Vegan spread applications of alternative protein from torula yeast: product development and consumer perception

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Alternative protein sources are gaining attraction in food industry and consumers. Proteins obtained by single-cell organisms, such as torula yeast, are of enormous interest, as they are highly scalable, efficient, and sustainable, and the production costs are comparably low. Nevertheless, proteins obtained from yeasts are still mostly known and studied for feed applications, despite their nutritional, functional, and sensory benefits for various food applications. Testing consumer acceptance of products, especially products containing alternative proteins provides insights into, e.g., market success, consumer perception, and optimization potential. In this study, the development of two vegan spread powders, high in protein and containing torula yeast as an alternative protein source, is introduced. The result of food product development using torula yeast were "Leberwurst"-style (14.7% protein) and a "Balkan"-style (9.7% protein) spreads both meeting the criteria "at least 20% kcal from proteins of total product kcal" and thus claimable as "high-protein." The application of the alternative protein from torula yeast within the final products was studied by a consumer acceptance test ($n = 123$) within three different countries (Germany, Iceland, and Sweden). Consumers also rated their trust in food production actors, the food industry in particular, and their willingness to try new foods. Overall, both spreads received acceptance values in the range of "like slightly." It is noticeable that the consumers liked the spread "Balkan style" more than "Leberwurst"-style. The background variables revealed higher neophobic characteristics of Icelandic consumers compared with Swedish or German consumers. However, German consumers felt transparency, and communication was missing, but Icelandic consumers, in general, had more trust in the overall food value chain. This knowledge allows for the development of strategies that address cultural-specific barriers and capitalize on cultural values that promote openness to culinary innovation. The identification of cultural variations in consumer preferences emphasizes the need for customized approaches to product development and marketing. These findings could have implications for businesses and policymakers in understanding and catering to the preferences and concerns of consumers in these respective countries. Businesses might benefit from emphasizing transparency and improving communication strategies. This could involve providing clear information about the sourcing, production, and other aspects of the food value chain.

1 Introduction

By 2050, the world population is expected to reach up to 9.8 billion people accompanied by debate about carbon footprint reduction, sustainable and biodiverse food systems, and the sufficient protein supply in future (Ismail et al., 2020; Grossmann and Weiss, 2021; Jach et al., 2022; Di Lena et al., 2023). Alternative protein interest and their use in different food products are not only steadily increasing and gaining huge market share but are also one of the most discussed food science topics (Grossmann and Weiss, 2021; Banach et al., 2022; Verstringe et al., 2023).

Alternative protein attraction by the consumer can be divided into plant-based proteins, single-cell organisms, aquatic organisms, and insects (Sawicka et al., 2020). As the global population continues to grow, alternative protein sources can help address food security challenges by providing efficient and scalable sources of protein (Henchion et al., 2017; Rusu et al., 2020). The alternative protein market exceeded 50 billion USD in the year 2020 and is estimated to grow up to 155 billion USD by 2027. These numbers are a result of the growth of concerns about the environment, the increasing demand for alternative protein products, and the growing number of vegans, vegetarians, and flexitarians worldwide (Ahuja and Bayas, 2021). The people who belong to these three dietary groups helped expedite the use of alternative proteins in common food products, while also the food industry observed the benefit of the commercialization of products using such protein sources (Ismail et al., 2020). The development of alternative protein sources is ongoing, influenced by factors such as flavor, texture, cultural perceptions, and technological advancements. As consumers become more conscious of their dietary choices and their impact on the planet, the demand for diverse and sustainable protein sources is likely to continue to increase (Banach et al., 2022).

Single-cell organisms, such as yeasts in particular, are of interest, as single-cell proteins have the advantage of being highly scalable and efficient in terms of resource utilization. In addition to the low-cost biomass production with low environmental footprint (as well as the possible cultivation of side-stream products from various agro-industries), single-cell proteins show nutritional advantages, especially with regard to high protein content with a well-balanced amino acid profile, enzymes, trace minerals, and vitamins (Bekatorou et al., 2006; Jach et al., 2022).

