measurement of Vaccine-Induced Antibodies and Immunoglobulin Isotypes

For the present study we used blood samples from 179 hens ($n = 109$ LB and $n = 70$ LD). Slaughter blood was collected from the hens in potassium-EDTA (Kabe Labortechnik GmbH, Nümbrecht-Elsenroth, Germany). Blood was centrifuged at 2,500 g for 20 min, and the supernatant was stored at −20°C for later analysis.

Plasma concentrations of vaccine-induced antibodies against Newcastle Disease Virus (NDV), Infectious Bronchitis Virus (IBV) and Avian Metapneumovirus (AMVP), were analyzed by commercially available ELISAs following the protocols recommended by the manufacturers (ND Synbiotics ProFLOK+®, IB Synbiotics ProFLOK®, Synbiotics Corporation, San Diego, CA, USA: Avian Rhinotracheitis Antibody test kit; BioChek, Reeuwijk, NL).

Commercial ELISA Kits (IgY: Kit No. E30-104; IgM: Kit No. E30-103; IgA: Kit No. E30-102; Bethyl Laboratories, Inc, Montgomery, TX, USA) were used to analyse immunoglobulin concentrations (IgY, IgM, IgA) in EDTA-plasma samples ($N =$ 175). ELISAs were performed according to the manufacturer's instructions. A pooled plasma sample served as a control among all plates. The laboratory-specific intra-assay CV and inter-assay CV for the analysis ranged between 5.0 and 7.6% and 7.7 and 10.4%, respectively.

Statistical Analyses

The experimental unit was a hen for the statistical analysis of all variables presented in this study. The vaccine-induced antibody titers and Ig data were subjected to analysis of variance by using the GLM procedure in the SAS/STAT (Version 9.4) software of the SAS System for Windows (SAS Institute Inc., Cary, NC, USA). The statistical model included fixed effects of host genotype, nematode infection, wpi and all possible interactions among these three factors, plus blocking effect of the pens.

Least-squares means (LSM) and their standard errors (SE) were computed for each fixed effect in the model, and all pairwise differences in these LSMs were tested with the Tukey-Kramer correction for multiple comparisons. In addition, the SLICE statement of the MIXED procedure was used for performing partitioned analyses of the LSMs for the two- or three-way interactions (e.g., test of infection within the levels of wpi in each genotype). Effects and differences were considered significant at $P \leq 0.05$, or tended to be significant $0.05 < P \leq 0.10$. Unless a significant interaction between the effects of investigated factors was present, results were presented only for the main effects in tables or figures. In case of significant interactions, results were additionally illustrated in figures.

Pearson correlations between body weight (BW), IgY, IgA, IgM, and antibody titers against NDV, IBV, and AMPV were calculated for each genotype separately, using genotype-pooled data across different weeks post-infection.

In a further analysis, responsiveness to vaccination was evaluated statistically using the distribution of the respective antibody-titer data. For this purpose, distribution of the respective antibody-titer data were used to classify birds as responder or weak-responder to vaccination. Birds which did not show vaccine-induced antibody titers within the range of 2 SD below the overall mean of a particular antibody titer were considered as weak-responders (i.e., mean titer−2 SD > weak-responder) for that particular vaccination. Frequencies of the weak-responder and responder birds (i.e., mean titer−2 SD ≤ responder) were then calculated. Potential effects of relevant factors on the probability of being a weak-responder to vaccination were quantified using a Generalized Estimating Equations (GEE) logistic regression model with a logit link function using GLIMMIX procedure of SAS software. The statistical model included the fixed effects of host genotype, nematode infection, wpi, and the interaction between genotype and infection, whereas interactions of genotype and infections with wpi were excluded, as the number of weak-responder vaccinees for the combination of the three factors were limited. Odds ratios (Ψ) were calculated for all main effects included in the logistic regression model.

RESULTS

Parasitological parameters describing fecal egg counts, worm burdens and nematode-specific antibody levels of the two genotypes are presented in details elsewhere (9). In brief, there was no significant difference between LB and LD hens in terms of number of eggs per gram feces (EPG) at any time point ($P > 0.05$). All experimentally nematode infected hens harbored worm(s), ranging from a sum of 1–573 worms of both species per hen. On average each hen harbored 14 (SD =13.5) *A. galli* and 139 (SD =103) *H. gallinarum*. The overall average *A. galli* and *H. gallinarum* counts, which were based on the sum of the all juvenile and mature stages of the worms, did not significantly differ between the two genotypes ($P > 0.05$), whereas LB hens had higher levels of reinfection with *H. gallinarum* than did LD hens ($P < 0.05$). The levels of ascarid-specific IgY levels in both plasma and egg-yolks were also higher in LB than in LD following experimental and subsequent secondary (naturally occurring) reinfections. Both fecal egg counts and parasitological examination of the intestines confirmed infection free status of the uninfected control animals in both genotypes.

Plasma concentrations of total immunoglobulin isotypes of the hens strongly depended on the host genotype (**Table 2**), with LB hens having higher levels of circulating IgY ($P = 0.012$), IgM ($P < 0.001$), and IgA ($P < 0.001$) than those of the LD hens. No effects of the nematode infection on the immunoglobulin concentrations were quantified, either as the main effect or as the interaction with wpi or host genotype ($P > 0.05$). Time had a significant effect on IgY levels of the hens ($P < 0.001$; **Figure 1**) without an interaction with host genotype or infection or both ($P > 0.05$). The IgY levels of the hens, irrespective of their genotype or infection statues, were higher at wpi 4 than at wpi 6 and 14 ($P < 0.05$). Furthermore, the IgY levels tended to be higher at wpi 4 than in wpi 10 ($p = 0.052$), as well as at wpi 2 than in wpi 6 ($p = 0.086$).

The two genotypes did not differ in IBV titers (**Table 3**; $P = 0.112$). Similarly, nematode infection induced no effect on the IBV titers ($P = 0.810$). IBV titers of the hens did not change significantly throughout the experimental weeks ($P = 0.177$). Furthermore, no significant interaction effects among the three main factors were quantified ($P > 0.05$). Nematode infection did not influence NDV titers of the hens of either genotype at any time point ($P = 0.386$; **Table 3**). A significant interaction of genotype by time ($P = 0.022$) indicated higher NDV titers in LB hens than in LD hens at wpi 2 ($P < 0.05$; **Figure 2**). In the following weeks, no other significant differences were found between two genotypes ($P > 0.05$). A triple interaction between the effects of genotype, infection and wpi was not observed on the NDV titers ($P = 0.350$).

On average, LB hens had higher AMPV titers than LD hens (**Table 3**; $P < 0.001$). Similarly, infected hens had higher levels of AMPV antibodies than their uninfected counterparts ($P = 0.038$). However, as revealed by the significant interaction among

TABLE 2 | Concentrations of total immunoglobulin isotypes, IgY, IgM, and IgA in plasma samples of laying hens of Lohmann Brown Plus (LB) and Lohmann Dual (LD) genotypes exposed to an experimental mixed-nematode-infection (Inf.) or kept as uninfected control (Con.).

	Genotype				Nematode infection				Further effects (*P*-values, ≤)				
Item	**LD**	**LB**	**SE**	**P,≤**	**Con.**	**Inf.**	**SE**	**P,≤**	**wpi**	**Inf.*Gen.**	**Inf.*wpi**	**Gen.*wpi**	**Inf.*Gen.*wpi**
IgY, mg/ml	6.56	7.49	0.288	0.012	6.87	7.18	0.287	0.389	0.001	0.877	0.267	0.564	0.887
IgM, mg/ml	0.63	0.76	0.027	0.001	0.69	0.69	0.027	0.806	0.916	0.344	0.249	0.947	0.792
IgA, mg/ml	0.27	0.33	0.009	0.001	0.29	0.30	0.009	0.547	0.082	0.286	0.170	0.268	0.467

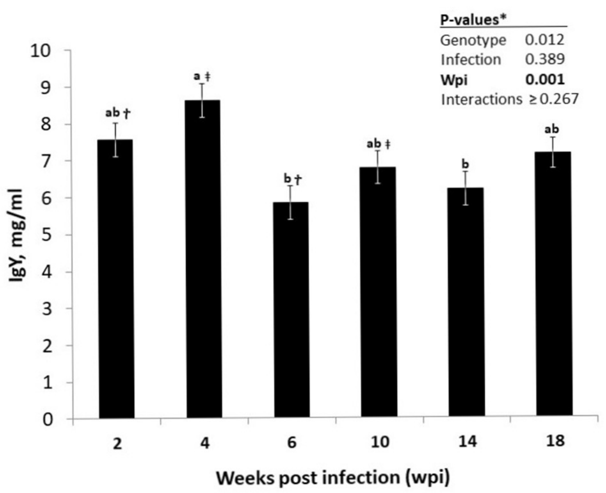

FIGURE 1 | Time-dependent alterations in the course of circulating IgY levels in infected or uninfected hens of Lohmann Brown Plus and Lohmann Dual genotypes over the experimental period. *For the significant genotype differences as well for the non-significant *P*-values for all possible interaction effects see **Table 2**. [ab]Different letters indicate significant differences between different time points ($p < 0.05$). †Time points (wpi) sharing the sign tend to differ ($p = 0.086$). ‡Time points (wpi) sharing the sign tend to differ ($p = 0.052$).

the effects of genotypes, infection and time, the differences between infected and uninfected hens of the two genotypes were shown to be time dependent (**Figure 3**; $P = 0.024$). At wpi 2, infected LD hens had lower AMPV titers than LB hens with or without infection ($P < 0.05$). At both wpi 6 and wpi 14, uninfected LD hens had lower AMPV titers than the hens of other three groups ($P < 0.05$). At wpi 18, uninfected LD hens tended to have lower AMPV titers than infected LB hens ($P = 0.068$).

Figure 4 presents all possible correlations between total Ig isotypes, vaccine-induced humoral immune responses and BW in both genotypes, separately. As confirmed within either genotype, IgA correlated positively with IgY and IgM ($P < 0.05$), whereas no correlation was found between IgY and IgM ($P > 0.05$). Similarly, significant positive correlations were calculated between IBV and NDV titers in both genotypes ($P < 0.05$). Although the relationship between IgM and AMPV titer appeared to be inverse in both genotypes, a significant correlation was found only in LB hens ($P < 0.05$).

There were additional relationships, which were specific to only LD hens (**Figure 4**). For instance, BW correlated negatively with IgY, IgA, NDV and AMPV ($p < 0.05$). On the contrary, AMPV titers were positively correlated with IBV and NDV titers ($P < 0.05$). Although IgY and IBV titers correlated positively in LD hens ($P < 0.05$), this relationship was also absent in LB hens ($P > 0.05$).

Responsiveness to IBV vaccination was 100%, and antibody titers were detected in all birds irrespective of genotype or nematode infection status. In contrast to the case with IBV, a total of 6.8 and 9.1% of the hens were weak-responders to NDV and AMPV vaccinations, respectively. As presented in **Table 4**, a higher percentage of LD hens were weak-responders to vaccinations with NDV (12.9%) and AMPV (20.6%) as compared to LB hens. Probability of being weak-responder to NDV was 4.45 times (i.e., $\Psi = 5.45$) higher in LD than in LB hens ($P = 0.021$). When compared to LB hens, the LD hens were ∼13 times more likely to be weak-responder to vaccination against AMPV ($P < 0.001$). Approximately half the weak-responder LD hens were simultaneously weak-responders to both NDV or AMPV (**Supplementary Figure 1**).

Nematode infection did not influence the probability of weak-responding to any vaccination ($P \geq 0.387$; **Table 4**). There were also no interaction between the effects of host genotype and nematode infection on the probability of weak-responding to vaccination against NDV or AMPV ($P > 0.05$). Similarly, probability of being weak-responder to vaccinations did not depend on time after infection ($P > 0.05$).

DISCUSSION

We investigated the effects of nematode infections and host-genotype on total immunoglobulin isotypes and vaccine-induced specific antibodies of vaccinated hens for a period of 18 weeks following experimental infections. Our results collectively suggest that nematode infections have no adverse effects on non-specific or vaccine-induced humoral immune responses in already vaccinated chickens. Hens of the dual-purpose genotype had lower levels of all immunoglobulin isotypes than did the LB hens, but both genotypes developed and maintained similar levels of vaccine induced antibody titers against IBV for a relatively long period of time. Uninfected LD hens had temporary lower AMPV titers than those of LB hens, although nematode infection did not aggravate this effect. We identified a sub-cluster of LD hens, which were particularly under risk as weak-responder to vaccinations against NDV and AMPV. An increased body weight in LD hens was associated with lower antibody titers against NDV and AMPV. In the following sections, we address potential mechanisms underlying differences between nematode infected

TABLE 3 | Vaccine-induced antibody levels against Infectious Bronchitis Virus (IBV), Newcastle Disease virus (NDV), and avian Metapneumovirus (AMVP) in laying hens in relation to host genotype and mixed-nematode infection.

	Genotype				Nematode infection				Further effects (*P*-values, ≤)				
Item	**LD**	**LB**	**SE**	**P,≤**	**Con.**	**Inf.**	**SE**	**P,≤**	**wpi**	**Inf.*Gen.**	**Inf.*wpi**	**Gen.*wpi**	**Inf.*Gen.*wpi**
IBV titer	13,986	16,030	1,011	0.112	14,854	15,162	1,012	0.810	0.177	0.131	0.401	0.874	0.210
NDV titer	9,716	9,633	419	0.875	9,444	9,905	420	0.386	0.028	0.631	0.652	0.022	0.350
AMPV titer	20,122	25,551	921	0.001	21,616	24,057	916	0.038	0.115	0.162	0.083	0.222	0.024

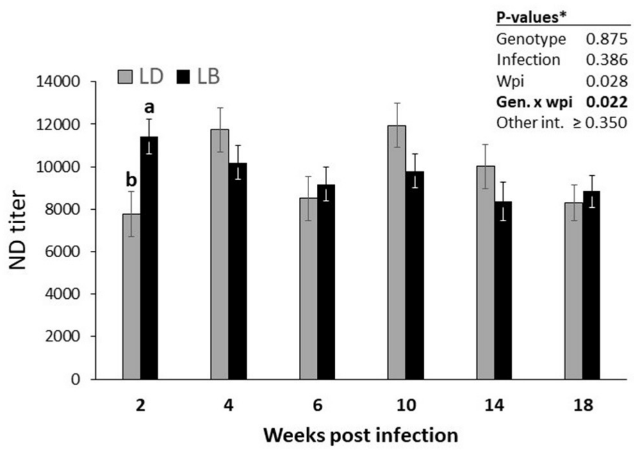

FIGURE 2 | Time-dependent alterations in the course of vaccine-induced NDV titers in Lohmann Brown Plus (LB) and Lohmann Dual (LD) genotypes over the experimental period. *Exact *P*-values for all possible interaction effects are presented in **Table 2**. [ab]Different letters between two genotypes indicate significant differences at the same wpi ($p < 0.05$).

and uninfected vaccinated hens of the dual-purpose (LD) and the layer-type (LB) chicken genotypes in response to common antiviral vaccinations.

Non-specific Immunoglobulins

According to Koenen et al. (29), meat-type chickens show a lower cytokine response but a strong short-term humoral immune response, whereas layers rely on a strong cellular response accompanied by a long-term humoral immune response. LB hens had higher concentrations of immunoglobulin isotypes (i.e., IgY, IgM, IgA) than the LD hens. These differences might reflect, at least partly, different types of immune programming in broiler and layer type chickens, which corresponds to their productive lifespans. Differences in the immunoglobulin patterns of chickens with respect to breeding objectives was investigated previously in male birds of LB, LD and Ross-308 genotypes during the first 10 weeks of life (8). When compared with broilers, LB birds had higher IgY but lower IgM levels, whereas dual-purpose birds were more closer to LB than to Ross. The overall concentrations of both IgY and IgM in young birds were however approximately the half of the mature hens in the present study, implying that immunoglobulin concentration is age-dependent (30). A sex-dependent difference between immunoglobulin levels of LB and LD genotypes can however not be ruled out. Although nematode-infected male birds of both LB and LD genotypes had higher levels of IgY and IgM than their uninfected counterparts (8), there was no significant difference in immunoglobulin levels of the hens induced by the nematode infections. These results are in agreement with data presented by Saasa et al. (31), who found no difference between antibody titers to sheep red blood cells in dewormed or un-dewormed chickens that were naturally infected with helminths.

Vaccine-Induced Antibodies

Under commercial conditions, pullets of layer type chickens receive a series of vaccinations against viral, bacterial and protozoon pathogens during the growing period (e.g., **Table 1**). As shown previously, pronounced differences exist between layer and meat type chickens in innate and adaptive immune responses following vaccination (32) and infection with IBD (33), implying the necessity of genotype specific vaccination regimes. We measured humoral immune responses to vaccination against IBV, NDV and AMPV in both nematode-infected and uninfected hens of two genotypes. The results suggest that nematode infections have no adverse effects on total Ig isotypes or vaccine-induced humoral immune responses in vaccinated chickens of either genotype, though genotype effects appear to be more important.

Our results may appear to be in contradiction with previous results demonstrating that nematode-infected animals have impaired vaccine-induced humoral immune responses against NDV (20, 23). However, there are crucial differences between designs of the present and previous studies. One of the main differences between the present and previous studies, which may have caused the different outcome, is that we first vaccinated the hens and thereafter infected them with nematodes. By using the order of "vaccination > infection" we intended to mimic commercial farming conditions, where animals generally receive immunizations against several pathogens other than nematodes during the growing period, and thereafter encounter nematodes usually much later when they are in production farms. In contrast to our study, in both previous studies (20, 23) chickens were first naturally or experimentally infected and thereafter received vaccination against NDV. It is likely that the order of nematode infection and vaccination can influence the outcome of the immune responses. The study of Pleidrup et al. (20) reports an interesting result that *A. galli* infected hens had lower vaccine-induced NDV titers as compared to their *A. galli*-uninfected but ND-vaccinated counterparts. There was however no difference

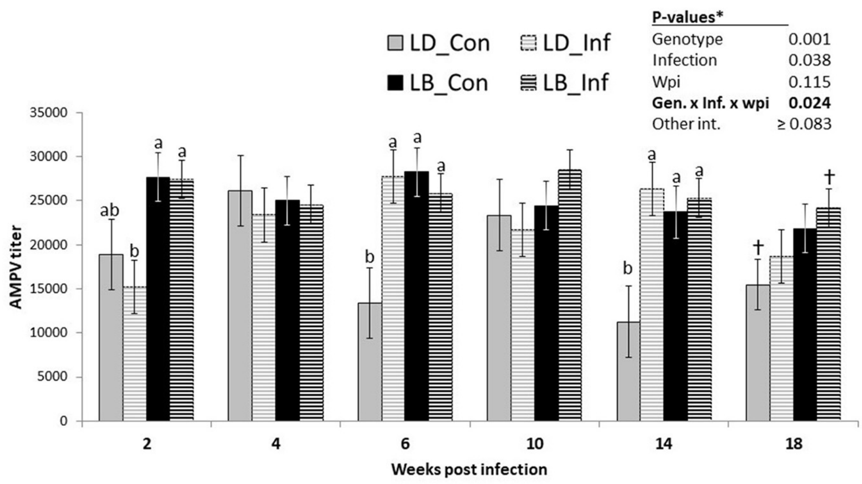

FIGURE 3 | Course of vaccine-induced Avian Metapneumovirus (AMVP) titers in nematode-uninfected (_Con) or infected (_Inf) hens of Lohmann Brown Plus (LB) and Lohmann Dual (LD) genotypes over a period of 18 weeks post-infection. [ab]Different letters indicate significant differences among 4 groups at a given wpi ($p < 0.05$). †Groups sharing the sign tend to differ ($p = 0.068$).