Torula yeast (as well as most of the other yeast types) is mostly known and studied for feed applications so far, e.g., in fish diets (Olvera-Novoa et al., 2002; Leeper et al., 2022) and broilers (Lezcano and Herrera, 2013), shrimp (Mbuto, 2017). However, in the context of the growing population, the importance of food grade that produced yeasts is steadily increasing (Bekatorou et al., 2006). Jach et al. (2022) reported the useful integration of yeast biomass into food as emulsifiers, flavor enhancers, and vitamin carriers. Beyond that, Bekatorou et al. (2006) specified the use of yeast proteins as an ingredient within meat alternatives, seasonings, sauces, soups, and dips. This is of particular interest for providing products for flexitarian consumers, who prefer to reduce meat-based products in their diets

and are looking for corresponding meat alternatives that resemble appearance, flavor, texture, and price of meat products (Joseph et al., 2020). The use of alternative proteins in food products is essentially accompanied by consumer acceptance, assuring market success and thus comprising interest in consumer perception of these products (Aschemann-Witzel et al., 2020).

Consumer attraction to alternative proteins in food is multifaceted and influenced by health, sustainability, ethics, culture, taste, and price. Aspects, influencing consumer acceptance, can be divided into three main categories, namely, product-related characteristics, psychological factors, and external environments such as trust and social environment, also covering food neophobia aspects (the unwillingness to eat and the habit of avoiding novel food products; Onwezen et al., 2021; De Kock et al., 2022). Different studies revealed that consumer acceptance of products including alternative proteins depends on the expected (Michel et al., 2021) or experienced sensory properties (especially. taste) of the products (Dietrich et al., 2016; Grahl et al., 2020).

In this study, analysis of the sensory acceptance by consumers from three different countries (Germany, Iceland, and Sweden) of two developed vegan spreads (Leberwurst and "Balkan"-style) containing alternative proteins from torula yeast as an ingredient has been performed. In addition, additional information on the general acceptance of the protein concepts and consumer confidence is discussed.

2 Materials and methods

2.1 Vegan spreads

Two types of vegan spreads based on different spices were developed. The final spreads were developed to be a "ready-to-use"-powder. Thus, the end-user of the products, namely, the consumer, is required to add vegetable oil and boiling water, enabling the highest possibilities of convenience and easy and long-term storage opportunities. Torula yeast powder (ARBIOM, Paris, France) was evaluated within the NextGenProteins EU project, which had high potential for use based on its sensory characteristics (such as umami and meat-like characteristics) in food application.

The first variant of spread developed resembled a meat-like product in accordance with the German "Leberwurst" (liver sausage). Leberwurst is a type of sausage that originates from Germany, which has a distinctive smooth and spreadable texture, and is commonly consumed as a spread on bread or crackers. Leberwurst generally has a rich and savory characteristic, though it can vary in flavor depending on the specific recipe and region. Thus, the goal was to achieve a meat-like and savory flavor, accompanied by a reddish to brown color, a spreadable texture that translates to soft and smooth mouthfeel, and finally meeting requirements for "high protein" claims (according to the Regulation (EG) 1924/2006).

The second spread was designed to have a smoked/rich paprika-flavored spread, called the "Balkan"-style. The Balkan cuisine has a rich culinary tradition characterized by a variety of flavors and ingredients, with influences from Mediterranean and Eastern European flavors. "Balkan"-style generally refers to the spices and herbs commonly used in the cuisine of the Balkan Peninsula, such as sweet and hot paprika, oregano, thyme, garlic, onion, and coriander. The goal was to achieve a smoked, savory, and paprika-spiced flavor and a reddish color. The Balkan spread was designed to have similar textural and mouthfeel properties to the "Leberwurst" spread and also meet the requirements of the "high protein" claim.

The following raw materials were additionally considered: broth, texturized vegetable proteins (TVP), seasonings, herbs, vegetable/onion plant powders and flavors for flavor development, caramel powder, fruit and vegetable powders for color development, pea protein and other (protein-rich) flours, and oil for texture and mouthfeel-optimization. For the composition of the final products, it was decided that at least 50% w/w of the powder should consist of protein- and texture-defining ingredients (proteins, flours), and flavoring/coloring ingredients should account for the remainder of the recipe.