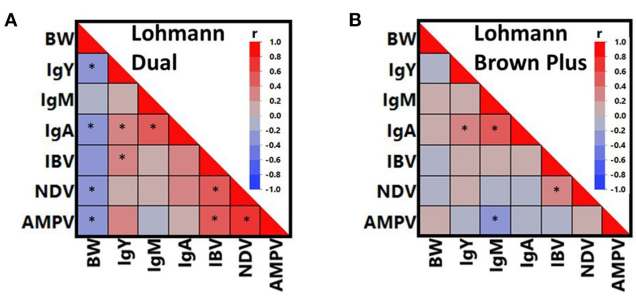

FIGURE 4 | Color maps presenting correlations between body weight (BW), total immunoglobulin isotypes (IgY, IgM, IgA) and vaccine-induced antibody titers against Infectious Bronchitis Virus (IBV), Newcastle Disease Virus (NDV), and Avian Metapneumovirus (AMPV) in Lohmann Dual **(A)** and Lohmann Brown Plus **(B)** chicken genotypes. *The sign indicates a significant correlation at $p < 0.05$.

in NDV-titers between *A. galli* infected and uninfected animals that were not NDV-vaccinated but challenged with the NDV. This observation implies that if chickens are first exposed to NDV-vaccination and then nematode-infection, their response to vaccination may differ from the case if they would be infected with the nematode first and thereafter vaccinated against NDV. This is indeed reasonable as immunomodulatory properties of nematodes may particularly affect the effector phase of vaccine responses (20), whereas in vaccinated animals that have already established vaccine-induced immune responses impact of nematode infection appears to be insignificant. Thus, the order of vaccination and nematode-infections appears to play an important role in producing antibody response to vaccination, and it should particularly be investigated in future studies.

Irrespective of the nematode infection, LB hens had higher NDV titers than LD hens 2 weeks after infection, implying an age- but not infection-dependent difference between the two genotypes in generating and/or maintain an immune response to vaccination against NDV. In general, LB hens had higher AMPV titers than LD hens (**Table 3**), but this difference was not constant, as it was shown to be both time and infection dependent (**Figure 3**). Although there was no difference in AMPV titers of infected and uninfected LD hens at 2 wpi, infected LD hens had lower AMPV titers as compared with infected or uninfected hens of LB genotype. In contrast to this, uninfected LD hens had lower AMPV titers than infected counterpart birds of the same genotype at wpi 6 and 14. We do not have an explanation why uninfected LD hens necropsied at these two time points showed lower AMPV titers than did uninfected LD and both infected or uninfected LB hens. Nevertheless, these differences occurred at the two time points, when IgY levels of all hens were at the lowest level (**Figure 1**), implying a general stress likely associated with increasing laying performance.

It is crucially important to note that we used the term "weak-responders" for animals that did not show antibody titers within the range of 2 SD below the overall mean antibody titers measured 9–25 weeks after the last vaccinations. This definition excludes the possibility that animals classified as weak-responders might initially have well-responded to vaccination, but failed to maintain the level of antibody titers at the time of blood sampling, i.e., > 9 weeks post-vaccination. A possible failure could likely be due to the combination of factors related to quality of the humoral response (e.g., memory cell induction) and the short half-life of IgY antibodies, which ranges from 36 to 65 h in chickens (34). Nevertheless, both genotypes were subjected to the same classification, thus responsiveness to vaccination allows a relative comparison of the two genotypes in terms of maintaining their antibody titers long time after vaccinations. The results indicated that responsiveness to vaccination against both NDV and AMPV was genotype dependent, with a higher percentage of LD hens being classified as weak-responders than those of LB hens (**Table 4**). As compared with LD hens,

TABLE 4 | Frequency (%) and odds ratios (Ψ) assessing the probability of being weak-responder to vaccination against Newcastle Disease Virus (NDV), and Avian Metapneumovirus (AMVP) in relation to host genotype, nematode infection, and weeks post-infection (wpi) in laying hens.

Factors		NDV		AMPV	
		%	Ψ	%	Ψ
Genotype	LD	12.9	5.45	20.6	13.99
	LB	2.8	1.00	1.9	1.00
	P-value	*0.021*		*0.001*	
Nematode infection	Uninfected	7.3	0.94	13.2	1.97
	Infected	6.5	1.00	6.5	1.00
	P-value	*0.931*		*0.387*	
Genotype x infection	*P-value*	*0.808*		*0.803*	
Weeks post-infection	wpi 2	13.8	1.37	13.4	1.09
	wpi 4	0.0	0.01	6.9	0.45
	wpi 6	6.9	0.61	6.9	0.45
	wpi 10	0.0	0.01	3.5	0.20
	wpi 14	7.4	0.62	7.4	0.48
	wpi 18	11.8	1.00	15.6	1.00
	P-value	*0.953*		*0.663*	

the LB hens were ∼4.5–13 times more likely to respond to vaccinations with elevated levels of NDV and AMPV antibody titers, respectively. It is interesting to note that about half of the weak-responder LD hens did not respond to both NDV and AMPV (**Supplementary Figure 1**). As elaborated above, layer and broiler type chickens differ in their immune programming (29). The dual-purpose genotype used in the present study is a combination of layer and broiler lines, and takes an intermediate position between layer and meat type chickens for most growth parameters (8) and immunological responses after vaccination (32). There is however a large heterogeneity in the body weight of LD birds. Urban et al. (12) identified a distinct bimodal distribution in body weight of male birds of the dual-purpose genotype, which may imply an incomplete fixation of the genome for growth related parameters. Whether such body-weight related differences have a link to immune responsiveness within the dual-purpose genotype deserves further detailed investigations.

Overall, per capita egg mass production is lower in LD hens than in LB hens. Furthermore, LD hens have lower body weights than LB hens (9), due to existence of a sex-linked dwarf gene, which has major suppressing effects on body weights only in females of LD genotype (1). Despite the smaller body size, *ad libitum* consumption of conventional layer diets increases body fat content in LD hens (35). Indeed, Röhe et al. (35) found a positive correlation between BW and body fat content, whereas egg production was negatively correlated with body fat content in LD hens. In the present study, correlation analysis revealed remarkable relationships of BW with non-specific and vaccine-induced humoral immune responses in LD hens, which were absent in LB hens. Body weight in LD hens correlated negatively with IgY, IgA and antibody titers against NDV and AMPV, implying the higher BW the lower most humoral immune responses in LD hens. This finding is in line with vaccine failures and increased susceptibility to infections in obese people, likely due to immunosuppressive effects of fat tissue that produces different cytokines and adipokines, which interact with T and B cell receptors (36). In agreement with this, different studies confirm an elevated risk of being non-responder to hepatitis B vaccination in health workers (37) and in hepatitis B virus naïve women (38), suggesting obesity-associated factors interfere with vaccine immunogenicity (38).

All vaccine-induced humoral immune responses were positively correlated in LD hens, whereas only NDV and IBV titers correlated in LB hens. These positive correlations in LD hens may indicate that the individuals that are able to successfully generate and maintain an immune response following vaccination against one pathogen, will also do so with vaccination against another pathogen. In turn, LD birds that cannot mount or maintain an immune response after vaccination against one pathogen, will not be able to do so against another pathogen, too. In line with the observations of Urban et al. (12) on the bimodal distribution of body weight in LD genotype, the differences in the patterns of relationships between humoral immune responses and body weight in LD and LB birds indicate that LD hens are not as uniform as the LB hens in terms of developing immune responses to vaccinations. Considering the presence of a larger group of weak-responders to vaccinations against NDV and AMPV in LD than in LB genotypes, and negative associations between BW and vaccine-induced immune responses in LD hens, it is reasonable to postulate that adaptive immune responses of LD hens might have unintentionally been traded-off with growth-traits through the genetic selection and crossbreeding procedures. This hypothesis is in line with the outcome of a meta-analysis by van der Most et al. (39) that confirms compromised immune functions due to selection for growth in poultry. In the particular case of the LD genotype, a more reasonable explanation might be that an increased body weight associated with higher body fat content compromises immune function (36). As shown in the present study, dual-purpose genotypes are not necessarily superior to high performing genotypes in terms of non-specific and vaccine-induced immune responses. This implies that dual-purpose genotypes that could potentially contribute to prevention of culling of male birds as well as to the mitigation of high-performance associated health and welfare problems, should also be genetically improved for immune functions.

CONCLUSION

Our results collectively suggest that nematode infections induce no adverse effects on non-specific and vaccine-induced humoral immune responses in already vaccinated hens of either genotype. LB hens have higher levels of total immunoglobulin isotypes than LD hens. Except for IBV, vaccine-induced humoral immune responses show a dependency on genotype. Dual-purpose hens show lower responsiveness to vaccinations against NDV and

AMPV, likely due to factors associated with increased body fat reserves in this genotype.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The animal study was reviewed and approved by Lower Saxony State Office for Consumer Protection and Food Safety, Germany, Permission no.: 33.19-42502-05-15A594; Mecklenburg-Western Pomerania State Office for Agriculture, Food Safety, and Fisheries, Germany; permission no.: 7221.3-1-080/16.

AUTHOR CONTRIBUTIONS

GD, MG, and SR obtained funding. GD, MG, CCM, and SR conceived and designed the study. GD, MA, MS, CS, and SR contributed to acquisition, rearing, vaccination, infection, and sampling of the hens and/or performed other works related to conducting the animal experiment. GD, MA, MS, and SR contributed to the analyses of the samples and collection of data. GD performed statistical analysis of the data and drafted the manuscript. MA, MG, MS, CS, CCM, and SR reviewed the manuscript. All authors read the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2021.659959/full#supplementary-material

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Effects of an Elevated Platform on Welfare Aspects in Male Conventional Broilers and Dual-Purpose Chickens

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To avoid killing day-old male chicks, one possibility is to keep dual-purpose chicken strains. Here, the hens were kept for egg production, and the roosters were kept for meat production. Both sexes had moderate performances compared to the respective hybrid chicken strains. However, until now, little has been known about whether male dual-purpose chickens may profit from enrichment in the environment in which broiler chickens are raised under conventional conditions. This study aims to further investigate the suitability of elevated structures for dual-purpose chickens (Lohmann Dual) with moderate growth and for fast-growing male broiler chickens (Ross 308). In two consecutive trials, we kept 686 Ross and 672 Dual chickens in 24 compartments (2 trials × 2 strains × 6 compartments). Half of the compartments were equipped with elevated grid platforms at a height of 50 cm (enriched group). In the other half of the compartments, no platforms were installed (control group). We analyzed the usage of the elevated platforms by scan sampling and assessed animal-based (walking ability, plumage cleanliness, and foot health) and management-based (litter quality) indicators. Both strains showed increasing use of the elevated platforms from the first week of life onwards. However, the fast-growing chickens used the elevated platform less than the slow-growing chickens. At the end of the fattening period, the birds used the elevated grids more at night than during the daytime. Slow-growing chickens kept in enriched compartments showed a better walking ability. In general, slow-growing chickens had better plumage conditions and foot health compared to fast-growing chickens. Our results show that natural behaviors such as perching can be supported by offering elevated platforms and that animal-based indicators such as walking ability can be improved, at least in slow-growing chickens. Moreover, the use of an alternative chicken strain avoids killing day-old male chicks, and in addition, these chickens show fewer animal welfare problems than a conventional fattening strain. Thus, the use of male chickens of a dual-purpose strain can substantially contribute to improving animal welfare in broiler meat production.

Keywords: animal welfare, dual-purpose strain, broiler chicken, environmental enrichment, elevated platform

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INTRODUCTION

Societal discussion about the killing of day-old male layer chicks started several years ago and is still continuing. A solution that can be practically implemented has not yet been found, but there are some approaches to avoid the unnecessary killing of day-old male chicks. The sex of the embryo can be determined in the incubated egg (1), which has already been performed but has only been accessible to a small niche until now. Another alternative is to rear and later slaughter the male chickens of layer hybrids. However, this possibility is hampered by the clear antagonism between muscle growth and egg production (2), resulting in very slow growth and poor feed efficiency in male layer chickens. Dual-purpose strains can be a more efficient alternative. For example, studies have shown that certain dual-purpose strain (Lohmann Dual) hens have a moderate egg performance (250 eggs/year) in contrast to hybrid hens (320 eggs/year), but the roosters have a better growth rate (25 vs. 15 g/day) and a higher live weight at an age of 67 days (1,700 vs. 1,061 g) compared to male layer chickens (3, 4). In parallel to the moderate performance, hens of this dual-purpose strain did not show any damaging behaviors, i.e., feather pecking, resulting in complete plumage by the end of the laying period (5).

In comparison to conventional fast-growing broiler chickens, dual chickens show moderate growth rates. Rapid growth during a short fattening period is associated with certain welfare and health problems, such as impaired walking ability, reduced locomotor activity, and a high prevalence of foot pad lesions (6). In addition, conventional broiler chickens are most often kept in a barren housing environment, where a variety of species-specific behaviors can hardly be expressed. By offering elevated platforms, further behavioral patterns such as perching can be supported. Perching is performed by chickens during the daytime as well as at night. At night, perching serves as an antipredator behavior, i.e., animals seek shelter on higher places. During the daytime, preening, standing, locomotion, exploration, or resting is performed, and perching birds can escape aggressive encounters on perches (7). Furthermore, enrichment of the housing environment with possibilities for perching can positively support birds' activity (8) and walking ability (9). By using non-littered elevated platforms and increasing activity, such as locomotion, chickens have less contact with litter on the chest. By reducing the number of times chickens stay in the litter area, the moisture in the litter may be reduced due to improved ventilation. Drier litter can contribute to improved foot health (10) and possibly to cleaner plumage (11).

This study aims to further investigate the suitability of elevated platforms for both fast-growing male broiler chickens and dual-purpose chickens with moderate growth. We have already shown that broilers prefer elevated grids compared to perches (12) and frequently use elevated grids offered at a height of 50 cm (8). Thus, in a recent study, we offered an elevated grid with an area sufficient for ∼60% of the chickens to both fast-growing (Ross 308) and slow-growing (Lohmann Dual) chickens. To test the effects of the platforms on certain welfare aspects, platforms were offered in only half of the test compartments.

Due to their minor activity and impaired walking ability, we hypothesized that fast-growing male broiler chickens would use the elevated platform less frequently than male dual-purpose chickens. In addition, we expected that chickens in compartments with elevated platforms would have a better walking ability due to possible training effects. Furthermore, we hypothesized better foot health in chickens from enriched compartments because usage of the grid platforms may allow drier feet when not permanently exposed to often-moist litter. However, the plumage condition of chickens in the compartments enriched with platforms will be worse because feces of chickens may drop on chickens below the elevated platform.

MATERIALS AND METHODS

Housing Conditions

The study was conducted at the research station of the Institute of Animal Welfare and Animal Husbandry (FLI, Celle, Germany). All investigations were carried out with the approval of the Lower Saxony State Office for Consumer Protection and Food Safety (LAVES, Oldenburg, Germany, file number 33.19-42502-04-16/2108).

In two successive trials, two different broiler chicken strains, Ross 308 [Ross, fast-growing strain; Aviagen® (13)] and Lohmann Dual (Dual, slow-growing strain), were kept in groups of 56–57 birds each (depending on the total number of chickens delivered). In both trials, each group of a strain was randomly assigned to 12 experimental compartments (**Figure 1**), resulting in a total of 686 Ross and 672 Dual chickens. All birds were obtained as day-old male chickens from commercial hatcheries and were reared to 5 (Ross; body weight at hatch, 44.2 ± 1.3 g; live weight at slaughter, 2,051.7 ± 351.3 g) and 10 weeks of age (Dual; body weight at hatch, 41.8 ± 0.7 g live weight at slaughter, 2,237.8 ± 232.7 g). Sexes were determined in the respective hatchery by professional sorters using cloacal sexing for Dual and feather sexing for Ross (**Supplementary Table 1**).

The climate in the barn was controlled by an automatic ventilation and heating system according to a program set for broiler chickens. The lightening regime was artificially maintained at a minimum of 20 lx during the light period by flicker-free tube bulbs (Newlec cold white, HFT 18/840, REXEL Germany GmbH & Co. KG, Munich, Germany). During the first 3 days, the barn was lighted for 24 h, and from the fourth day of life, lighting was reduced stepwise from 3 days to 16 h/day, resulting in a dark period of 8 h. Between light and dark periods, there was a dimming phase of 15 min.

In each experimental compartment, the floor area [L (length) × W (width), 3 × 2 m] was covered with wood shavings and equipped with one feeding trough and one round water dispenser. All chickens had *ad libitum* access to water and to single-phase pelletized feed (21% crude protein, 12.90 MJ ME/kg) meeting the energy requirements for both strains.

In both trials, half of the compartments were equipped with elevated plastic grids (L × W, 3 × 0.6 m; mesh size, 18.7 × 20 mm; slat width, 10 mm; MIK International GmbH & Co. KG, Ransbach-Baumbach, Germany) adjacent to one of the

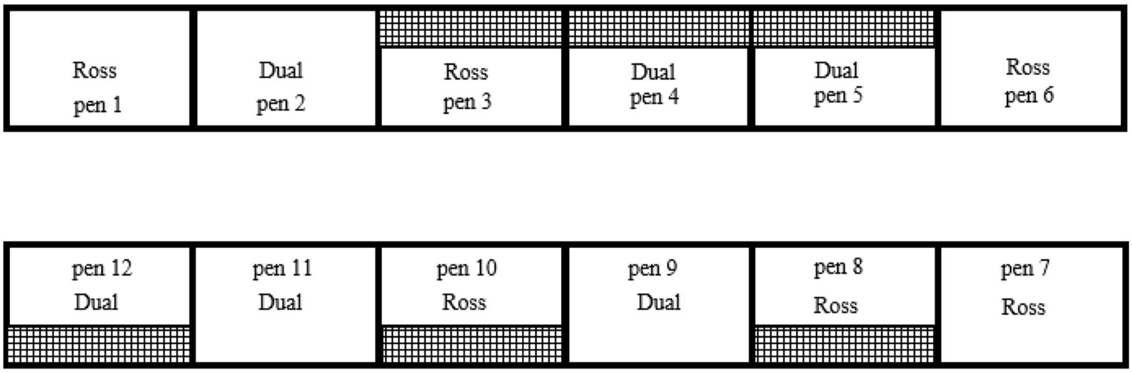

FIGURE 1 | Schematic view of the allocation of strains and treatments across the 12 experimental compartment. In both trials, strains (Ross 308, Lohmann Dual) and treatments (with/without an elevated platform) were randomly assigned to the compartments, resulting in three replicates of each combination per trial. Data were collected in two trials, resulting in a total of six replicates per combination.

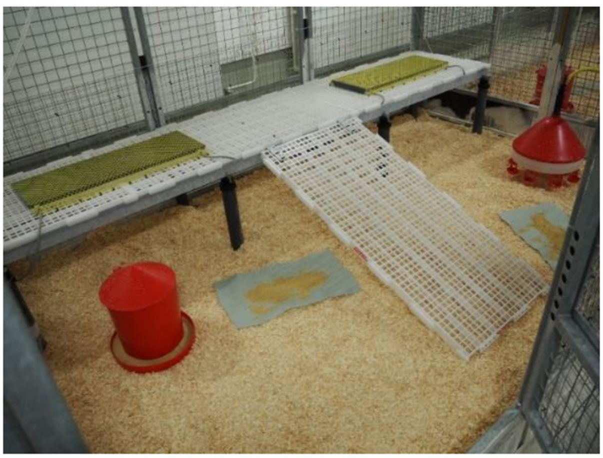

FIGURE 2 | Photo of a compartment equipped with an elevated grid platform and a ramp for easy access. Platforms were installed in half of the compartments (enriched compartments). Control compartments were identical but without platforms.

longer partition walls of the compartments at a height of 50 cm and equipped with a ramp (L × W, 0.9 × 0.6 m; inclination angle, 29.1°; same material as the elevated grid, **Figure 2**). The area below the elevated platform was accessible to the birds. Compartments with elevated platforms had an additional area of 20% in relation to the floor area compared to compartments without platforms. In the following, compartments with elevated platforms are termed enriched, and the others are termed control compartments.

Measurements and Statistical Analysis

Usage of Elevated Platforms

In each of the enriched compartments, an infrared video camera (Model VTC-E220IRP, color camera for corner mount with IR-LEDs; SANTEC BW AG, Ahrensburg, Germany) was installed opposite to the elevated structure to record the usage of the platforms from the first day until the end of the fattening period.

The usage of the elevated platforms was analyzed by counting the number of chickens on the grids using scan sampling in 15-min intervals every week of life throughout two successive days (Saturday and Sunday), including 64 time points during the light period. During the dark period, usage was recorded at five time points, as a former study showed less variation in the use of elevated structures during the night (12).

Walking Ability

We assessed the walking ability 2 and 1 day before slaughter (Ross, end of the fifth week of age; Dual, end of the tenth week of age) by two methods. Two methods were used because there was an association between them, and any differences were checked.

First, the chickens were placed in a small arena outside their home pen with two other chickens to assess the gait score after Kestin et al. (14) with a 6-point scale (0 = fluent walking without detectable abnormality for chickens, 1 = slight undefined defect in gait, 2 = definite changes and defects and waddling walk, 3 = clearly fluent gait restriction, 4 = severe gait defect, difficult to move, and 5 = unable to walk). To motivate the chicken to walk, the focus animal was placed on one side with two other chickens on the other side of the small arena. Gait scores were assessed while the chickens were walking. Directly after the assessment of gait scores, the chickens were transferred to a rotarod test (15) installed in the corridor of the barn. The test chicken was placed on a stationary rod. After the chicken grasped the rod, the rotarod test started, and the rod started to rotate after 1 s. The test was completed when the chicken left the rod actively or passively. Detailed information on the rotarod test is given in (15). As a proxy for walking ability, the latency to leave the rod in seconds was recorded.

For the chickens of both strains, we used different diameters of the rod to match the rod to the different foot sizes of the chickens (length from the middle to the back toe: Ross 308, 89.1 mm; Lohmann Dual, 105.6 mm). The diameter of the rod was 57 mm for Ross chickens and 67 mm for Dual chickens. For

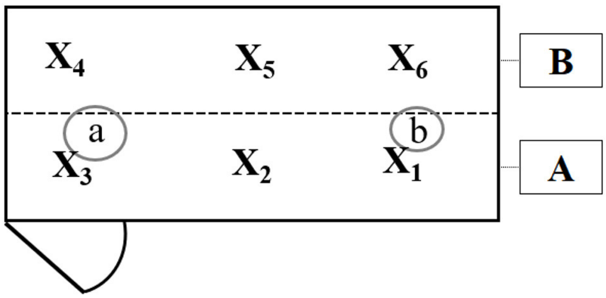

FIGURE 3 | Schematic view of the areas of litter sampled and subsequently analyzed for dry matter content. Area "A" contained the feeding trough (a) and drinkers (b), and area "B" was below the elevated platform. From both areas, a mixed sample was taken, respectively (A: x_1, x_2, x_3; B: x_4, x_5, x_6).

each strain, we tested a total of 114 chickens (114 = 19 chickens × 6 compartments). The animal sample size was calculated by power analyses (*F*-test, power = 0.8) based on previous results.

Weight, Plumage Cleanliness, and Foot Health

For weighing and assessment of animal-based indicators, we examined the chickens that passed the rotarod test. The weight of day-old chicks was measured at the pen level [average weight = (all chicks in one box per pen – tara value of the box)/number of chicks].

To assess plumage cleanliness and foot health, we used the Welfare Quality® (16) scoring system. The state of the plumage cleanliness of the back and chest was classified into 4 scores (0 = clear and fluffy, 1 = slightly dirty, 2 = moderately dirty, and 3 = completely dirty). The foot pads and hock burns were classified using 5 scores (0 = no evidence of foot pad dermatitis or hock burn, 1 = slight changes, 2 = moderate changes, 3 = major changes, and 4 = severe evidence of foot pad dermatitis or hock burn).

Litter Quality

After each fattening period, two mixed samples (50 g) were taken from each pen (A = three small samples from the area around the water dispenser and feed troughs, B = three small samples from the area under the elevated structure; **Figure 3**). To determine the relative moisture content, each sample was dried in a forced-draft oven at 105°C for 24 h [Darr method, DIN 52,183; (17)] and weighed immediately afterwards.

Statistical Analysis

For statistical analyses of the usage of the elevated structure, the latencies of the rotarod test, and the weight, we applied linear mixed-effect models (LMEs) using the nlme package (18) of RStudio Version 1.2.5042. To test for differences in the relative usage of elevated structures, we included the strain (Dual, Ross), weeks of age (5, 10 weeks), and time of day (dark, light periods) as fixed factors. The compartment ID nested within the trial (1, 2) was considered a random factor. Effects on latency in the rotarod test and weight were tested by LME, including the strain and treatment (enriched or control), and their interaction as fixed factors. The compartment ID nested within the trial was included as a random factor.

The relative moisture content of litter taken from the two areas (A, B) was analyzed using a linear model (LM) with treatment, strain, and their two-way interaction as fixed factors. One trial was removed from the final model, as it did not show any significant effect on the relative moisture content. Within the enriched compartments, another LM for litter quality was conducted to examine differences between the "A" and "B" positions with strain and position and their two-way interaction as fixed factors. All dependent variables were log(x + 1) transformed. In the case of significant effects of the factors, a *post-hoc* comparison with a pairwise *t*-test (Bonferroni correction) was conducted.

Effects on the gait score, plumage cleanliness score, and foot health score were tested by generalized linear mixed models (glmer) with a Poisson distribution using the package lme4 (19). To analyze differences in gait score between treatments, single models were used for each strain due to convergence issues in the model processing. The effects of treatments and strains on plumage cleanliness and foot health were tested by including the treatment and strain (except for gait score) and their interaction as fixed factors. The compartment IDs nested within the trials were considered random factors in each model. Model outputs were extracted from GLMER using the package car (20).

RESULTS

In the following section, we present the main results of the study (see the **Supplementary Material** for the whole output of the statistical models).

Usage of Elevated Platforms

The chicks can be observed on the ramp from the second day of life. On the elevated platforms, they are only from about the third day of life. The usage of elevated platforms was significantly affected by a two-fold interaction between weeks of age and time of day [$F_{(1, 163)} = 26.12$, $P < 0.0001$] and by the strain [$F_{(1, 9)} = 199.09$, $P < 0.0001$; **Supplementary Table 2**]. Chickens of both strains increasingly used the elevated platforms with increasing age (**Figure 4**). Especially in the second week of life, the platforms were used more often than in the first week of life. Dual chickens were observed more often on the elevated platforms in light compared to during the dark period until the seventh week of age. Afterwards, they used the platforms more often during the dark period. The Ross chickens showed comparable usage of the elevated platforms during the light and dark periods. However, Ross chickens used the elevated structures less than Dual chickens. The highest usage of elevated platforms was observed in Ross chickens in the fourth week of life during the light period, with a mean proportion of 17.1 ± 3.5%. Dual chickens showed the highest usage in the 10th week of life during the dark period, with a mean proportion of 67.3 ± 6.8%.

Walking Ability

The latency to leave the rod in the rotarod test was significantly affected by the strain [$F_{(1, 8)} = 100.4777$; $P <$

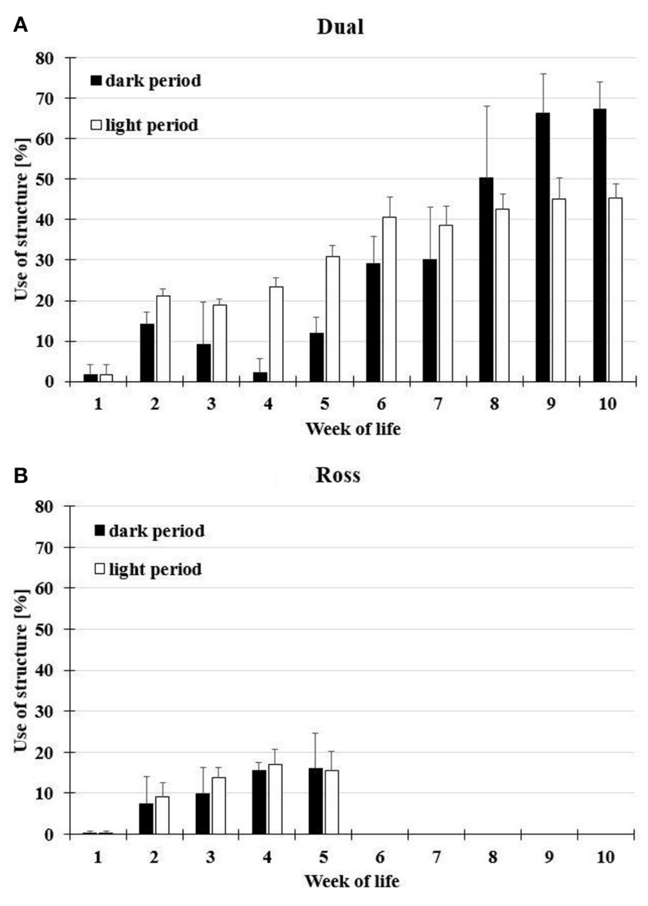

FIGURE 4 | Effect of age and time of day on the usage of the elevated platforms (means ± SD) by **(A)** Dual and **(B)** Ross chickens.

0.0001] and treatment [$F_{(1,\ 8)} = 6.5439$, $P = 0.0337$, **Figure 5**; **Supplementary Table 3**]. Dual chickens showed a better walking ability than Ross chickens, as indicated by longer latencies. Furthermore, Dual chickens from the enriched treatment showed longer latencies to leave the rod compared to Dual chickens from the control group.

Based on the second method used to assess walking ability, which was the gait score system, Dual chickens also showed a better walking ability than Ross chickens (see **Table 1**). However, based on this method, the walking ability was not affected by the treatment in either of the strains (Ross, $P = 0.373$; Dual, $P = 0.557$; **Supplementary Tables 4, 5**).

Weight, Plumage Cleanliness, and Foot Health

The weight of the chickens was affected by the strain ($P = 0.0027$; **Supplementary Table 6**), and Dual chickens showed a higher weight at the end of their fattening period (10th week of life) than Ross chickens (5th week of life; **Table 2**).

The cleanliness of the chest was affected by the strain ($P < 0.0001$) and that of the back was affected by the treatment ($P = 0.0005$, **Table 3**; **Supplementary Tables 7, 8**). Compared to

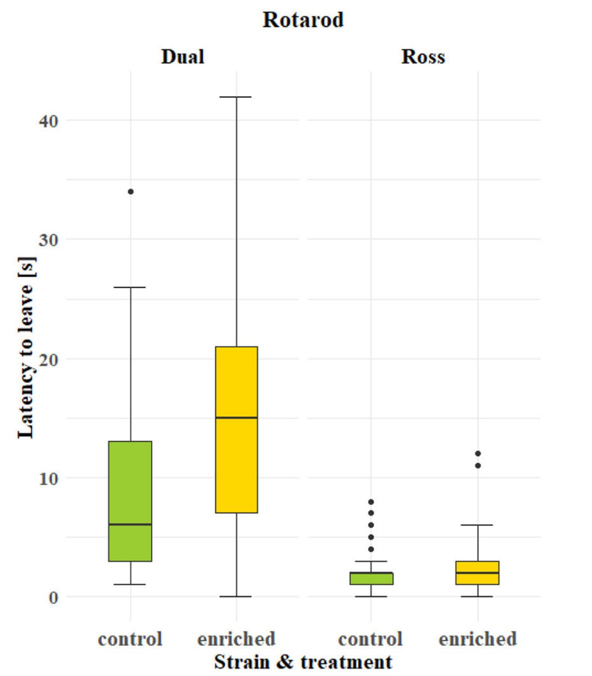

FIGURE 5 | Effect of the strain (Dual or Ross) and treatment (control or enriched) on the latency to leave the rotating rod (boxplots) in the rotarod test.

TABLE 1 | Proportion of chickens of the two strains (Dual and Ross) showing the respective gait score at the 33rd/34th (Ross) and at the 70th day of life (Dual) (G = gait score, *n* = 114 per strain).

		G0	G1	G2	G3	G4	G5
Dual	Control	57.9%	36.8%	5.3%	0%	0%	0%
	Enriched	50.9%	45.6%	0%	1.8%	1.8%	0%
Ross	Control	0%	15.8%	31.6%	49.1%	3.5%	0%
	Enriched	0%	24.1%	38.9%	35.2%	1.9%	0%

TABLE 2 | Average body weight (means ± SD) of Dual and Ross chickens across and within treatments (control and enriched) at the 35th (Ross) and the 70th day of life (Dual).

Strain	Treatment	Average weight (g)	±SD
Dual	Total	2,237.8	232.7
	Control	2,211.0	210.3
	Enriched	2,264.6	250.3
Ross	Total	2,051.7	351.3
	Control	2,089.4	326.4
	Enriched	2,013.3	371.0

Dual chickens, Ross chickens were clearly dirtier on the chest. Chickens from the enriched groups were dirtier on the back than chickens from the control groups, and this was most obvious in Dual chickens.

Chickens of the two strains differed in their foot health. The mean scores for foot pad lesions [score 0: 62% (Ross) vs. 76%

TABLE 3 | Proportions of Dual (70th day of life) and Ross (35th day of life) chickens showing the respective scores for cleanliness (S = score, $n = 234$ per strain).

Strain	Treatment	Cleanliness of chest (%)				Cleanliness of back (%)		
		S0	S1	S2	S3	S0	S1	S2
Dual	Total	0.4	88.9	10.7	0	35	64.1	0.9
	Control	0.9	91.5	7.7	0	53	47	0
	Enriched	0	86.3	13.7	0	17.1	81.2	1.7
Ross	Total	0.4	23.1	62.5	25.4	61.2	37.1	1.7
	Control	0	5.1	61.5	33.3	68.4	31.6	0
	Enriched	0.9	18.3	63.5	17.4	53.9	42.6	3.5

TABLE 4 | Proportions of Dual (70th day of life) and Ross (35th day of life) chickens showing the respective scores for foot pad health (S = score, $n = 234$ per strain).

Strain	Treatment	Foot pad change (%)					Hock burn (%)				
		S0	S1	S2	S3	S4	S0	S1	S2	S3	S4
Dual	Total	76.1	20.1	3.85	0	0	95.7	4.27	0	0	0
	Control	87.2	9.4	3.42	0	0	98.3	1.71	0	0	0
	Enriched	65	30.8	4.27	0	0	93.2	6.84	0	0	0
Ross	Total	62.1	37.5	0.43	0	0	78.4	21.6	0	0	0
	Control	59.8	40.2	0	0	0	77.8	22.2	0	0	0
	Enriched	64.3	34.8	0.87	0	0	79.1	20.9	0	0	0

(Dual); $P = 0.01077$] and hock burns [score 0: 78% (Ross) vs. 96% (Dual); $P = 0.0012$; **Supplementary Tables 9**, **10**] were higher in Ross chickens than in Dual chickens (**Table 4**). The treatment affected the foot pad health ($P = 0.0113$). Dual chickens from the control groups showed better foot pad health than birds from the enriched group.

Litter Quality

The litter quality in the enriched and control compartments was significantly affected by the strain for position "A" ($P = 0.0002$) and by the two-fold interaction between strain and treatment for position "B" ($P = 0.04$). For both strains, the relative moisture content of the litter below the platforms was higher than that of the same area in the control compartments ($P = 0.013$, **Figure 6**; **Supplementary Tables 11**, **12**).

Within the enriched compartments, litter taken from below the elevated platforms (position "B") had a higher relative moisture content, i.e., was moister, than the litter taken around the feeding throughs and water dispensers (position "A") in both strains ($P = 0.03$; **Supplementary Table 13**). Generally, the litter in the compartments with the fast-growing chickens was moisture than that of the slow-growing chickens.

DISCUSSION

Our results show that regardless of the growth rate, chickens of both strains used elevated structures offered at a height of 50 cm during both the light and dark periods. However, the frequency of usage differed, and slow-growing chickens used the elevated structures more often than fast-growing chickens. Furthermore, the elevated structures improved the walking ability as measured by the rotarod test in slow-growing but not in fast-growing broilers. Fast-growing broilers had more difficulties in mobility. Their plumage was dirtier on the chest and cleaner on the back compared to slow-growing animals despite their shorter fattening period and lower slaughter weight in this study.