Product development was performed under "trial-and-error"-conditions, starting with texture and mouthfeel-related raw materials and adding further flavoring and coloring compositions until a near optimal product formulation was attained. Final recipes were tasted and associated with nutritional calculations based on raw material nutritional values before consumer testing.

2.2 Consumer testing

2.2.1 Recruitment and questionnaire development

The target group was selected based on a screening questionnaire. Essential criteria were age (18–45 years) and certain openness toward new and innovative foods. The selection of the target group, comprising participants up to 45 years old with a specific level of openness toward new and innovative foods, is rooted in a strategic approach to capture a dynamic and influential demographic. The decision to focus on individuals of up to the age of 45 years is driven by the recognition that this age range represents a critical segment of the population characterized by a heightened receptivity to novel food experiences. The empirical evidence suggests that younger demographics, up to this age, tend to exhibit greater openness to experimentation with novel food items. Research indicates that individuals in this age bracket are more likely to adopt and adapt to innovative food products, making them a pivotal focus for understanding consumer preferences and potential market success. In addition, the incorporation of individuals with varying levels of openness and potential food neophobia enhances the robustness of our study, offering valuable insights into both the successful commercialization of innovative food products and the identification of potential obstacles in diverse consumer clusters.

Further questions were related to the education level the size of household, and known food allergies. Only participants who fulfilled the selection criteria were invited to the test.

The questionnaire was developed and consisted of two parts. In the first part, the overall sensory acceptance of the products was measured without giving any additional information. Afterward, an open question was asked to specifically ask about product strengths and weaknesses. Second, the acceptance of the alternative proteins was asked again after providing information about the protein source used for the corresponding product. The questionnaire ended with the collection of background variables (trust in the stakeholders, trust in the food industry, food neophobia, and sociodemographic questions).

2.2.1.1 Acceptance

Acceptance of the consumers was analyzed using a 9-point hedonic scale starting from 1 = dislike very much up to 9 = like very much in constant distances, with 5 = neither like nor dislike as a neutral opinion. The results are collected per product with a comparison between the countries as a mean value. Within-country mean values were tested for significance using Student's t-test. The Kruskal–Wallis test was further used to compare the mean values between the countries.

2.2.1.2 Background variables

All background variables were presented in the distribution of the entries in %, and the distribution was tested by the means of Chi-square tests. All background variables were collected after testing.

Trust in stakeholders: The focus was on trust toward actors in the food value chain. A modified scale (Siegrist and Hartmann, 2020) was applied to measure respondents' trust in various actors (stakeholders) of the food chain. The query was carried out using selected actors on a scale from 1 = no trust at all to 5 = a high level of trust.

Trust in food industry: A scale after Mcready et al. (2020) was used for the measurement of trust in the food industry. The question construct contains 9 items, which were evaluated on a seven-point Likert scale from 1 (do not agree at all) to 7 (agree completely).

Food Neophobia: The tendency to avoid novel foods was measured by the alternative Food Neophobia Scale (FNS-A), which was recently developed by de Kock et al. (2022). Eight items were measured on a scale; answers were provided with seven-point scales ranging from 1 (do not agree at all) to 7 (agree completely).

The questionnaire was initially prepared in English and then translated into the language of each target country by the respective native-speaking authors.

The questionnaire data were collected using a computer/tablet program. In Germany, the data were collected using sensory software FIZZ (2.51) in Sweden and Iceland, and the online questionnaire from SoSciSurvey was used.

Table 1 shows the composition of the recruited target group for the spreads. A total of $n = 123$ test persons participated in the test, with 50 consumers from Germany, 48 from Sweden, and 25 from Iceland.

The distributions between the countries were very similar, but there were differences in the characteristics of gender, education level, and household status. While in Germany and Iceland, approximately 40% male and 60% female consumers participated, the ratio in Sweden was 30/70%. It is striking that, especially in Germany 60% of the participants have a secondary level of school education. This proportion is lower in the other countries, where more people with a university degree or higher participated in the test. While in Germany the majority (36%) of the participating consumers from this test live together with a partner, 36% of Icelandic participants still live at home with their parents and in Sweden almost half (48%) live alone.

TABLE 1 Composition of the target group for spreads per country.

	Germany	Sweden	Iceland
Total	$N = 50$	$N = 48$	$N = 25$
Gender	%	%	%
Male	40	29	40
Female	60	70	56
Diverse	0	1	4
Prefer not to say	0	0	0
Age	%	%	%
18–24 years	22	21	24
25–34 years	36	38	36
35–45 years	42	42	40
Education level	%	%	%
Basic education/elementary or lower	0	2	8
Secondary education (vocational qualification, high school)	60	35	28
University education (bachelor's degree)	34	25	32
University education (master's degree or higher; MA/MSc, PhD, MD)	4	25	28
Other, please specify	2	13	0
Prefer not to say	0	0	4
Household	%	%	%
I live at home with my parents	16	6	36
I live alone	22	48	8
I live alone with my child/children	0	4	12
I live with my spouse	36	19	8
I live with my spouse and child/children	18	15	28
I live with other adults (other than spouse or family members)	8	6	8
Prefer not to say	0	2	0
Basic dietary behavior	%	%	%
I regularly eat products of animal origin and non-animal origin (omnivorous)	68	71	84
I only eat meat sometimes (e.g., beef, pork, poultry, fish, seafood)	12	6	8
I avoid red meat (e.g., or pork, beef), but eat other meat products like chicken or fish	5	6	0
I do not eat meat (e.g., beef, pork or poultry), but I eat fish (I'm a pesco-vegetarian)	9	4	8
I do not eat meat (e.g., beef, pork, poultry or fish), but I eat other products of animal origin (e.g., eggs, cheese, milk) (I'm a lacto-ovo-vegetarian)	6	6	0
I do not eat any meat, eggs or dairy products (I'm a vegetarian)	1	2	0
I do not eat anything of animal origin (I'm a vegan)	0	4	0

2.2.2 Product preparation

The corresponding amount of vegan spread powder (22.2% w/v) was mixed with vegetable oil (11.1% w/v) and further homogenized after the addition of 66.7% w/v of boiling water. Both spreads are prepared 1 day in advance to cool down completely. The spreads were served by piping them on bread without a crust for consumer testing.

2.2.3 Test procedure

The consumer testing was conducted in three different countries (Germany, Iceland, and Sweden) as a central location test (CLT). Consumers neutralized their taste with water between the two samples. All consumers provided informed consent and privacy

statement before the start of the test and provided signatures of written consent. The test was conducted as a semi-monadic test, and the samples were rotated.

2.2.4 Data analysis for consumer testing

2.2.4.1 Statistical analysis

Mean values per product and country were formed for the overall acceptance. The mean values were tested for differences using a non-parametric test, as the conditions for a normal distribution were not met. The mean values between the countries were tested using the Kruskall–Wallis test. Mean values were compared by the

Kruskal–Wallis test with a level of significance of alpha = 5%, displaying the significance by either using "*" or different letters. The null hypothesis is: There are no differences in the sensory acceptance of the overall impression in the countries tested (Germany, Sweden, and Iceland). The pairwise differences between the countries were tested by the multiple pair-wise comparisons using the Steel–Dwass–Critchlow–Fligner. The statistical analyses were carried out by using IBM SPSS 29 software.

3 Results

3.1 Vegan spread powder development

The recipes of both powder–based vegan spreads were composed of the base of pea protein, torula yeast powder, and different flours which are mainly responsible for the texture of the produced spreads and to achieve the "high protein" claim. In the case of the "Leberwurst"-style, spread crushed TVP, made up of pea protein and torula yeast powder, was added to the final recipe, as certain coarseness was expected for this product.

In terms of flavoring and coloring substances, the "Leberwurst"-style spread powder consisted of vegetable broth, onion and leek powder, caramel powder, dried chives, and beetroot powder. The taste was further complemented by marjoram, pepper, and citric acid.

The internal defined characteristics collected revealed a typical reddish to brownish color, accompanied by detectable onion and leek smell, connected with meat-like properties. The umami flavor and oily notes were recognizable followed by the taste of herbs and slightly caramel. The texture was further characterized as soft and spreadable.