Usage of Elevated Platforms

The comparison of the two strains showed different intensities of usage of the elevated structures. Beginning in the second week of life, more Dual than Ross chickens were observed on the grids. We expected this difference in usage between the strains, as it has already been described in previous studies (8, 12). With increasing age, chickens of both strains increasingly used the elevated structures. In Ross chickens, this increase was seen until the fourth week, but from the fifth week, usage decreased during the daytime. This decline in usage has also been shown by Norring et al. (21) and is most likely due to rapid growth, a poorly developed bone structure and enormous muscle mass with increasing age (6), which reduces the locomotor activity and ability of these birds (12).

Dual chickens showed higher usage (almost 70%) of the elevated structures from the eighth week of life, particularly at night. Previous calculations (22) showed that the elevated area offered in our study provided space for ~60% of the chickens in a compartment (~32 of 50 animals). In the eighth

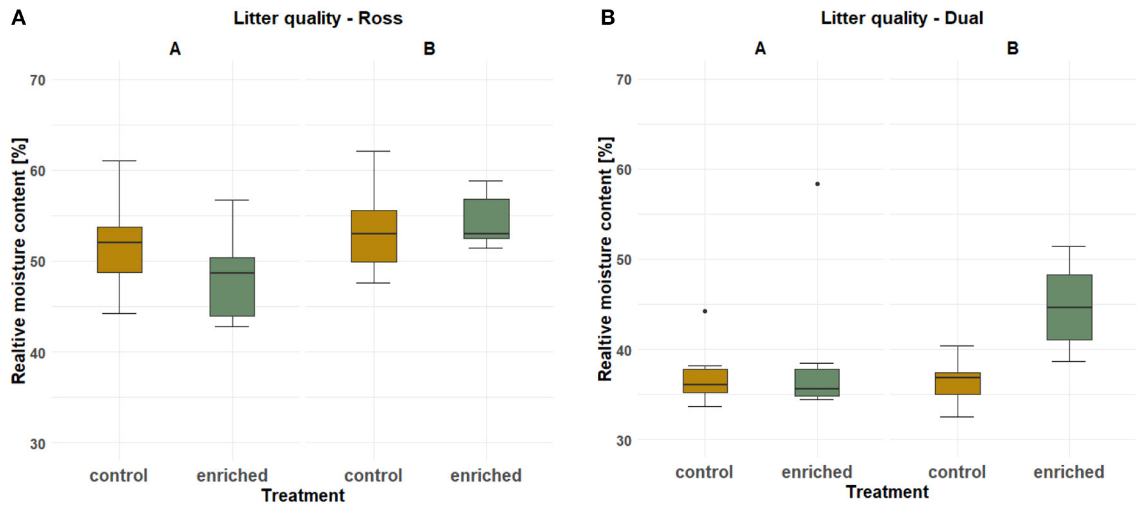

FIGURE 6 | Effect of treatment (control or enriched) and position (A or B, **Figure 3**) on the litter quality (dry matter content, DM, and boxplots) for each strain [**(A)** Ross and **(B)** Dual], respectively.

week of life, the elevated grid area was completely occupied by chickens, and it can be assumed that more space would have led to even more animals on the elevated structures. In pullets, it can also be observed that from the first week of life onwards, most layer chickens look for higher sleeping places (23). There is also a relationship between early access to elevated structures and the frequency of early night-time roosting (24).

Interestingly, male Ross chickens showed higher use of the elevated structures (by up to 17% during the light period and 16% at night) compared to the results of our previous studies (8, 12). In these previous studies, we offered a smaller ramp to reach the grid platforms, and platforms were offered at three different heights (10, 30, and 50 cm). The higher usage in the present study may thus indicate that elevated platforms at a height of 50 cm with a wider, more stable ramp provide better access to the platforms, especially for fast-growing broiler chickens. The area of the elevated grids was narrower than that in the current study but never occupied at full capacity.

In conventional broiler husbandry, male and female broiler chickens are reared in mixed-sex groups. Generally, female chickens are lighter than male chickens (13). There is evidence that lighter chickens use elevated structures more often than heavier chickens (25). Consequently, a higher frequency of usage of elevated structures could be possible in mixed-sex groups. Thus, we suggest that elevated platforms should provide space for ∼20% of fast-growing broilers in a barn because it is likely that female birds will use the elevated platform more than male birds. However, this should be validated by on-farm studies in larger groups of broiler chickens, such as Kaukonen et al. (9), to provide more precise details.

Walking Ability

In both methods for assessing walking ability (rotarod test and gait score system), slow-growing chickens showed a better walking ability than fast-growing chickens. The association between the growth rate and walking ability has also been found in other studies, such as in Kestin et al. (26) and Knowles et al. (27).

An advantage of the rotarod test is that, in this test, the latency to leave the rotating rod as a proxy for walking ability is measured as a continuous variable, in contrast to the gait score system with its categorical variable. In addition, the validity of the gait score system is vulnerable to differences in subjective assessment (15). Thus, with the rotarod test, walking ability can be assessed more sensitively, and smaller differences can be recorded. This is probably the reason why we found an effect of the elevated structures on the walking ability of slow-growing dual-purpose chickens when applying the rotarod test but not with the gait score systems. By using the elevated structures, the motor skills and the walking ability of the chickens of the slow-growing strain were trained, as indicated by a longer latency in the rotarod test. This effect was not prevalent in Ross chickens, as also shown by Bailie et al. (28). In contrast, Kaukonen et al. (9) and Pedersen and Forkman (29) found an improvement in walking ability in fast-growing broiler chickens when elevated structures were offered. The possible training effect of our offered elevated platform does not seem sufficient to improve the walking ability in these fast-growing chickens.

Plumage Cleanliness and Foot Health

The majority of chickens showed only light to moderate degrees of dirtiness of their plumage. Slow-growing chickens showed cleaner plumage on the chest than Ross broilers. This probably resulted from the lower activity of Ross chickens at the end of the fattening period, when they spend most of their time budget sitting in often moist and soiled bedding (30). In the enriched groups, chickens from both strains showed dirtier back plumage compared to the control groups. The area under the elevated structures was freely accessible to the chickens, and excrement from chickens on top of the elevated structure could fall through the grids. This probably resulted in dirtier backs for the chickens from the enriched compartments compared to the control compartments.

The foot pad health and hocks indicated more lesions in Ross chickens than in slow-growing chickens. This may be due to the lower activity and longer contact time with wet litter in the fast-growing chickens (31). We expected that chickens from enriched compartments showed fewer alterations in the foot pads and hocks. However, the foot pad health and hocks did not differ between the treatments. Either resting on grid platforms affected these measures, or the prevalence of these measures in our study was too low to find any effect of the treatment.

Overall, our results show that natural behaviors such as perching can be supported by offering elevated platforms. In particular, male dual-purpose chickens additionally benefited from the elevated platforms, as indicated by their improved walking ability. The use of such an alternative chicken strain avoids killing day-old male chickens, and in addition, these slower-growing chickens show fewer animal welfare problems than conventional fast-growing broiler chickens. Thus, the use of male chickens of a dual-purpose strain can substantially contribute to improving animal welfare in broiler meat production.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The animal study was reviewed and approved by Lower Saxony State Office for Consumer Protection and Food Safety (LAVES, Oldenburg, Germany) (LAVES, Oldenburg, Germany, file number #33.19-42502-04-16/2108).

AUTHOR CONTRIBUTIONS

JM and LS conceived and designed the project. JM collected and analyzed the data. All authors contributed to the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2021.660602/full#supplementary-material

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ORIGINAL RESEARCH
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The Need for an Alternative to Culling Day-Old Male Layer Chicks: A Survey on Awareness, Alternatives, and the Willingness to Pay for Alternatives in a Selected Population of Dutch Citizens

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A concerning by-product of producing laying hen chicks are the hatched male layer chicks. As a consequence of their inability to lay eggs, these male chicks are culled as day-old chicks in the hatchery. To find an alternative for this ethical dilemma (generally), three alternatives are under study, namely, *in ovo* sex determination, using dual-purpose breeds, and the rearing of layer cockerels. In order to assess the awareness of this practice and preference for one of the alternatives, we conducted an online survey of the Dutch public. Most of the 259 respondents completing the survey were highly educated woman (HEW, $n = 143$) versus others (REST, $n = 86$). The questionnaire was divided into six topics: (1) general knowledge of the poultry industry, (2) awareness of culling male layer chicks (CMC), and (3) its acceptability, (4) alternatives to CMC, (5) willingness to pay (WTP) for eggs without CMC, and (6) WTP for cockerel meat. Awareness about CMC was 52%, and its acceptability was rejected by 78% (HEW) and 67% (REST). The level of acceptability increased when more salient facts were given, and almost all respondents agreed that an alternative was needed (90% HEW, 84% REST). For both groups of respondents, more than 50% preferred *in ovo* sex determination over keeping the current practice or using dual-purpose breeds or male layers. Furthermore, the majority of respondents were willing to pay more than double the price for eggs without CMC being involved. Roughly 40% would not buy processed cockerel meat burgers, most likely due to their vegan or vegetarian diet. Of the remaining respondents, half were willing to pay the current price or 1 euro more for processed cockerel meat burgers. The most important factors when buying poultry meat or eggs without CMC were food safety, animal friendliness (welfare), and the environment; price was the least important factor. Despite the skewed respondents' background, the results of our survey show that consumers are willing to pay more for poultry products that do not require culling day-old male chicks.

Keywords: chicken, in-ovo sexing, willingness-to-pay, dual-purpose chicken, male layer chicks, day-old chicks

INTRODUCTION

A moral dilemma within the egg production industry is the culling of day-old male layer chicks (1). In order to produce eggs, laying hens are bred. The "brothers" of these bred laying hens are immediately culled at hatch, as male layers do not lay eggs and are deemed unqualified for the production of chicken meat. Culling of day-old male layer chicks (CMC) is noted to be of animal welfare concern within the egg production chain in the EU, and alternatives are seeked for this practice (2). Yearly, at least 7 billion male chicks are culled at hatch (3). The method for CMC in the United States of America is by shredding or maceration, leading to immediate death (4). The most common used method for CMC in Dutch hatcheries, however, is by asphyxiation with a high percentage of carbon dioxide (CO^2) (5). After asphyxiation, deceased chicks are often directly frozen and used as food for snakes (6), reptiles, birds of prey, or other types of animal feed. The CMC raises ethical concerns with regard to animal welfare (7) and the number of animals culled (8) and has led to political debate on CMC (1, 9). Especially within Germany, this issue has been raised (10). The ethical dilemma in the egg production industry likely has led to bans on CMC in France and Germany from 2021.

As a result of the political and societal disapproval toward CMC, research is aimed at finding alternatives for this practice (3). There are three alternatives that are currently used to varying degrees in the egg industry, while others are still being further refined. The three alternatives are *in-ovo* sex determination (3), keeping the roosters of dual-purpose breeds for meat production (11–14), and rearing roosters of layer breeds for processed meat products (15).

In-ovo sex identification is the determination of the sex of the embryo while in the egg (16, 17). With *in-ovo* sex identification, male embryos can be detected and then excluded from further development prior to or during incubation. Different sex determination techniques exist that differ in the level of invasiveness, which can influence hatchability (18, 19) [see (3), for review]. In the Netherlands, a Biotech company developed an *in-ovo* sexing technique using biomarkers. On day 8 of incubation, the egg is penetrated by a needle and a small amount of biological material is removed to determine the sex of the embryo with the use of a specific biomarker (https://inovo.nl/solutions/in-ovo-egg-sexing). A similar method is described by Weismann et al. (16, 17), where *in-ovo* sexing takes place by analyzing estrone sulfate in the allantoic fluid in the incubated eggs (20). Male embryos have lower levels of estrone sulfate compared to females, and sexing accuracy above 98% could be attained with this technique (16). The technique requires penetrating the egg, which could be a risk for survival due to infection risks. This *in-ovo* technique was shown to reduce hatching rate and rearing performance of layer females, which were sampled at day 9 of incubation as opposed to an unsampled control group, but no effect on laying performance was noted (17).

Another technique of *in-ovo* sex determination is by optical imaging methods (3) such as reflectance (21), infrared (22), and Raman spectroscopy (23–26). By penetrating the egg with a CO^2 laser and using spectroscopy on the embryo, the sex of the embryo can be determined based on different absorption spectra (3). This method is less invasive than removing biological material, but it still requires opening the eggshell. Reflectance spectroscopy allows sex identification with 90% accuracy when performed at day 10 of incubation (21). Fourier transform infrared spectroscopy is possible in non-incubated eggs because it is based on assessing the blastoderm cells in the germinal disc (22). For these optical imaging methods to assess sex, the eggshell needs to be opened, which is a risky avenue as the dimension of the hole in the eggshell reduces hatching rate (23). Through the hole in the eggshell, near-infrared fluorescence can identify the sex of the embryo [for details, see (24–26)]. These imaging techniques are preferred over assessing biomarkers from the allantoic fluid due to their low risk of contamination, being contact free and fast, and can be made automatic. At what age of embryonic development the *in ovo* techniques are applied could be an important aspect that may help people determine whether or not this technique is chosen as an alternative to CMC. A non-penetrating *in-ovo* sex identification method is *via* genetic marking of sex chromosomes (27, 28). Cockerels possess two Z sex chromosomes (i.e., they are homogametic), while females have one Z and one W sex chromosome (i.e., they are heterogametic). Genetically engineering the females is studied by Doran et al. (29) and Quansah et al. (30). They marked the breeding hens' Z chromosome with a fluorescent protein. In the germinal disc, sex-specific patterns could be determined to assess sex in non-incubated eggs (29).

Another alternative to CMC at hatch is by rearing the male layer chicks for their meat, which in some studies has been chosen as an acceptable alternative (15, 31). Layer chickens are bred for the production of eggs; therefore, both sexes are lean, have a high feed intake, and are of less mature body weight compared with broilers specifically bred for high growth rate and muscle mass (32). Furthermore, the carcass qualities of layer males are quite different compared to broiler chickens (33). Layer males would be kept up to 18 weeks of age in order to reach a body weight of around 2 kg (9). Broiler chickens (male or female) can grow to 2 kg in 33 days and grow out to 5 kg in 70 days depending on the genotype used (2). Body parts such as the breast muscle or thighs of broilers are used as meat products, but the meat of layer cockerels needs to be processed into different products, such as burgers (15). The meat products obtained from the layer cockerel are of lesser quality and quantity (34), thus more costly (i.e., less economical), and less sustainable compared with broiler meat because of the higher cost of feeding and housing these birds for a longer period of time and further processing demands. At present, only a limited number of farmers in the Netherlands use this avenue likely due to the economic and sustainable issues.

By using dual-purpose chickens, the cockerels are slightly more suited for meat production as the conventional layer genotypes (35). The meat from dual-purpose breeds is more comparable to broiler meat in taste and texture (14). Dual-purpose roosters can become heavier than layer roosters (i.e., 3 kg over 2 kg) (9). However, compared to the conventional layer or broiler genotypes, dual-purpose chickens produce fewer eggs and have lesser meat production being less economical and sustainable, as they need 14 weeks to attain 2 kg over 5.5 weeks for the common broiler (9). This means that dual-purpose chickens need 9.5 weeks longer to get the same body weight as the common broiler. The dilemma of CMC—i.e., there is no ideal alternative based on animal welfare, economics, ethics, and sustainability—makes it difficult to choose an alternative; therefore, we focused on animal welfare in this study.

Research has also suggested that alternative chicken meat products would not be fully accepted by Dutch society or the poultry industry (9, 36). To assess the public views, awareness, and acceptance of cockerel meat products, several surveys and workshops (3) have taken place in the EU [Germany: (10, 37–39); Switzerland: (40)]. Based on surveys in the Netherlands, public awareness on this topic increased from 42% in 2007 to 55% in 2015 (9, 36). The preference for *in ovo* sexing and keeping layer males instead of CMC was compared by Gremmen et al. (36) in an online survey conducted in the Netherlands in 2015. Neither one of the approaches was fully accepted. Leenstra et al. (9) looked at the public view to nine alternatives to CMC and accepting CMC. As the practice of CMC and the pros and cons of the alternatives are likely unknown to the participants Leenstra et al. (41), Leenstra et al. (9) provides background information *via* video footage. In this study, *in-ovo* sexing of the fresh egg and keeping a dual-purpose chicken were chosen as most preferable to CMC. More than half the respondents who choose an alternative to CMC were willing to pay an additional 5–10 euro cents per egg from dual-purpose breeds or eggs obtained using the *in ovo* method (9). These results give the suggestion that Dutch consumers of poultry products became more aware of the practice of CMC over the years (36) and are inclined to pay more for poultry products where CMC is excluded. These surveys in the Netherlands were conducted more than 5 years ago, and therefore, we wanted to assess the current public awareness of CMC and their preferred alternative (*in-ovo* sexing, rearing male layers or dual-purpose chicken) and their willingness to pay (WTP) for that alternative. Slightly similar to the study by Leenstra et al. (9), we wanted to provide information on the poultry industry to the participants in order to assess their change in acceptance of CMC. Our goal was to reach an evenly distributed population of respondents with different demographic background, however our respondents mostly fitted a highly educated subset and thus our results are limited to those people of the Dutch population.

MATERIALS AND METHODS

An online questionnaire was created in Dutch using Qualtrics (see Additional file 1). Respondents could fill in the questionnaire from July 3 until August 1, 2020. Only questions were provided, and no video or other footage was used. Questions were formulated to obtain information on six different topics by order of appearance in the survey: general knowledge on the poultry industry, of CMC, WTP for eggs without CMC, WTP for cockerel meat without CMC. Each topic was introduced so as to provide the respondents with our aim for the questions and—if needed—to establish background needed for answering the questions. In some cases, this text provided respondents with answers to the previously asked questions (**Table 1**). The survey was made up of six parts. Part 1: Eight questions regarding the poultry industry in the Netherlands. First two questions with multiple-choice answers, followed by six questions with a *true/false/I do not know* answer option. Part 2: Four questions regarding the acceptance of CMC, following were six questions on acceptance of keeping chickens for food and the alternatives for CMC, which could be answered based on a Likert agreement scale (1 = strongly disagree, 5 = strongly agree). Part 3: Ranking the alternatives according to preference (1 = most preferable, 4 = least preferable). Part 4: Seven questions on factors playing a role in the choice for poultry products on a Likert importance scale (1 = not important at all, 5 = very important). These factors included price, environment, availability of the product, food safety, naturalness (not specifically defined), animal friendliness/animal welfare, taste of the product, and feasibility of the alternative. Part 5: Six questions with multiple-choice answers regarding choice for poultry products and WTP for eggs and cockerel meat without CMC. First, respondents were asked which type of eggs or poultry meat they typically buy. Next, they were asked how much they are willing to pay for eggs and cockerel burgers without the CMC and whether a label on the product showing that the product is produced without CMC assists in their choice for these egg or poultry meat products. To determine if there had been a change in acceptability of CMC prior to and after completing the questionnaire, respondents were again asked on their agreement for CMC using the Likert agreement scale. Part 6: Eight questions regarding sociodemographics and personal information such as sex, age, highest level of education, annual income, province of residence; diet-choice; owning of pets; and whether they donate money to charity. The invitation to participate in this questionnaire was distributed through social media (Facebook, Twitter, and LinkedIn) *via* the personal accounts of all three authors. This has resulted in a biased background in the respondents. Only fully completed questionnaires were used for analysis (i.e., 259 out of 372).

Statistical Analysis

The data were analyzed using Statistical Package for the Social Sciences (SPSS, version 23). Descriptive analysis was performed on the sociodemographic information of the respondents. We noticed a high number of women with a high education level originating from two specific provinces out of 12 provinces in the Netherlands as can be seen in **Table 2A**. The data were divided into two subsets (**Tables 2A,B**), so that any statistical analysis would not be wrongly attributed to the large group of highly educated women (HEW). That is, more than half of the respondents were HEW, subset 1 ($n = 143$). Subset 2 contained the rest of the respondents (REST: $n = 86$). Our aim was not to compare subsets but to limit incorrect conclusions on demographics as a consequence of the background of HEW skewing the dataset. In order to have an equal number of respondents in specific categories, we combined provinces together as follows: South NL: Limburg and Noord-Brabant; Urban South-West: Noord-Holland and Zuid-Holland; North NL: Overijssel, Drenthe, and Groningen. The same was done

TABLE 1 | Additional information given in the survey on culling day old male layer chicks.

Content of information provided	When was information provided	Prior to which questions—paragraph content
The poultry industry is specialized. Chickens for meat and chickens for eggs. This survey is aimed to test your knowledge and opinion on eating cockerel meat	At the start of the questionnaire	1–8. Paragraph 1. Knowledge on the poultry industry
In the Netherlands, 90,000,000 chickens are kept yearly. 45,000,000 chickens for meat and 45,000,000 chickens for eggs. Because cockerels of layer chicken do not lay eggs they are culled at the hatchery. Once chicks hatch sex is determined manually by a specialist. Once the sex is determined to be male, male layer chicks are culled via CO_2 asphyxiation. Yearly 45,000,000 male layer chicks are culled. The culled chicks are used for zoos, reptiles and birds of prey and other animals.	After first paragraph of questions regarding the numbers of chicken in the Netherlands, which day old male chicks are culled (broiler and layer or only layer), the sexing method, the method of culling and what happens with the culled male layer chicks.	9–12 Paragraph 2. Acceptance of culling day old chicks
Culling day old chicks is causing a discussion on animal and ethics. Research is being conducted on alternatives for culling day old layer males. In this survey we look at three alternatives. We consider herein the perspective of keeping the animals under the highest welfare conditions. 1. Keeping layer males for special cockerel meat products. 2. Double purpose chickens for keeping the cockerels for meat and the hens for egg production. 3. Sex determination of the embryo in the egg. With a needle fluid is being taken from the embryo which is used to determine the sex. Male embryos will be excluded from further development and used in animal feed.	After paragraph 2. Acceptance of culling day old chicks.	13 Paragraph 3. Acceptance of alternatives to culling day old male layer chicks 19 Paragraph 4. Preference of alternatives to culling day old male layer chicks
Broiler chickens are slaughtered at 6 weeks of age. When cockerels of layer breeds will be kept for meat this takes ∼15 weeks, because they take longer to grow. The feed and care costs are higher as compared to broiler chicken. This makes the meat of these layer cockerels more expensive than meat of broiler chicken. Meat from cockerel layers is less tender than meat from broiler chicken, and therefore the meat is processed into sausages or burgers.	After paragraph 2. Acceptance of culling day old chicks.	13–18 Paragraph 3. Acceptance of alternatives to culling day old male layer chicks 19 Paragraph 4. Preference of alternatives to culling day old male layer chicks
A double purpose chicken is a chicken breed which can be used for meat and eggs. The meat of double purpose chicken is more expensive because they do not grow as fast at the broiler chicken. The feed and care costs for double purpose chicken are higher as compared to the broiler chicken.	After paragraph 2. Acceptance of culling day old chicks.	13–18 Paragraph 3. Acceptance of alternatives to culling day old male layer chicks 19 Paragraph 4. Preference of alternatives to culling day old male layer chicks
Layer cockerel meat is mainly being used for sausages and burgers. This is currently the cockerel burger from layer cockerels available in one specific supermarket chain. 	After question 31 in Paragraph 6. Willingness to pay for chicken products	32

for age group 51–60 and 60+ in subset 1. We excluded one respondent below 17 years old and two in the category 17–21 due to low sample sizes.

First, descriptive analysis on knowledge levels of the Dutch poultry industry (true/false answer options for part 1) was performed. Likert scale data were analyzed as frequencies of respondents adding agree + strongly agree and adding disagree + strongly disagree together and comparing these frequencies with a chi-square test. Change in acceptability of CMC was calculated for the subsets by comparing the response to the first and second questions on acceptability (in the beginning and at the end of the survey). To test which alternative was preferred, the overall percentage of first preference was calculated and analyzed with a chi-square test. The relative importance of the factors influencing choice of product was assessed with a Wilcoxon signed rank test. The WTP for eggs and for meat without CMC was assessed with a Wilcoxon rank sum test. A chi-square test was used to determine whether income levels were affecting the price respondent were willing to pay for eggs and for meat with or without CMC.

RESULTS

The sociodemographic data of both subsets can be seen in **Table 2A** (HEW) and **Table 2B** (REST). Under the respondents in subset REST, there were more men than women (76 vs.

Table 2A | Socio-demographic characteristics of subset 1: Highly educated women.

	Sample (*n* = 143)	Sample (%)	Dutch population* %
Age			
21–30	39	27.3	12.7
31–40	38	26.6	12.2
41–50	31	21.7	13.1
>50	35	24.5	14.5
Income (per year, per household)			
Low (< € 29.999)	37	25.9	60.7
Middle (€30.000–€49.999)	37	25.9	31.9
High (>€50.000)	41	28.7	7.4
Unknown	28	19.6	
Province			
South NL	20	14	21.2
Urban South-West	39	27.3	37.8
Utrecht	36	25.2	7.8
North NL	20	14	14.8
Gelderland	28	19.6	12.0

*All 143 respondents in subset 1 were women with a high education level (University degree) *Dutch Central Bureau for Statistics (CBS statline), accessed August 2020. Income: Low: < € 29.999; Middle: €30.000–€49.999; High: >€50.000 (per year per household). NL, The Netherlands.*

Table 2B | Socio-demographic characteristics of subset 2: REST.

	Sample (*n* = 86)	Sample (%)	Dutch population* %
Sex			
Men	65	75.6	49.6
Women	21	24.4	50.3
Education			
Middle	48	55.8	36.7
High (University)	38	44.2	32.3
Age			
21–30	17	19.8	12.7
31–40	21	24.4	12.2
41–50	12	14.0	13.1
51–60	18	20.9	14.5
60+	18	20.9	25.3
Income (per year, per household)			
Low (< € 29.999)	22	25.6	60.7
Middle (€30.000–€49.999)	21	24.4	31.9
High (>€50.000)	31	36.0	7.4
Unknown	12	14.0	
Province			
Urban South-West	28	32.6	37.8
Utrecht	20	23.3	7.8
South NL	12	14.0	21.2
Gelderland	26	30.2	12.0

**Dutch Central Bureau for Statistics (CBS statline), accessed August 2020. NL, The Netherlands.*

24%), more people with a high income compared to middle or low (36 vs. 24% and 26%). In both subsets, the province of Utrecht was overrepresented compared with the Dutch percentage (**Tables 2A,B**).

Awareness Regarding the Practice of Culling Day-Old Male Layer Chicks and General Knowledge of the Poultry Industry

For both subsets, roughly 52% knew about the practice of CMC (**Figure 1**). The majority of respondents were aware that culled chicks are used as animal food (HEW: 74.8%; REST: 79.1%). Roughly half of the respondents knew about the method of culling (HEW: 50.3%; REST: 58.1%) and that only male layer chicks are culled and not male broiler chicks (HEW: 44.8%; REST: 47.7%). The majority of respondents knew that sex determination of chicks takes place after hatch (HEW: 73%; REST: 65%) by a specialist (HEW: 74%; REST: 64%). Regarding the general knowledge on the Dutch poultry industry, < 50% of the respondents answered all questions correctly (HEW: 34.4%; REST: 32.6%). The most incorrect answers were given on the question regarding the chicken population in the Netherlands (HEW: 37.1% and 46.5%).

Acceptance Regarding the Poultry Industry, the Practice of Culling Day-Old Male Layer Chicks, and Alternative for Culling Day-Old Male Layer Chicks

See **Table 3** for mean and median levels of the respondents' acceptance levels on 10 statements regarding CMC. All five questions regarding accepting the practice of CMC were disagreed (1) or strongly disagreed (2) (min–max mean levels: HEW: 1.72–2.02; REST 2.13–2.45). This was also significantly shown by the percentage of respondents disagreeing with CMC in HEW (78.8%) and REST subset (67.3%), $X^2 = 3.65$, $P = 0.05$. A smaller percentage of respondents disagreed with CMC as unavoidable (HEW: 44.8%; REST: 26.7%; $X^2 = 7.03$, $P < 0.001$). Keeping chickens for food tended to be accepted based on high Likert scale levels (1 = strongly disagree, 5 = strongly agree: HEW: 3.52; REST: 3.92). Roughly half of the respondents agreed with keeping chicken for food production (51%: HEW; 45.3% REST). Very high levels of agreement were seen regarding finding an alternative for CMC (HEW: 4.49; REST: 4.22), with highest levels of acceptance for *in-ovo* sex determination (3.85 for both subsets).

Change in Acceptance Levels of Culling Day-Old Male Layer Chicks Prior to and After the Questionnaire

For both subsets, the percentage of respondents who disagreed with the practice of CMC increased, although not significantly ($X^2 = 1.55$, NS; **Figure 2**). At the start of the survey, for HEW, 40.6% strongly disagreed to accepting CMC vs. 45.5% after the survey. At the start of the survey, for REST, 27.9% strongly disagreed with accepting CMC vs. 33.7% after the survey.

Preference for Alternatives for Culling Day-Old Male Layer Chicks

Respondents were asked to arrange the alternatives to CMC in order of preference. The majority of the respondents chose *in*

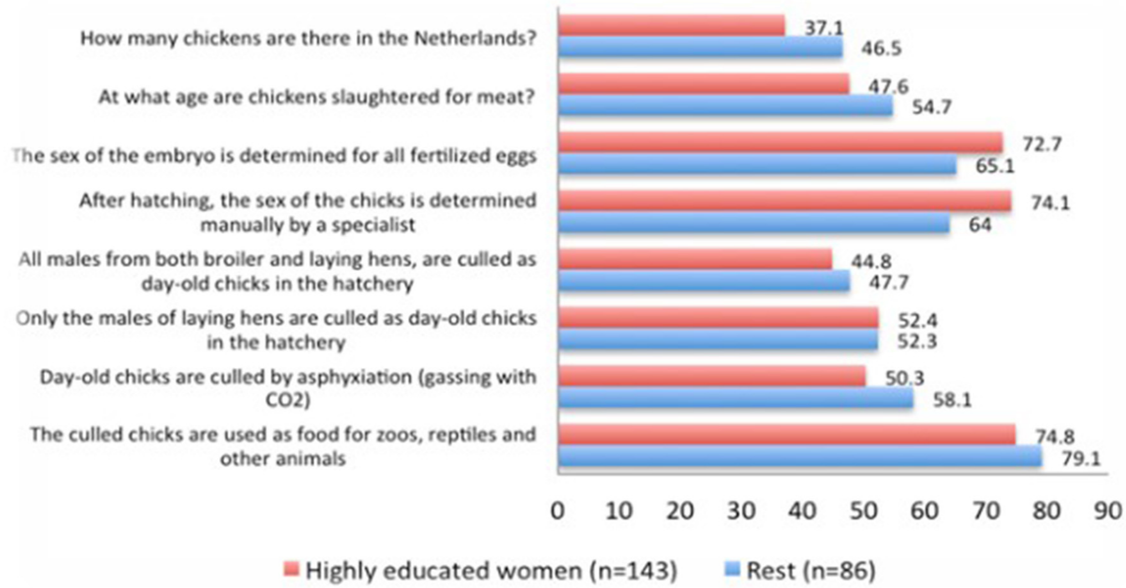

FIGURE 1 | Percentage of respondents correctly answering general knowledge questions/statements on the poultry industry, its practices and the culling of day-old males correctly.

Table 3 | Mean and median outcomes for 10 agree/disagree questions rated on a Likert scale (1 = strongly disagree, 5 = strongly agree) regarding the acceptability of practices in the poultry industry.

Questions regarding practices in the poultry industry	Highly educated women (*n* = 143)		REST (*n* = 86)	
	Mean	Median	Mean	Median
The culling of day-old male layer chicks is a good solution.	1.72	1	2.24	2
There is no problem with culling day-old male layer chicks.	1.66	1	2.13	2
The culling of day-old male layer chicks is inevitable.	1.87	2	2.37	2
Day-old male layer chicks may be culled	2.07	2	2.45	2
Because day-old male layer chicks have another use, this eliminates the need for an alternative to CMC.	2.01	2	2.41	2
Chickens can be kept for food production.	3.52	4	3.92	4
An alternative is needed for the culling of day-old male layer chicks.	4.49	5	4.22	4
The use of dual-purpose breeds is a good alternative to the culling of day-old male layer chicks.	3.41	4	3.24	3
Rearing male layers is a good alternative to the culling of day-old male layer chicks.	3.51	4	3.47	4
In-ovo sex determination is a good alternative to the culling of day-old male layer chicks.	3.85	4	3.85	4

Likert scale used here: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.

ovo sex determination as first preference as alternative to CMC (HEW: 57%; REST: 51%; **Figure 3**), followed by keeping dual-purpose breeds (HEW: 29%; REST: 23%). Rearing layer males were scored the least as first preference (HEW: 6%; REST: 10%), even lower than keeping the current situation (HEW: 8%; REST: 16%). For effects due to income, education level, awareness, and change in acceptability, see **Table 4**. More respondents with a higher level of awareness ($X^2 = 15.08$, $P < 0.05$) and higher income ($X^2 = 19.15$, $P < 0.05$) chose *in-ovo* sex determination as first preference.

Factors Influencing the Choice of Alternatives for Culling Day-Old Male Layer Chicks

The most important factor for choice of alternatives for CMC is food safety in both subsets, followed by animal friendliness, the environment, naturalness, taste, feasibility, availability of the product, and price (**Table 5**; HEW: $X^2 = 273.7$, $P = 0.000$; REST: $X^2 = 152.03$, $P = 0.000$). No relationship was found between whether price was the most important factor and income level (HEW: $X^2 = 15.89$; REST: $X^2 = 27.9$, NS).

Willingness to Pay for Eggs Without the Practice of Culling Day-Old Male Layer Chicks

WTP more for eggs without CMC was seen in 41.9% of respondents vs. 45.3% who is willing to pay equal to the general costs for 10 eggs. There is a significant difference in WTP for the general costs for 10 eggs and the extra costs for 10 eggs without CMC (REST: $Z = -4.134$, $P = 0.000$). In the HEW, respondents were willing to pay more for 10 eggs without CMC ($Z = -7.368$,

$P = 0.000$). Here, 62.9% of HEW are willing to pay more for eggs without any culling, whereas 26.6% are willing to pay equal to the general costs for 10 eggs. Only 10.5% of HEW and 12.8% of the remaining respondents are not willing to pay more for eggs without any culling.

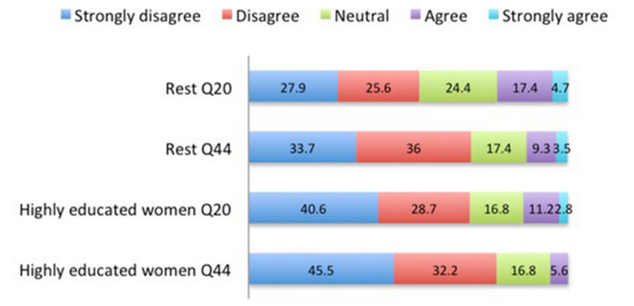

FIGURE 2 | Percentage of respondents' agreement on culling day-old male chicks at the beginning of the survey and at the end. Q20 "Day-old males may be culled"; Q44 "In this survey you received information about the poultry industry and its practices. To what extent do you agree that day cockerels are killed?" Highly educated women ($n = 143$), Rest ($n = 86$).

Willingness to Pay for Chicken Meat Without the Practice of Culling Day-Old Male Layer Chicks

In both subsets, a large group of respondents answered not applicable to the question WTP cockerel burgers (HEW: 43%; REST: 39%), see **Figure 4**. Of this N/A group, 77% had a special diet in HEW, and 52.9% in REST. WTP (and effects of income levels) was, therefore, only assessed for the remaining respondents. The WTP for two cockerel meat burgers was €3.50 in HEW (21.7%; mean: 4.07; median: 4.00) and €4.50 in REST (18.6%; mean: 3.86; median: 4.00). The set price for cockerel burgers was €2.50, indicating WTP 1 or 2 € on top of the original price. Income levels did not affect respondents' WTP for 10 eggs with or without culling for both subsets (HEW: general cost: $X_2 = 22.064$; NS, no culling: $X_2 = 17.390$, NS, and REST: general cost: $X_2 = 19.78$, NS; no culling: $X_2 = 24.097$, NS). No relationship was seen between income level and the WTP for cockerel meat in both subsets (HEW: $X_2 = 16.533$, NS; REST: $X_2 = 16.625$, NS). WTP for cockerel meat was affected by whether the product contained a label "produced without CMC" (HEW: $X^2 = 48.17$, $P = 0.03$; REST: $X^2 = 22.25$, $P < 0.05$). No relationship was found between income level and WTP for cockerel meat (HEW: $X^2 = 16.53$, NS; REST: $X^2 = 16.63$, NS).