The prepared vegan spread "Leberwurst"-style (with the addition of oil and water) resulted in 10.8% lipids, 3.0% carbohydrates, 1.5% fibers, and 14.7% protein, calculated by the used raw material nutritional values. With regard to the Regulation (EG) 1924/2006, the prepared spread can be legally claimed as "high protein" as 34% of the total energy is produced by the protein.

Flavoring and coloring substances selected for the final "Balkan"-style spread were tomato, mustard, onion, miso and leek powder, smoke flavor, vegetable broth, and raw cane sugar complemented by muscat, cardamom, salt, and paprika spice.

The spread was characterized as follows: A reddish, paprika-like color with visible herbs together with smoked paprika and a spicy smell connected with meat-like properties. The taste was summarized as spicy and fruity associated with "Balkan"-like characteristics supported by a soft, creamy, and spreadable texture.

The" Balkan"-style spread recipe occurs with 10.3% lipids, 2.3% carbohydrates 0.4% fibers, and 9.7% proteins, based on the information about raw materials. The benefit of "high protein" claim, according to the Regulation (EG) 1924/2006, is also applicable to this spread.

For the final application, in the case of both powder-based vegan spreads, 50 g of the spread powder was blended with 25 g of vegetable oil before pouring over 150 mL of boiled water under stirring. After cooling down to room temperature, the spreads could be used on the top of the bread. This easy preparation guarantees the highest convenience for the consumer. Furthermore, high-protein characteristics, both spreads resulted in vegan, including alternative

FIGURE 1
Both vegan spreads containing torula yeast: "Balkan"-style spread without topping and "Leberwurst"-style spread with green topping.

proteins from single-cell protein (torula yeast). Figure 1 shows both vegan spreads on baguette bread.

3.2 Consumer acceptance

Figure 2 summarizes the spontaneous overall acceptance of both spreads.