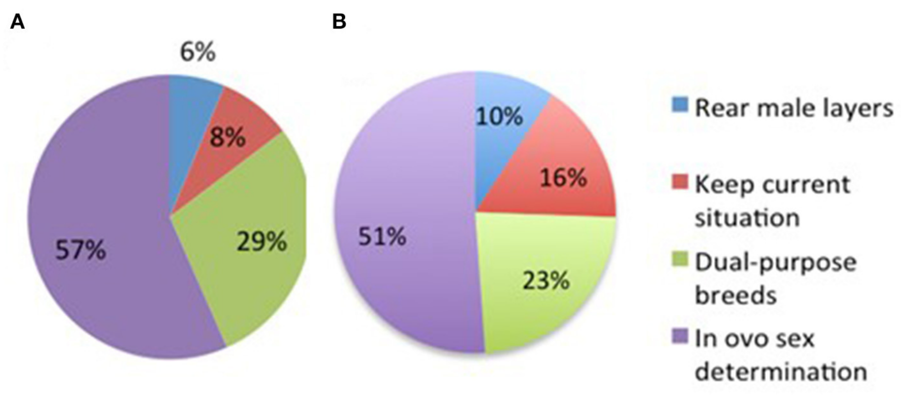

FIGURE 3 | Percentage of respondents' preference of alternative to culling day-old male chicks **(A)** Highly educated woman ($n = 143$) and **(B)** Remaining group of respondent ($n = 86$).

Table 4 | Chi-square test-statistics representing effects of income levels, education level, awareness levels and change in acceptance of culling day-old male layer chicks on alternatives for this practice.

	Rear male layers		Accept current situation		Dual-purpose breeds		In-ovo sex determination	
	HEW	REST	HEW	REST	HEW	REST	HEW	REST
Income level	$X^2 = 8.56$ $P = 0.48$	$X^2 = 12.12$ $P = 0.21$	$X^2 = 13.35$ $P = 0.147$	$X^2 = 5.02$ $P = 0.83$	$X^2 = 11.88$ $P = 0.22$	$X^2 = 12.10$ $P = 0.208$	$X^2 = 3.47$ $P = 0.94$	**$X^2 = 19.15$** **$P = 0.02$**
Education level	N.D.	$X^2 = 1.92$ $P = 0.59$	N.D.	$X^2 = 3.61$ $P = 0.31$	N.D.	$X^2 = 2.74$ $P = 0.434$	N.D.	$X^2 = 0.72$ $P = 0.87$
Awareness	$X^2 = 7.02$ $P = 0.32$	$X^2 = 5.55$ $P = 0.48$	$X^2 = 6.68$ $P = 0.34$	$X^2 = 6.92$ $P = 0.33$	$X^2 = 7.77$ $P = 0.26$	$X^2 = 10.36$ $P = 0.110$	$X^2 = 11.70$ $P = 0.07$	**$X^2 = 15.07$** **$P = 0.02$**
Change in acceptability	$X^2 = 1.45$ $P = 0.69$	$X^2 = 0.19$ $P = 0.98$	$X^2 = 4.07$ $P = 0.25$	$X^2 = 0.94$ $P = 0.82$	$X^2 = 4.19$ $P = 0.24$	$X^2 = 3.66$ $P = 0.30$	$X^2 = 2.21$ $P = 0.53$	$X^2 = 5.72$ $P = 0.13$

HEW, subset highly educated woman; REST, remaining subset; N.D., not determined only one education level in this subset. Bold represent significant factors.

Comparison to Other Surveys

When comparing our results with other surveys on CMC (**Table 6**), we note that the percentage of respondents being aware of CMC was similar to the Dutch study in 2015 (52 vs. 55%) but lower to a German study in 2016 (70%) and higher than the Dutch study in 2011 (42%) and a Swiss study (25%). Percentage of respondents not accepting CMC or indicated that there is a need for an alternative to CMC was relatively high (67.3–78.8%) compared to the previous Dutch studies in 2011 (58%) and 2015 (47%). In a recent German study with 482 respondents, a need for an alternative was chosen by 89%. No direct comparison could be made between studies regarding preferences for alternatives to CMC, as the presented alternatives slightly differed, i.e., more information on *in ovo* techniques was given (39) or the focus was on dual-purpose chicken (10, 40), and rearing male layers was not included (9, 10, 39, 40). However, *in-ovo* sex determination as an alternative to CMC was preferred in more than 50% of our respondents, which was higher than in any other study except for a study in Germany in 2018 (75%).

Table 5 | Ranking of determining factors when buying eggs or poultry meat (rated on Likert scale 1–5).

	Highly educated women ($n = 143$)	Rest ($n = 86$)
Food safety	5.86	5.84
Animal friendliness	5.62	5.48
Environment	5.18	4.87
Naturalness	4.76	4.76
Taste	4.43	4.70
Feasibility	4.17	4.48
Availability of the product	3.15	3.25
Price	2.83	2.62

Factors were not explicitly defined. Highly educated women Friedman's test: $X^2 = 273.769$, df = 7, P = 0.000; Rest Friedman's test: $X^2 = 152.024$, df = 7, P = 0.000. Post hoc analysis with Wilcoxon signed-rank tests. The higher the value, the more important respondents find this factor.

DISCUSSION

In this study, we aimed to assess the awareness of the Dutch public at this point in time on the practice of as a common practice in the egg-producing industry. We also aimed to determine which alternative to CMC was most preferable and assess WTP for eggs and cockerel burgers without CMC. However, probably due to the sampling technique (distribution *via* social media channels of the authors), our sample distribution was biased toward a select subset of Dutch society.

Data

The data cannot be seen as representing the Dutch population. Due to this limitation, we have been careful not to overinterpret the sociodemographic aspects of our results. For both subsets, we had an underrepresentation of people with a low income and an overrepresentation of participants from the provinces of Utrecht and Gelderland, which was likely to be because we used personal connections of the authors for our survey. For the future, distribution *via* other sources is recommended [i.e., *via* egg producers (10), survey companies (9, 36), at supermarkets (40)] to obtain a more balanced view of the Dutch population and their buying habits. However, even though respondents do not represent the Dutch population, and subset REST was more diverse than subset HEW, and the result of both subsets were overall very similar. It appears that our respondents fit the targeted consumer class of "Price-insensitive In-Ovo supporters" (10, 38) as cost (WTP) was the least important factor for choice of alternatives to CMC. Our results should be a trigger to do further research on this topic in a broader range of the Dutch society to include other classes of consumers (10, 38). The setup of our study could be used in future surveys on CMC by giving insight on which factors to include, i.e., provide information on the poultry industry and including more elaborate information on the alternatives with regard to sustainability and economics.

A further explanation for the skewed respondents' background might be due to the topic of the questionnaire and the ethical issues it raises. People may feel uneasy knowing

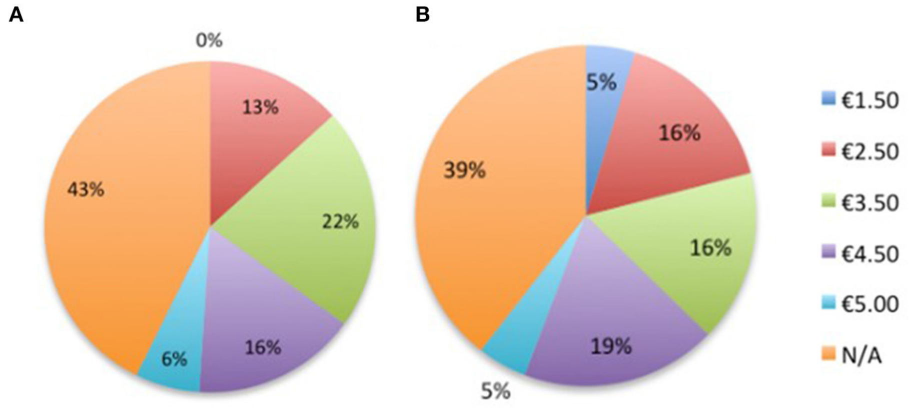

FIGURE 4 | The percentage of respondents and their willingness to pay an absolute price for cockerel meat burgers in **(A)** Highly educated woman ($n = 143$) and **(B)** Remaining group of respondent ($n = 86$).

Table 6 | Surveys on culling day-old male layer chicks.

Reference by recent publication date	Date of survey and country where survey was conducted	Type of survey	Type of respondents, sample size, incentive to participate	Percentage of respondents' being aware of the practice of culling day old male layer chicks (CMC)	Percentage of respondents' not accepting/need for an alternative to CMC	Percentage of respondents' first preference for alternatives to CMC focusing on keeping dual purpose (DP) chicken; rearing layer males and in-ovo sex determination
Current study	July-Aug 2020	Online survey 34 questions	259*, (in)directly within personal network of authors	52%	67.3–78.8%	6–10% rearing male layers 23–29% DP chicken 51–57% in-ovo sex determination
Reithmayer et al. (39)	Dec-March 2019 Germany	26 min Online survey 26 questions	482, given a small financial incentive	N.S.	89%	N.D. rearing male layers N.D. DP chicken Different in-ovo sex determination techniques: 48%
Reithmayer and MuBhoff (38)	2018 Germany	Online survey, 4 parts, DCE[d], information part, questions	400, given a financial incentive	N.D.	N.D.	27% DP chicken 0% rearing male layers 75% in-ovo sex determination
Busse et al. (10)	2016 Germany	20-min telephone interviews, 43 questions	1,000 consumers of an organic farming initiative	70%	67%	N.D. Rearing male layers 50% DP chicken N.D. in-ovo sex determination
Gremmen et al. (36)	Oct-Dec 2015 The Netherlands	Online survey[a], 10 questions, 2 blocks of informative text,	1,022[b]	55%	47%	41.3% DP chicken 41.3% rearing layer males 37.5–43.2%[c] pref. in-ovo sex
Gangnat et al. (40)	Jan-Feb 2016 Switzerland	10-min survey on DP, at 8 supermarkets, 18 questions, text, photos, ruler for WTP	402[e], small gift	25%	N.D. % but preference for in-ovo sex determination over CMC	N.D. % alternatives N.D. Rearing male layers No preference for DP over CMC Preference for in-ovo sex determination over CMC
Leenstra et al. (9)	N.S. The Netherlands	Online survey[f], film, 10 alternatives	1,199	42%	58%	24% DP chicken N.D. rearing male layers 25% in-ovo sex determination

*Dataset divided in Highly Educated Women (n = 143) and REST (n = 85). N.S., Not specified; N.D., not determined; [a]Survey made with use of a valorization panel: stakeholders (farmer representatives), consumers; retail and animal protection organizations, n = 10; [b]overrepresentation of highly educated people and 50–69 age group; [c]different types of in ovo sex determination were examined (genetic modification, invasive and non-invasive methods); [d]DCE: discrete choice experiment; choose between 2 or more alternatives, [e]Respondents were either given questions focussed on eggs or on chicken; [f]Survey made with use of 6 focus groups with 6–7 people, tested on 44 students.

that the CMC takes place for the production of eggs and prefer to remain blind to the subject [i.e., a moral lock-in; (31)]. This might explain the high number of respondents initially starting the questionnaire but not finishing it (259 out of 372).

Awareness

Our study showed comparable awareness levels (52%) as in other studies in the Netherlands in 2018 [55%; (36)] and 2011 [55%; (9)] but higher than in Switzerland [25%; (40)], see **Table 6**. Awareness and disapproval of CMC show an increase in several EU countries (36). Highest awareness levels were found in the provinces where most chicken farms are present in the Netherlands[1]. The rise in awareness from 2011 to 2018 in the Netherlands was accredited to media attention in 2013 caused by a study commissioned by The Dutch State Secretary of Agriculture on public views on alternatives for CMC (36). In France and Germany, a rise in public awareness on CMC likely caused pressure to ban CMC and seek viable alternatives.

Alternatives to Culling Male Layer Chicks

A very high percentage of our respondents agreed that an alternative to CMC is needed. Keeping the current situation was also less preferred as opposed to a study in 2018, where 28% chose keeping CMC (36). The first choice for an alternative for CMC was *in-ovo* sex determination, by 57% of the respondents, which is higher than that in other studies (9, 36). In our study, we only looked at alternatives that are available on the Dutch market and did not distinguish between types of *in-ovo* sexing techniques and at which embryonic stage the *in-ovo* technique is applied (3) as Leenstra et al. (9) did. They showed that *in-ovo* sex determination was most preferable, but only on non-incubated eggs. With this method, the sex of the embryo is determined in the fresh egg, and male eggs are excluded from incubation as opposed to determining the sex of the embryo in incubated eggs during early or late development (9). An aspect to consider in *in-ovo* sex determination that people may choose or not choose this alternative to CMC is at what age it takes place (39, 42, 43). Studies on neural development of chick embryos (44, 45) indicate that afferent nerves develop around day 4 of incubation and that the synaptic connection *via* the spinal cord is not present before day 7 of incubation, which make nociception impossible prior to this stage. At what age *in-ovo* sex determination is performed should be included (and explained in the survey), as it does influence respondents' attitude to *in-ovo* sexing (38). In another study in Dutch citizens, *in-ovo* sex determination was only accepted by 11% of respondents (36). In Switzerland, no difference was found between *in-ovo* sexing and keeping dual-purpose chicken as an alternative to CMC (40). An informed decision for an alternative requires knowledge of the pros and cons of the alternative and the current practice (9). Underlying social norms and values may overrule the initial choice (10) for an alternative. At the same time, when more information is provided about the alternatives, the decision for one or the other may not be so easy (9). Zoll et al. (11) developed a decision support tool for the case of a dual-purpose alternative to CMC in Germany, which could be used when targeting the Dutch society. Based on our outcome and the results of surveys in the past in the Netherlands and other EU countries, it appears that the majority of participants in these studies respond to the knowledge on CMC by disagreement and are strongly in favor of an alternative to CMC.

[1]https://www.cbs.nl/

Welfare Cockerels

Based on our results, the respondents indicated that at this point in time, *in ovo* sex determination is more likely to be chosen as an alternative to CMC over rearing male layers and keeping dual-purpose chickens. It should be noted that aspects of sustainability and economics were absent specifically from our study, and that the choice of alternative should be under the highest level of welfare. Studies on keeping layer males (15) or dual-purpose chicken (13, 46, 47) are relatively scarce and require more investigation as to whether and how these cockerels can be kept under high as there might be issues with aggression (48).

Economic incentives are needed to pursue this avenue also with respect to sustainability issues since it takes longer to raise cockerels, which require more food and other costs, as opposed to broiler chicken. In Thailand, layer males are kept for 60 days to achieve a body weight of 0.8–1.2 kg (49). In a growing world population where broiler chicken meat production is more sustainable than other sources of animal protein, it makes the choice for other—less profitable (50, 51)—chicken meat difficult. Additionally, the meat of layer cockerels has a different texture and taste from those of broiler meat (52). In Asia and Africa, however, meat of cockerels of layers and native chicken is very popular (53, 54).

Willingness to Pay

Respondents were willing to pay [willingness to pay (WTP)] more for eggs without CMC involved even above the current price for existing CMC-free eggs [Kipster® (www.kipster.nl: keeping male layers for meat products); Respeggt (www.respeggt.com: *in-ovo* sex determination and exclusion of male embryos for further development)]. Price per egg on the Dutch market varies by type of farming system the hens are kept as well as the type of hen (i.e., brown or white). The price of eggs fluctuates due to seasonal changes, demand and supply, and legal restrictions (i.e., keeping hens indoors during bird flu). At present, the price per egg (approximation over different Dutch supermarkets; 2021) from white barn layers is €0.16, from brown barn layers is €0.20, free-range white or brown layers is €0.29 and for organic layers is €0.45. Currently, Dutch Kipster eggs are sold (at a specific supermarket) for €0.25 per egg and German Respeggt eggs are being sold for €0.39 per egg. Most of the respondents who consumed eggs were WTP at least or more than €0.35 per egg without CMC. This is consistent with earlier studies, showing that 50–60% of respondents were WTP 5–10 cents more per egg (9). Although our respondents were less inclined to buy processed poultry meat products, they are WTP at least €3.50 for two processed cockerel burgers, 1€ more than the current price of cockerel burgers in the Netherlands. However, it should be mentioned that a large percentage of our respondents (HEW: 28.7%; REST:

36.0%) had a relatively high income (>€50.000, income levels were similar to those by Dutch statistical database; statline.nl), which may have skewed this result. Furthermore, no relationship was found between the importance of price and income level. This also supports the aforementioned idea that our respondents who buy meat and eggs fit within the "Price-insensitive In Ovo supporters"—a specific class of consumers, and the results should be viewed as biased toward this type of consumers (38). We did not ask how often meat or eggs are bought as done by Gangnat et al. (40) and Busse et al. (10), and thus, we cannot fully assess the motives of our respondents, and further research is needed to understand which factors influence choice for specific poultry products. One issue in surveys is whether the WTP given is the real WTP of consumers (55), i.e., the price people indicate to pay and the real price they are paying. Therefore, future research on this topic should include indirect measures of WTP and estimate a hypothetical bias that is higher for niche products, such as eggs without CMC and cockerel meat.

Factors for Choosing

The most important factor when buying poultry meat or eggs was food safety, similar to a study of the Dutch public in 2018 (36). Interestingly, this was not the first factor in earlier studies on the alternative for CMC under the Dutch public (9). All three studies [this study, (36), and (9)] have animal friendliness as an important factor for choice of alternative for CMC. In the study by Leenstra et al. (9), animal friendliness was the most important factor. Likely due to the provision of more in-depth understanding of the topic (i.e., by a film and focus group), respondents could make a better assessment on the factors of importance for this type of animal-based product. The image of culling day-old chicks may have also further shocked participants in that study, as it did regarding information on CMC in the survey in Switzerland (40). Naturalness was an important factor in alternatives to CMC (9) and when accepting specific foods and certain technologies involving food production (56). This aspect is consistent across countries and years, indicating that it might be one of the most important factors to include when promoting CMC-free food products. We did not explain or define naturalness and whether this factor is excluding or including aspects such as animal welfare and the environment. In future surveys, the definition of naturalness should be provided either by the respondents (i.e., in a preliminary questionnaire) or given by the survey makers.

Informed Choice and Labels

Our results showed that providing respondents with information on the poultry industry decreased the level of accepting CMC, i.e., more disagreement after the questionnaire than before. This was comparable to Swiss consumers, who were more WTP when they knew more about the poultry industry (40), which is stipulated as important to make an informed choice in this matter (9). In our study, labels were preferred so as to make a choice for CMC-free products easier. These results were also found in other studies where labels were recommended (40). Pictures may provide shocking images but could also be helpful in communicating the essential ethical elements of CMC (57) and the process of *in-ovo* sex determination techniques in detail to establish a higher WTP (58).