The savory "Leberwurst"-style spread was equally well-received by consumers across three countries and is scored near 5 points on the scale (neither like nor dislike), which means they have a neutral opinion about the product. No significant differences are found between the mean liking values. The "Balkan"-type spread is rated significantly better in Germany and Sweden, with a mean score of 6.4, compared with Icelandic results with a score of 5.1. In detail, over 70% of responses from Sweden and Germany chose at least "like slightly," Icelandic results being slightly lower with nearly 40% in this range of likeliness. With regard to the "Leberwurst"-type spread, the countries differ: Icelandic participants show a higher acceptance within this type of spread compared with the "Balkan"-type and approximately 55% respond with "like slightly" or even higher. German (55%) and Swedish (45%) results are thus comparable to Icelandic responses but are rated generally lower compared with the "Balkan"-style spread.
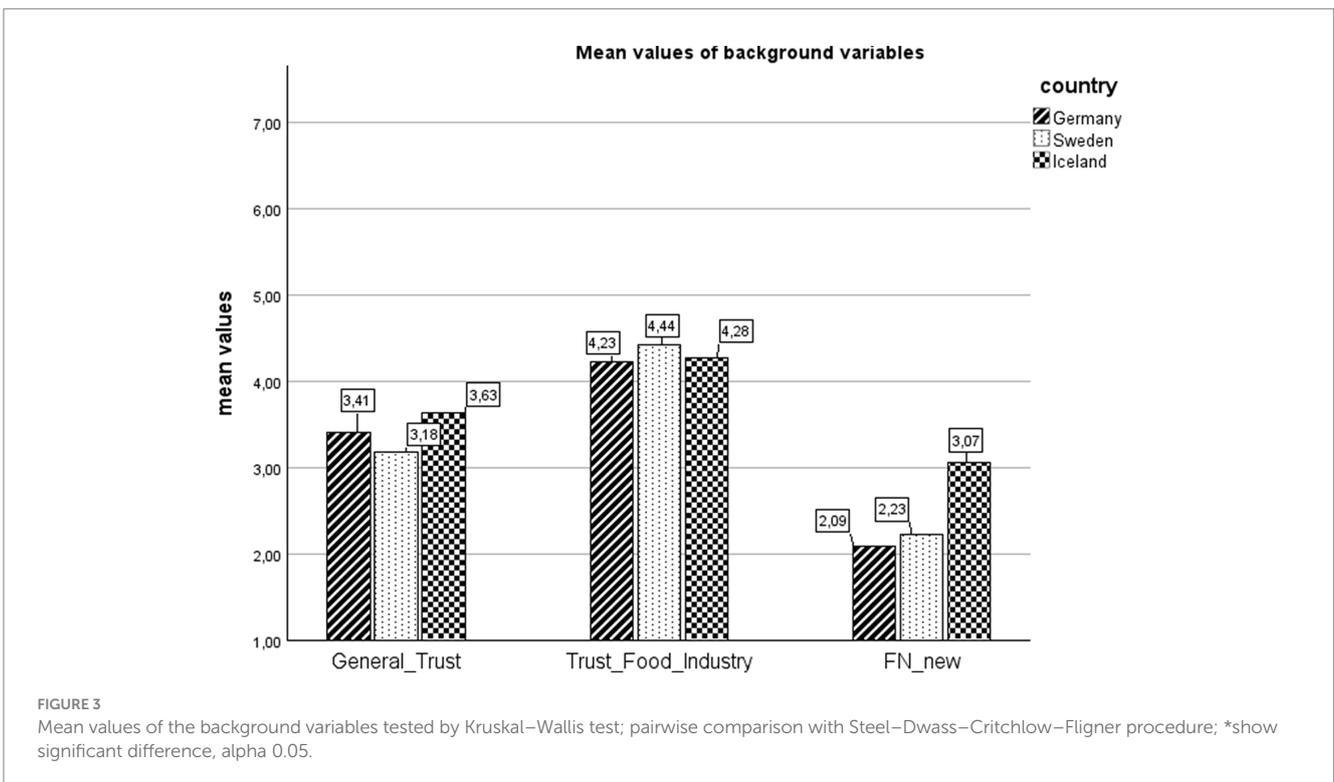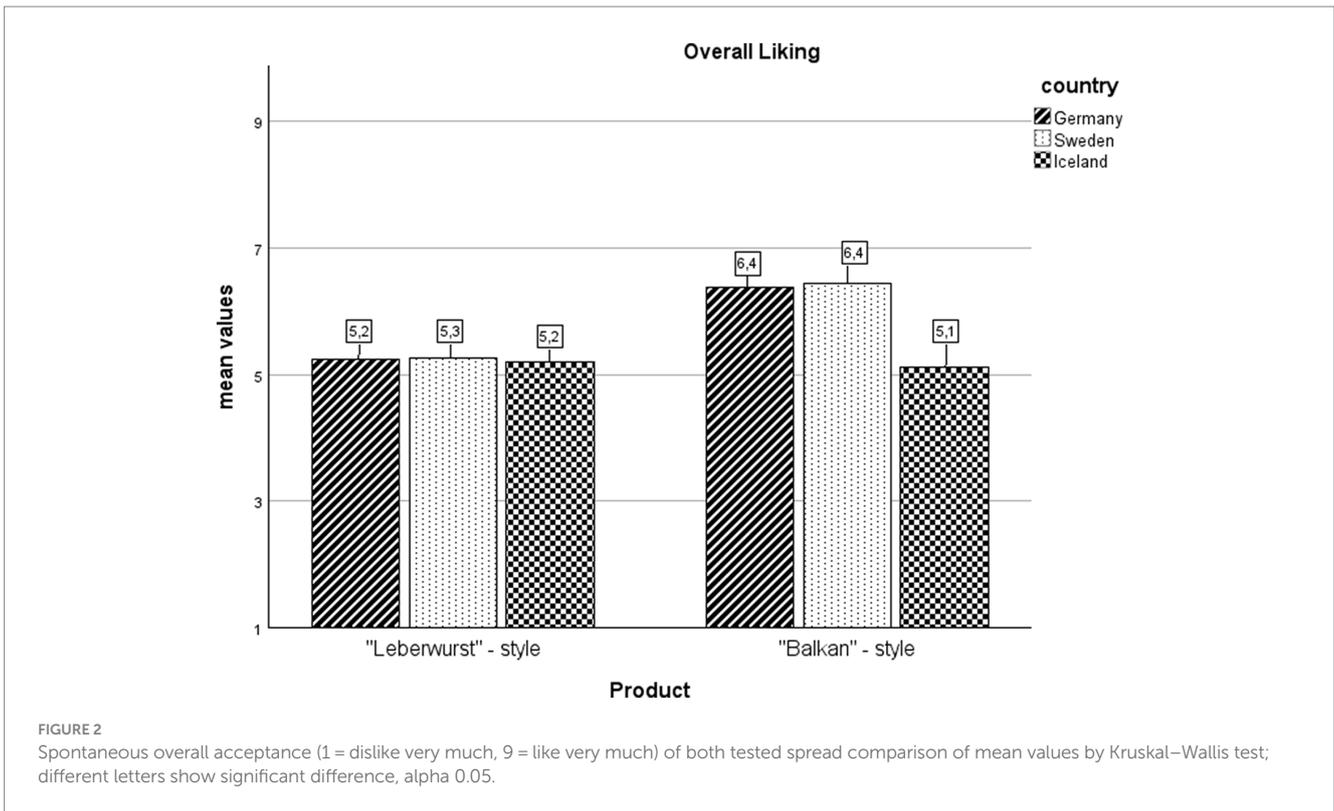
In comparison, consumers were asked to rate acceptance at a later stage of the testing after giving some information about the alternative protein source, such as Torula.

3.3 Background variables

At the end of the test, consumers were asked to answer questions related to trust and in particular, trust toward stakeholders in the food value chain and the food industry in order to complement an insight about how consumers rate the whole food value chain.

3.3.1 Trust in stakeholders

First, the participants were asked to answer the question "How much do you trust the following food industry players?," using the Likert scale, as presented in Figure 3.

FIGURE 2
Spontaneous overall acceptance (1 = dislike very much, 9 = like very much) of both tested spread comparison of mean values by Kruskal−Wallis test; different letters show significant difference, alpha 0.05.

FIGURE 3
Mean values of the background variables tested by Kruskal−Wallis test; pairwise comparison with Steel−Dwass−Critchlow−Fligner procedure; *show significant difference, alpha 0.05.

In most of the defined actors toward the food value chain, the trust, compared between the countries, is similar. Nevertheless, trust in primary food producers, food industry, and retailers is significantly higher among Icelandic consumers as compared with German and Swedish consumers.

3.3.2 Trust in the food industry

Moreover, consumers were confronted by different statements on trust toward the food industry, using the Likert scale as well. Table 2 includes all presented statements and the mean values of answers per country.

TABLE 2 Trust in food industry (1 = no or very little trust; 5 = very much trust).

Country	... is doing a good job with regard to producing food	... is competent enough to deal with the production of food	... has necessarily skilled people to produce food	... is acting in the public interest with regard to producing food	... listens to concerns regarding food production raised by public	... listens to what ordinary people think about food production*	... provides all relevant information about food production to the public	... is honest about the production of food	... is sufficiently open about production of food
Germany	5.0	5.2	5.3	4.3	3.8	3.9[a]	3.8	3.6	4.1
Sweden	5.1	5.3	5.3	4.4	4.3	4.5	4.3	3.9	4.0
Iceland	4.6	5.2	4.9	4.0	4.0	4.0	4.0	3.8	4.0

[a]Significant different to Sweden; Kruskal–Wallis test; $p < 0.05$. Comparison of mean values by Kruskal–Wallis test, alpha 0.05.

There are no significant differences between the mean scores of the countries, although German consumers seem to be less able to agree with the statements, dealing with information and transparency of the food industry.

3.3.3 Food Neophobia

Last but not least, food neophobia was inquired according to the alternative scale by De Kock et al., 2022. The results are presented in Table 3.

Significant differences between the three countries were measured on six items. Considering the mean values, it was found that Icelandic consumers are more likely to show neophobic characteristics compared with Swedish or German consumers.

Finally, correlations between all background variables have been analyzed in order to find and discuss potential relationships toward the overall impression of the product. The results are presented in Table 4.

The possible influence of background variables and the overall liking are of interest. The table shows that there are no significant correlations between the overall liking of the products and the named background variables. However, the negative correlation of the tested datasets implies that an increase in one variable (e.g., food neophobia) is accompanied by a decrease in the other (e.g., overall liking). As correlations are no proof of causality, this can be observed as indication and tendency.