CONCLUSION

This study aimed to assess awareness and acceptability of the practice of CMC of consumers in the Netherlands. Our results should be viewed as a pilot where we examined the opinion of a selective population of respondents toward CMC and its alternatives. Interestingly, providing information on the poultry industry during the course of the survey influenced acceptability (i.e. not accepting) of CMC. More detailed information on the alternatives with regard to economic, sustainability, and ethical factors is needed for respondents to assess their preference for alternatives and poultry products with or without CMC. A follow-up study on this topic with data from a more diverse population in the Dutch industry could be further improved/targeted using our results to help assess this complex issue within the egg industry.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

EdH idea and writing manuscript. EO conducted the research. MvG design survey. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2021.662197/full#supplementary-material

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Perspectives for Buck Kids in Dairy Goat Farming

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To start milk production, dairy goats need to give birth at least once. While most female kids are reared to become the next generation of dairy goats, only a small proportion of male kids (buck kids) are reared with reproduction aims. The market for buck kid meat, especially within Northern European countries, is currently relatively small compared to the number of bucks born. Therefore, the purposes for buck kids are limited and a substantial proportion of buck kid meat is used for pet food. Due to the limited economic value of buck kids, farmers are faced with a dilemma. Although raising bucks costs more money than it yields, the birth of kids is a prerequisite for production of milk and should be seen as an investment for business-wise healthy dairy goat farming. In that perspective, dairy goat farmers have an ethical responsibility toward buck kids, as well. In this paper, we compare various scenarios of dealing with the issue of surplus male animals. We provide recommendations for the rearing of buck kids based on the sector's experience and current practice in the Netherlands. Reducing the number of surplus (male) offspring, e.g., by an optimized prolonged lactation management and/or by artificial insemination with sex-sorted semen, could alleviate the issue of low value buck kids. Killing surplus animals before or directly after birth, on the other hand, is met with increasing societal scrutiny. Initiatives to propagate a market for buck kid meat for human consumption are important to enable a suitable and sustainable production system. To maintain the health and welfare of goat kids, amongst other factors, sufficient and good quality colostrum, milk, and an appropriate diet as they grow older, needs to be provided. One option to assure the safeguarding of health and welfare of all goat kids are quality assurance schemes for milk production. These schemes make dairy farmers accountable for the health and welfare of all kids in the rearing period, including the provision of colostrum and adequate care for newborn buck kids. We conclude that the combination of reducing the number of surplus kids, increasing the demand for goat products, and quality assurance schemes that may help to safeguard the welfare of buck kids.

Keywords: buck kids, dairy goats, farm animal welfare, surplus offspring, farm animal ethics

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INTRODUCTION

The dairy goat industry is an important sector in the Netherlands, which has grown substantially in the last decades. In 2010, ∼98,000 female dairy goats were kept for milk production while this number rose to ∼476,000 in 2020 (1). The majority of these goats are specialized breeds selected for milk production, mainly from the Saanen breed. To produce milk, a female goat needs to give birth at least once. The female offspring are mostly used as replacement for the dairy herd, thus replacing older and poorer performing goats. Most of the remaining female kids can be sold to other dairy farms within the Netherlands. The remaining surplus female kids are usually exported. In contrast, much fewer male kids (buck kids) are raised to serve reproduction, resulting in a surplus number of male offspring. Similar to other agricultural sectors specialized on female derived products (dairy, eggs), practical and ethical issues arise as there are only limited purposes for surplus male offspring (2–6).

Apart from the ethical concerns about the production of surplus male animals, potential welfare concerns rise, especially since the bucks have a limited economic value. Housing, health care, and slaughter cost a significant amount of money, and that investment is not returned in the revenue gained from the product yield from that individual animal. Therefore, buck kids may be at a higher risk for impaired welfare. Notably, these costs should be counted as total dairy goat farming management costs, and not per animal. Though limited scientific data exists for goats, the risks may be similar to those identified in male dairy calves (3, 4, 7). The British Veterinary Association and the Federation of Veterinarians of Europe have published recommendations and position papers regarding the production of surplus male animals, provide a framework for future research and practical solutions (2, 3).

Male offspring, e.g., male dairy calves, may be raised for slaughter (6). The market for goat meat in The Netherlands, however, is small (8), similar to that in other Northern and Western European countries. In Southern European countries, the market is relatively larger with a seasonal peak in goat meat consumption especially around Christmas and Easter (9). As the transport duration of young dairy goats to these countries is long and produces a risk of transmitting infectious diseases amongst the individuals, exporting these young dairy goats is undesirable (10–13). Therefore, virtually all surplus male goats stay in the Netherlands to be fattened for meat production, either for pet food or for human consumption. Most surplus buck kids nowadays are fattened on the farm they are born on. Specialized fattening facilities were commonplace within the Netherlands. However, currently the number of fattening facilities is rapidly declining, due to limited market opportunities and legal requirements (14). Currently, there are <5 fattening facilities remaining in the Netherlands (R van den Brom, 2021, personal communication), although they are still more common in other countries, such as Portugal, France and Italy (15).

Buck kids originating from breeds selected on milk yield and not on meat production, usually do not gain sufficient weight to be slaughtered for human consumption. As most buck kids are not used for breeding purposes, the rearing costs may exceed the benefits. Aside from structural and organizational costs (e.g., husbandry, marking and housing of the animals, health checks by veterinarians), the animals need sufficient nutrients to grow in the weeks before slaughter. When the costs of milk replacer were high, fattening facilities even charged the dairy farmer money to come and collect the kids (9). For many years, Dutch dairy goat farmers have been paying to get the buck kids to a fattening facility. A more recent trend is that buck kids are sold at a very young age for slaughter (for pet food) or are fattened on the farm of birth. Fattening the kids on the dairy goat farm where they are born circumvents the problem of transport and mixing animals from different farms, but may pose additional organizational and legal challenges to the farmer. Dairy goat farms may not have space to keep the bucks for fattening. Expanding the farm is not always possible, especially in densely populated countries such as the Netherlands, where local regulations may prohibit the expansion of existing farms. Housing conditions for kids raised on-farm may therefore be suboptimal, potentially resulting in reduced welfare. If the kidding season is stretched out over a longer period, kids from different ages may be housed together or in close proximity. This also increases the risk for transmission of infectious diseases.

In the case the buck kids are moved to a fattening facility, kids from a large number of farms are mixed into new groups and animals of different ages may be placed together. The mixing of kids from different farms and of animals of different ages increases the risk of social stress and the risk of transmission of infectious diseases. To provide buck kids a healthy start in early life, providing sufficient and good quality colostrum for passive immunity, umbilical disinfection immediately after birth, and proper hygiene should be practiced. Since the buck kids are not a significant source of income for the dairy goat farmer, and in many cases cost money, there may not always be sufficient attention for appropriate care, resulting in animals vulnerable to infection (16). Also, when there is a distinct kidding season during which workload is particularly high for farmers, there may not be enough time available to provide sufficient care for high-risk goat kids (VC Goerlich, 2021, personal communication).

The age at which the bucks are slaughtered can be divided into three groups. According to EU legislation, transportation from the farm to the slaughterhouse of goat kids of which the navel is not completely healed is prohibited. Additionally, kids under 7 days old must not be transported for more than one hundred kilometers (17). In practice, the youngest age at which kids are transported from the farm to the slaughterhouse therefore is between 7 and 14 days. According to the definition for the purpose of the carcasses of these animals, almost all of their meat is used for pet food, whereas no reliable statistics are available for the Netherlands. Kids that are raised for the Southern European market are fattened to a weight of around ten kilograms, which usually takes 3–4 weeks. After slaughter, the carcasses are exported. Finally, farmers may extend the fattening periods for 10 weeks to 5 months to produce "rosé meat" (similar to rosé veal meat from young calves which are not feed restricted to produce "white" veal). This meat is usually sold through short local chains such as artisan markets and is a niche product with an estimated 10% of the total goat meat market. The proportion of kids slaughtered at 7–14 days or 3–4 weeks is variable but roughly estimated equal around 45% (R van den Brom, 2021, personal communication). All in all, the major part of goat kids, including male kids, are either slaughtered at a very young age and used for pet food or slaughtered after ∼1 month for human consumption.

There are approaches to alleviate the issues of surplus or low value male animals in general, and buck kids in particular. These approaches fall into three categories: (1) reducing the number of unwanted male offspring, (2) increasing the value of male offspring, and (3) safe-guarding the welfare of male offspring.

In this paper, the legal, ethical, animal welfare and practical implications of these approaches will be reviewed and discussed, with the current situation in the Netherlands as the starting point. The experiences with approaches to alleviate the problem of surplus goat bucks may be applied to other countries facing the same challenge.

EVALUATION FRAMEWORK

Legislation

All possible approaches to the problem must adhere to relevant legislation. EU law contains standards on welfare, husbandry, transport and killing of goats. These standards are described in EU Regulations and EU Directives. Regulations are binding legislative acts which are implemented in all member states. Directives describe goals which should be met by the individual EU members by implementing them in national law. Additional national legislation may apply in the different member states.

Minimum standards for the protection of animals kept for the production of food, wool, skin, fur or other farming purposes are laid down in Council Directive 98/58/EC (18). It states that owners or keepers of animals should ensure that their animals do not suffer any unnecessary pain or injury and that their species-specific physiological and behavioral needs are met. In light of possible methods to decrease the number of unwanted male offspring using assisted reproductive technologies such as artificial insemination, Paragraph 20 of the Annex in particular is relevant. It states that:

> "*Natural or artificial breeding or breeding procedures which cause or are likely to cause suffering or injury to any of the animals concerned must not be practiced.*"

Council regulation No. 1099/2009 (19) establishes minimum rules for the protection of animals at the time of slaughter or killing. Chapter 2 Paragraph 3 states in general terms that:

> "*Animals shall be spared any avoidable pain, distress or suffering during their killing and related operations. The methods referred to in Annex I which do not result in instantaneous death (hereinafter referred to as simple stunning) shall be followed as quickly as possible by a procedure ensuring death such as bleeding, pithing, electrocution or prolonged exposure to anoxia.*"

For the purpose of this article, Chapter 2 Article 4 point 1 in particular is relevant when considering acceptable methods for the killing of surplus animals. It states that:

> "*Animals shall only be killed after stunning in accordance with the methods and specific requirements related to the application of those methods set out in Annex I. The loss of consciousness and sensibility shall be maintained until the death of the animal.*"

Additionally, according to Article 7 point 1:

> "*Killing and related operations shall only be carried out by persons with the appropriate level of competence to do so without causing the animals any avoidable pain, distress or suffering.*"

Another factor that may influence the management of goat kids, is the legislation around the application of electronic ear tags described in Council Regulation No. 21/2004, Article 4 point 1 (20):

> *"All animals on a holding born after 9 July 2005 shall be identified in accordance with paragraph 2 within a period to be determined by the Member State as from the birth of the animal and in any case before the animal leaves the holding on which it was born. That period shall not be longer than six months."*

Ethical Aspects

When applying moral standards to animal welfare issues, there are various ethical perspectives. The most common are the utilitarian perspective, the animal rights perspective, and the view with an emphasis on "ethics of care" (21, 22). The utilitarian perspective attempts to weigh the interest of all parties involved. In the case of surplus male goats, the interests of the farmer (such as time, money and effort involved) are weighed against the welfare needs of the buck kid. Seen from the animal rights perspective, animals have an intrinsic value of their own. If the concept of the intrinsic value is applied rigorously, it would be morally unacceptable to rear and kill animals for human consumption, and even more so producing "wastage." From the ethics of care perspective, keeping animals, including keeping them for food production purposes, creates a relationship between these animals and the human keeper. From this relationship results a greater moral responsibility toward the animals in human care (22). It can thus be regarded as part of the human moral responsibility in general, and of producers of animal products in particular, to improve sustainability and reduce wastage of resources in animal production systems, as well as ensuring the welfare of the animals involved. In conventional animal production, the utilitarian perspective seems to be dominant. However, in recent years societal debate in Europe around animal production is increasing and the number of people adhering to the ethics of care or animal rights perspective seems to be increasing (23). In the future, the view on how animals should be treated may therefore be based on these perspectives.

Animal Welfare

The aim of the welfare legislation is to ensure a minimum level of animal welfare. However, adherence to these rules does not necessarily mean optimal welfare is achieved. When judging the welfare implications of possible approaches to deal with surplus male goats, the first step is to clarify how welfare is approached. The Brambell committee (24) formulated the "five freedoms" as requirements for good welfare. Over the years, this definition has been modified by several researchers to provide space for adaptive capacity of animals and to place more emphasis on the animal experiencing positive emotions. For the purpose of this article, we use the concept proposed by Ohl and Van Der Staay (25):

> *An individual is likely in a positive welfare state when it is able to adapt to the demands of the (prevailing) environmental circumstances, enabling it to reach a state that it perceives as positive.*

Buck kids may not be provided with the necessities to achieve a positive welfare state. Early weaning, insufficient intake of colostrum and nutrition, transport, and an unstable social environment pose threats to their ability to adapt to the challenges. Finally, methods of killing surplus animals on farm and at slaughter, should be evaluated and refined so that they impose as little suffering as possible.

Practical Considerations

Apart from the legal, ethical, and welfare considerations outlined above, possible approaches to deal with surplus buck kids should also take practical considerations such as economics and sustainability into account.

Economic issues are, for example, that solutions that require a considerable time-investment from the farmer may require the recruitment of extra staff. Adapting housing to fatten bucks on farm can also require a considerable financial investment. For farmers, it is important that they are still able to obtain sufficient income. Some approaches may lower the margins on goat milk. Nevertheless, when producing goat milk, offspring is an unavoidable result of this production. The total management of a dairy goat farm consists of benefits (mainly milk, and sometimes some goats for trading purposes) and costs (housing, food, etc.). Buck kids can be seen as costs but are actually an investment to be able to produce milk. Therefore, farmers should be prepared to deal with the costs of raising these kids in a welfare-friendly and ethically acceptable way, just like they do with other production-associated costs.

"Sustainability" is a broad concept which can be defined as "acceptable now and in the future, related to consequences of functioning, morality of action and resource availability" (26). Producing animal products such as milk and meat put a strain on the environment. The ecological burden should be considered when judging potential approaches to deal with surplus male goats. The sustainability of raising buck kids for their meat needs to be checked on several attributes such as feed conversion efficiency and the use of resources such as water and land (27). High-quality feedstuffs (concentrates and roughage) and water are needed to sustain high-producing dairy goats, and to promote fast growth in meat-producing animals. If live animals or meat products are exported, the transport could increase the pressure on the environment (e.g., CO_2 emissions or spread of infectious disease). Types of animal production systems where the majority of the products are exported to other countries are currently under debate in the Netherlands. This debate raises the valid question whether the Netherlands should, instead, focus its production on high-quality animal products, with high welfare standards, produced for the national or regional market. As goat meat is hardly consumed in the Netherlands, this type of production would not fit with that focus, unless the sector initiates actions to stimulate goat meat consumption in the Netherlands.

PRACTICAL SOLUTIONS TO THE MALE SURPLUS DILEMMA IN THE DAIRY GOAT INDUSTRY

Decreasing the Number of Male Offspring

Sexed Semen

Nowadays, it is possible to sort semen based on DNA content in many species (28–30). In goats, there is a substantial difference in DNA content between X and Y chromosomes in buck spermatozoa, allowing for a clear sorting of these two populations with an accuracy of around 90% (31). The challenge of producing kids with artificial insemination is 2-fold: the preservation of the sex sorted semen and the successful insemination of the female. Although kids have been produced using sex-sorted, cryopreserved semen, fertilization rates were low, even though the sexed semen was delivered by laparoscopic intrauterine artificial insemination. Out of eight female goats that were inseminated with X-enriched semen, only one kidded, while 4 out of 5 kidded with Y-enriched semen (32). While laparoscopic insemination may be improved heighten insemination success (33), the technique is prohibited in the Netherlands (34, 35). Generally, when laparoscopic insemination is used, the welfare of the receiving goat may be impaired due to stress and pain from the procedure.

The use of sexed semen always requires artificial insemination which, although sometimes used in some countries, is not being used on a large scale in dairy goat reproduction. Artificial insemination (regardless of whether sexed semen is used) offers some advantages, most importantly the possibility to introduce new genetic material onto a farm while maintaining a high level of biosecurity (36). On farms that use artificial insemination on their goats, synchronization and induction of estrus are performed before inseminating the goats. Synchronization of females, however, requires additional techniques such as hormone therapy, which is considered undesirable by many consumers as it is considered unnatural (37, 38). Also, the production of the hormone 'pregnant mare serum gonadotrophin (PMSG)', which is used in most synchronization protocols for goats, involves sampling of live mares and is associated with substantial welfare issues for the horses involved (39).

From a practical point of view, sexing semen is, at the moment, still a costly and time-consuming practice. Sex sorting semen requires expensive flow-cytometers, while the processing speed greatly influences the accuracy of sorting. Moreover, conception rates with using sex-sorted semen are low which may necessitate multiple attempts before pregnancy is achieved (40). However, the financial consequences of using sexed semen may be partly offset by the reduction in costs for raising bucks, if technical results can be improved.

In conclusion, although the use of sexed semen is technically possible in goats and may reduce the number of surplus male offspring, similar as in dairy cattle (41). As artificial insemination with sexed semen will likely result in poor pregnancy rates, as sexed semen is only available in frozen form. The low conception rates and high costs preclude the routine use of this technique at this time, though methods may be improved (42). The use of hormones, however, associated with insemination with sexed semen could be problematic from a consumer point of view. Welfare issues for the mother goat may arise with laparoscopic insemination, which is not allowed in the Netherlands.

Genome Editing Techniques

In the future, genome editing techniques, in particular CRISPR/Cas9 systems, could provide additional methods to manipulate the sex of offspring. In pigs, knockout of the SRY gene using this technique has resulted in phenotypically female boars, although functionally these animals did not show heat (43). The authors suggested that targeting multiple genes on the Y chromosome during spermatogenesis to prevent the development of Y-chromosomal sperm could result in boars that only produce genetically and phenotypically female offspring. In goats, the CRISPR/Cas technique has successfully been used for genetic engineering (44), although not with the aim of producing only female offspring. Apart from the present technical challenges of using genome editing techniques (45), societal acceptance of these techniques may also pose a problem (46, 47).

Prolonged Lactation

In prolonged lactation [definition: lactation > 1 year without kidding, also referred to as extended lactation (48)], goats are not bred every year, and are sometimes bred only once during a lifetime. As a result of this, lactation continues for multiple years, leading to fewer offspring being born. As goats may give birth to one up to five kids at once, the reduction of the number of offspring depends on the duration of prolonged lactation.

Lactation curves within a prolonged lactation in goats are highly persistent, and goats may continue to be milked for 2–4 years (49) and even longer (R van den Brom, 2021, personal communication). When comparing milk yield of goats with an extended kidding interval of 24 months to goats with a 12-month kidding interval, the latter produced less milk from the 10th week of pregnancy (39th week of lactation) onwards, whereas extended lactation did not result in a decreased milk production (50). In the same study, milk composition was also analyzed. In late pregnancy (from week 12 onwards), the percentages of fat and protein were higher than in non-pregnant animals, while in the first 29 weeks of the second lactation they were lower than in the animals with prolonged lactation (50). The results of these studies thus suggest that prolonged lactation does not negatively affect milk yield.

Most health problems in older (multiparous) goats occur around kidding (51, 52). Pregnancy, parturition and the start of lactation are periods with a higher risk for health problems such as acetonaemia (twin lamb disease), hypocalcemia, endometritis, and mastitis. Multiparous, high-producing goats are particularly vulnerable to metabolic disease during the transitional periods around parturition (51, 52). The possibility of prolonged lactation in goats results in a limitation of the number of pregnancies during an animal's lifetime and may therefore improve health and welfare of the goat, alongside a reduced number of offspring produced.

On some farms, forced cessation of milk production ("drying off") before the next parturition is a routine management practice. Although, often omitting the dry-off period is also practiced, but negatively influences colostrum quality (53), which in turn may negatively affect kid health. Although research on the effects of drying off on goat welfare is scarce, work on other ruminant species suggests that drying off may negatively impact welfare. Abrupt cessation of milking may result in pain (54) and a higher risk for intramammary infections (55). When feed is reduced to decrease milk production, hunger may cause additional welfare impairment. Therefore, reducing the number of times a goat has to be dried off may further benefit her welfare.

Prolonged lactation is mentioned as possibly associated with pseudopregnancy (48). With pseudopregnancy, aseptic fluid accumulates in the uterus (hydrometra) in the presence of a persistent corpus luteum. Pseudopregnancy results in anestrus and affected animals may show considerable abdominal distension, making it difficult to distinguish from true pregnancy. Pseudopregnancy can be diagnosed by abdominal sonography and treated by two administrations of prostaglandin F2α with 10 to 14 days in between (48). Although, to the best of our knowledge, it is has not been described that affected animals experience discomfort caused by pseudopregnancy, the necessity to treat animals with hormones costs money and may be perceived negatively by consumers.

In summary, prolonged lactation reduces the number of offspring and does not seem to negatively affect milk yield. It may have additional welfare benefits for the goats, since diseases associated with the transitional period are less frequent and potential discomfort from drying off, if applicable, is reduced. A potential trade-off may be that limited pregnancies may impair selection for breeding for animals with a highly persistent milk production, since there is less offspring from these animals. More research is needed on the (long-term) effects of extended lactation period concerning the health of the female and overall milk yield. Studies need to investigate whether this approach is a sustainable alternative to the current shorter lactation periods, considering its potential to substantially decrease the number of surplus offspring (56).

Humane Killing

Given the organizational effort to keep buck kids until transport to a fattening facility (with minimal revenue), humanely killing the kids shortly after birth may seem as an option. In the case this socially unwanted option is chosen, appropriate killing methods must ensure either immediate unconsciousness and loss of sensibility, or a pain and distress-free non-aversive induction of unconsciousness and insensibility. Furthermore, the duration of unconsciousness should be significantly longer than the total time required to ensure death of the animal (57). Apart from requirements that minimize suffering for the animals that are killed, additional requirements such as operator safety, economic viability and esthetical acceptability may be considered.

There are several methods available for the humane killing of goat kids on-farm (57, 58). Barbiturate overdose is generally viewed as a humane, safe and esthetically acceptable euthanasia method, but it requires a veterinarian to administer it. This makes it an economically less viable option for farmers. Additionally, the carcass has to be discarded at a fee to the rendering plant (59) and cannot be used for pet food.

Carbon dioxide depresses the reactivity of both respiratory and non-respiratory neurons, producing anesthesia and analgesia, and in higher concentrations it also causes hypoxia, leading to death (60, 61). Carbon dioxide challenge is used to provoke panic attacks in human research settings and may produce anxiety and pain before inducing anesthesia (62, 63). However, in goat kids undergoing reversible carbon dioxide anesthesia in concentrations up to 30%, it did not cause spontaneous aversion or conditioned place aversion (64). It may therefore be a suitable method to stun kids. Nevertheless, the limited data available and the need for specialized equipment preclude use on farm at this time.

Non-penetrating captive bolt devices cause concussion and cerebral damage that stuns, and depending on the extent of trauma, kills the animal. A study using a non-penetrating captive bolt device produced stunning in all of 200 neonatal goat kids included in the study, and after adjusting the positioning of the device after 42 stuns, all remaining 158 animals were both stunned and killed with one shot. These results indicate that non-penetrating captive bolt devices may be a suitable method for humane killing in neonatal goat kids, but that proper training and education of the operator is paramount when applying this technique (58). From the farmers point of view, there are some costs associated with the purchase of the device and the (blank) cartridges powering the device. Additionally, post-stun convulsions, although associated with the onset of an isoelectric EEG, may be esthetically unpleasant.

Regardless of a suitable humane killing method, there may still be ethical concerns regarding killing of unwanted goat kids *per se*. Even when the process of killing itself does not cause welfare issues, it may be argued that killing an animal prevents it from experiencing future welfare states (65). These welfare states may be either positive or negative. In the case of unwanted goat kids, one may argue that killing them humanely prevents them from experiencing future negative welfare. However, from an ethics of care point of view, the owner has a moral obligation to provide proper care for the animals and to prevent the occurrence of negative welfare states as much as possible. It can also be argued that animals have an intrinsic value that is violated by merely treating them as disposable by-products.

Consumer attitudes seem to be shifting in favor of production systems that do not kill surplus male animals, also in other farm animal species. As an example, in laying hen production, the male chicks were killed routinely after hatching using CO_2 or maceration. This practice is subject to public concerns. Society prefers alternatives where the males are reared for slaughter (dual-purpose birds) or where eggs containing a male embryo are not incubated (47–49). Recently, Germany has decided to ban the killing of day-old male chicks from 2022 onwards (66) and other countries may follow. It may therefore also be of economic interest to look for alternatives for humane killing of unwanted animals.

Increasing Value of Male Offspring

Increasing Demand for Goat Meat

Traditionally, goat meat is not in high demand in Northern Europe, even though it has several positive qualities. Compared to other red meats such as beef and lamb, it has a lower overall fat, saturated fat and cholesterol content, but more polyunsaturated fatty acids (67–70), making it a healthier option overall. Consumers unfamiliar with goat meat however are often unwilling to try it, because they expect it to be strong-flavored and inconvenient (71). As a consequence, goat meat represents only a small proportion of circa 1.5% of the yearly per capita meat consumption in the Netherlands (8).

There may be several ways to stimulate the consumption of goat meat in northern Europe. When asked about marketing strategies to increase consumption, consumers stated that they would like to see more information on the packaging label regarding health benefits, origin of the meat, production practices and traceability (71, 72). Also, the production of cured sausages based on male goat meat may be a good option, although this requires extra labor and may be too costly.

Increasing the availability and visibility of the product could help in the acceptance of goat meat (71, 72). In recent years, there has been promotion for meat from male "surplus" animals. By telling the story of these animals and by presenting attractive dishes based on products from male animals, more consumers may start to buy meat from male animals. From the laying hen sector, the Dutch Kipster system may inspire goat farmers in countries where buck kids have limited purpose. In this system, the male brothers of the laying hens are grown to 17 weeks of age and used for chicken burgers that are sold under a special label in the supermarket that also has exclusive rights to the Kipster eggs. Similar examples are currently developing in the Dutch goat sector. One of those examples is "Biogoatmeat" (73) in which Dutch organic farmers have united to promote the consumption of meat from surplus bucks from the organic goat milk industry through short, local chains. The meat is sold to restaurants and retailers, but also directly to consumers through a separate brand called "De Bokkenbunker". Emphasis is placed on sustainability and animal welfare considerations. Biogoatmeat is also one of the participants in "Boktober" (and its international counterpart "Goatober") (74, 75), an initiative to promote the consumption of goat meat during the month of October. Several interest groups are united within this initiative, which aims to familiarize consumers with goat meat by adding a goat dish to restaurant menus and by encouraging people to prepare goat meat at home.

Increasing Value of Goat Kids by Other Means

Traditionally, goats have not only been used to produce milk and meat, but also for their fiber and skins.

Cashmere is very fine wool with a diameter of <19 μm and is mainly used to produce high-quality clothing articles (76). In the past, some calculations have been made on the profitability of crossbreeding dairy goats with cashmere goats in an attempt to produce kids that produce cashmere fiber (77, 78), showing it to be a potentially profitable endeavor. However, the heritability of the desired low fiber diameter was negatively correlated with the heritability of the amount of cashmere wool that could be harvested from crossbred goats, complicating further selection on these traits (79). To our knowledge, no further attempts have been made to crossbreed dairy goats with cashmere goats to increase profitability of the offspring.

Leather from surplus buck kids is not being used on a large scale at the moment, although some small initiatives do exist (80).

Safeguard Welfare of Buck Offspring

Regardless of the alternatives presented in previous paragraph, the challenge of surplus dairy goat buck kids is unlikely to be completely solved over a short period of time. Therefore, initiatives to safeguard the health and welfare of the kids that are produced are necessary.

There are several action points that could improve welfare of surplus bucks within existing production systems. These include ensuring the responsibility of the dairy goat farmer for the goat kids that are produced on the farm and improving the monitoring of mortality among goat kids.

To maintain the health and welfare of goat kids, amongst other factors, such as hygiene, housing, climate, sufficient and good quality colostrum, milk, and an appropriate diet as they grow older, needs to be provided, since they are essential. Colostrum quality and quantity are vital for a proper development of the immune system. Natural colostrum (either refrigerated or frozen) provides a much stronger boost to the immune system than commercially available artificial sheep colostrum. The peak in immune responsiveness of the goat kids was within 36 h for both natural colostrum sources and only after 30 days for the commercial colostrum (and the latter was 25 times lower) (81). Also, the following transitions from colostrum to milk or milk replacer and then to milk replacer and solid feed should be made with care. These transitions may impact health and resilience and may also be impacted by environmental conditions. A survey on the health and welfare status on 30 dairy goat farms in the USA, suggested that early kid management during birth to prevent illness/disease or mortality (e.g., warm and dry areas for kid rearing) was one of the main focus areas for future research (82).

An important prerequisite to monitor the well-being of goat kids was the ability to monitor mortality through improved identification and registration of young goats. Up until November 1st 2020, it was not mandatory for goat kids to be ear-tagged until they were 6 months old in the Netherlands. This hampered the ability to monitor mortality, as dead kids were just rendered to the animal carcass destructor in bulk. Under the new Dutch legislation, kids from dairy goat farms must be identified and registered within a 7 days after birth (83). At the same time, the sex of the kid must also be registered. Monitoring mortality provides the possibility to set limits for the maximal allowable mortality. Incrementally stricter limits are set to enforce stepwise reduction of mortality of goat kids.

As described previously, a common channel for Dutch dairy farmers for surplus buck kids was to have them collected by fattening facilities, usually at a cost for the dairy farmer. This meant there was not much incentive for the farmer to dedicate time and money to provide optimal care for these kids. In 2017, the Dutch Association of Dairy Goat Farmers (NGZO), together with the Netherlands Agricultural and Horticultural Association (LTO Nederland) created a plan of action to improve buck kid welfare (7). One of the starting points for this plan was the notion that the production of milk inevitably results in the production of offspring, and that the welfare of these animals is the responsibility of the dairy farmer up to the age of 21 days, regardless of whether the kids are fattened on farm or at a specialized fattening facility. Failure to ensure the welfare of the kids could ultimately result in withdrawal of the license to produce goat milk under the "Kwaligeit" label, the largest quality assurance scheme for goat milk in the Netherlands (84).

The number of fattening facilities in the Netherlands has declined rapidly. This may be partly due to the implementation of these stricter rules regarding the monitoring of kid welfare. There are, however, other factors that also influence the number of fattening facilities as well as the number of kids fattened on farm. An important factor in the Netherlands is legislation which prohibits the growth of goat farms. There are large local differences between municipalities on how strict this law is enforced; however, it is currently difficult both for fatteners and for dairy farmers to obtain permits to build facilities to keep dairy kids. There have been some changes in national legislation that have facilitated fattening on farm until 4 weeks of age, though restrictions on the expansion of farms continue to be an issue for farmers that want to fatten their own buck kids.

Another welfare-enhancing option, though critical for some health aspects, for both female and male kids would be to keep them in the dairy goat herd instead of moving kids to a fattening facility or separate them from their dams. Allowing goat kids access to their mothers for 24 h per day does not negatively affect somatic cell count in the milk or growth rate of the kids (85). Although the amount of marketable milk from the dams of the artificially reared group was somewhat higher, this was offset by the higher costs for labor and equipment in the artificially reared group. Notably, in intensive husbandry systems, the feasibility of keeping kids with their dams also depends on practical issues such as house design. From an animal welfare point of view, allowing goats and kids to perform their natural behavior (allowing them to adapt to the demands of the (prevailing) environment) and to develop the mother-offspring bond is favorable (86). However, weaning the kids from their mothers when their bond is already established and before the natural weaning age [which starts around 7 weeks (87)] may cause distress for both mother and kid, as indicated by e.g., increased call rates (88). An additional health risk in large groups may also be that newborn goat kids lose their mother in the group and start suckling from other females, thereby not taking up sufficient colostrum. Therefore, the benefits and risks for health and welfare of keeping goat kids in the dairy herd needs to be investigated in more depth.

DISCUSSION

The issue of surplus male animals in animal production is not limited to dairy goat farming. Similar challenges are present concerning the male offspring of dairy cows or laying hens. These challenges have their multi-faceted nature in common, as they entail ethical, animal welfare, practical, and economic aspects. Several stakeholders are involved such as farmers, dairy companies, retailers, consumers, and citizens. Therefore, holistic programs aimed at sustainable and animal welfare friendly strategies need to be developed, taking into account the various aspects of the issue and the needs of the various stakeholders. In this review we have described some fundamental issues concerning surplus buck kids, and introduced potential solutions.

To induce change, legislation plays an important role. In some countries (e.g., France and Germany), as an example, the ban of killing day-old chicks has put pressure on the sector to develop alternatives, such as sex determination of embryos and the destruction of eggs prior to birth. Nonetheless, the ethical question remains—whether it is acceptable to prevent male animals from being born or to kill them humanely shortly after birth. The dairy goat sector, as well as veterinarians, do not approve of routine humane killing of surplus male animals (2, 3, 7).

Overlooking the techniques to reduce the number of male offspring that is produced, optimization of prolonged lactation as management tool seems a very promising strategy with many positive effects and with a potential to reduce the number of offspring born by 50–75%. Other techniques, such as sex-sorting sperm, may also be a promising strategy, however, the technique is in need of further research and refinement. Although we described humane methods for killing surplus goat kids, this is the least desirable option as it poses ethical problems and is under increasing scrutiny by consumers and society, the dairy goat sector and veterinarians.

To increase demand for goat meat, marketing strategies need to be formulated to attempt to raise the attractiveness of male goats to the consumer and the profitability for the farmer. Examples of such marketing strategies come from the poultry industry and are slowly developing in the goat sector, as well. Although Southern Europe provide a market for 3–4-week-old goat kids from the Netherlands, dependence on this market leaves farmers vulnerable in case of contingencies, such as closed borders due to notifiable diseases. Therefore, the development of new, preferably local, markets is of importance to ensure the continued sale of goat meat.

The development of quality control programs that ensure appropriate care, have great potential to safeguard the welfare of buck kids. The Dutch example, where the dairy goat farmers made responsible for quality control, especially in combination with improved registration of young animals at the individual level shows great promise. Although economic aspects should be considered when deciding on suitable solutions, it is necessary that dairy farmers understand that when they want to produce milk and sufficient replacement animals, the production of surplus male offspring is unavoidable. The costs of appropriate care for these animals are just as much part of production costs as, for example, the cost of food for the adult goats. As an example, a Dutch farmer reported that in his case, the costs of fattening bucks were identical to the benefits, when growing buck kids to 8 kg (4 kg carcass yield): this results in an income of 14 Euro. The cost for 7 kg of milk replacer is also ∼14 Euro (89).

TABLE 1 | Expected effects of approaches to alleviate the problem of low value buck kids in the Dutch dairy goat sector.

	Legal	Ethical	Welfare	Practical
Decreasing the number of male offspring	0	+	0	+
Increasing the value of male offspring	0	+	+	?
Safe-guarding the welfare of male offspring	+	+	+	+

+, positive; 0, neutral; ?, unknown.

Implementation of benchmarks such as maximum mortality within quality assurance programs for milk production help instill this notion. To help farmers reach these benchmarks, training and exchange of experience between farmers, with the aim to reduce kid mortality, would be helpful.

Finding a sustainable approach calls for the involvement of several scientific disciplines. Social scientists and economics need to advise on the economic aspects, animal welfare scientists, biologists, veterinarians and ethicists need to be involved in research on management of dairy goat herds, and techniques such as artificial insemination, optimalisation of prolonged lactation management, appropriate kid raising, and humane (on farm) killing. Farmers need to be supported and informed on their options.

In this paper, we discussed three main approaches to address the issue of unwanted male offspring in dairy goats: (1) reducing the number of unwanted male offspring, (2) increasing the value of male offspring, and (3) safe-guarding the welfare of male offspring. We evaluated effects on legal, ethical, welfare and practical aspects (**Table 1**).

We conclude that all three approaches have positive effects on these aspects or that they are neutral. For legal aspects, the strongest effect is expected from safe-guarding welfare of male offspring, as this is a legal requirement. All three approaches are expected to have positive effects on ethical aspects, as a system where fewer male goat kids are produced and which focuses on increased value and product quality while paying attention for safe-guarding buck welfare is expected to be ethically more acceptable than a system where these aspects are taken into account to a lesser extent. Similarly, regarding welfare, positive effects are expected in a production system more focused on increases value and product quality and with attention for safe-guarding buck welfare. Regarding practical considerations, decreasing the number of male offspring (through an extended lactation period or the optimized use of artificial insemination) and safe-guarding buck welfare (through a quality control system) seem to be the most feasible. Approaches to increase the value and the market for buck meat in Northwestern Europe so far have had limited success, and could benefit from increased support of the retail sector.

AUTHOR CONTRIBUTIONS

TR conceived the original idea for the manuscript. EM drafted the manuscript. VG, RB, and TR revised the manuscript. RB, MG, SA, and TR provided critical remarks to improve the manuscript. All authors read and approved the final manuscript.

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