4 Discussion

The present study underlines the sensory acceptance of both developed vegan spreads in powder form, as they are one of a kind and contain novel proteins derived from Torula yeast. No comparable products on the market were identified at the time of writing this study, especially with regard to the use of torula yeast in foods. This shows the unicity of the torula yeast food application.

Two flavors were developed: a spicy "Balkan" style spread and a savory-type spread "imitating" German "Leberwurst."

Of the two tested products, the "Balkan"- style spread performed slightly better than the "Leberwurst"-style product based on sensory properties alone. In Germany and Sweden, the "Balkan"- style spread was rated significantly better than in Iceland.

The open questions from the blind tasting provide additional information about the optimization potential for both spread products. Essentially, the seasoning and the mouthfeel are characteristics, in which the "Balkan" - style product, in particular, can be optimized. Some consumers in all countries remark that the product tastes too spicy and in general too intense. In addition, sandy and slimy characteristics were identified. The "Leberwurst"-type spread was described as "not visually appealing" by the consumers, and the taste itself was not intense enough. In addition, some consumers noted a pappy aftertaste. An optimization of the products in terms of these characteristics could therefore be required to further increase the overall acceptance.

Both seasoning and mouthfeel are crucial factors that interact to create a holistic sensory experience when eating (Fiorentini et al., 2020). A well-seasoned dish with a pleasing mouthfeel can result in a more enjoyable and memorable dining experience. Seasoning refers to the use of various flavor-enhancing components and helps

TABLE 3 Alternative Food Neophobia scale, comparison of mean values (scale 1 = disagree strongly; 7 = agree strongly) by Kruskal–Wallis test; different letters show significant difference, alpha 0.05.

Country	New food eating experiences are important for me (R)	I am afraid to eat things I have never had before	I do not trust new foods	New foods mean an adventure for me (R)	I like to challange myself by trying new foods (R)	It is exciting to try new foods when travelling (R)	Foods from other cultures look too weird to eat	Foods that look strange scare me
Germany	1.7[a]	2.2	2.5	3.1	2.4	2.1	2.4	2.4[e]
Sweden	2.0	2.0	2.4	2.3[c]	2.3[d]	1.9	2.0	3.1[f]
Iceland	2.7	3.4[b]	2.8	3.1	3.2	2.6	2.6	4.1[g]

[a,c]Significant different to Iceland. [b]Significant different to Sweden and Germany. [d]Significant different to Sweden and Iceland. [e,f]Significant different to Germany and Iceland; all comparisons by Kruskal–Wallis test; $p < 0.05$.

TABLE 4 Pairwise correlation (Pearson correlation) of background variables and overall liking of consumers (N = number of datasets).

		Overall liking	General trust	Trust in food industry	Food Neophobia
Overall liking	Pearson correlation	1	−0.013	−0.006	−0.138
	Sig. (2-tailed)		0.889	0.947	0.129
	N	246	123	123	123
General trust	Pearson correlation	−0.013	1	0.440**	0.047
	Sig. (2-tailed)	0.889		<0.001	0.604
	N	123	123	123	123
Trust in the food industry	Pearson correlation	−0.006	0.440**	1	0.002
	Sig. (2-tailed)	0.947	<0.001		0.980
	N	123	123	123	123
Food Neophobia	Pearson correlation	−0.138	0.047	0.002	1
	Sig. (2-tailed)	0.129	0.604	0.980	
	N	123	123	123	123

**Correlation is significant at the 0.01 level (two-tailed).

to bring out the natural flavors of ingredients, balance out flavors, and create a harmonious and pleasing taste profile. Seasoning can vary greatly, depending on cultural preferences, regional cuisines, and individual tastes (Jeong and Lee, 2021). Proper seasoning can elevate a dish from being bland or one-dimensional to being rich and complex in flavor. Mouthfeel, on the other hand, refers to the tactile sensations that food creates in the mouth. It encompasses a range of sensations, such as texture, temperature, viscosity, and the physical sensations experienced while chewing and swallowing. The mouthfeel of food can greatly impact the overall eating experience (Suzuki et al., 2021).

The consumer tests showed that the spreads, both using the alternative protein from torula yeast, are accepted by consumers but still have the potential for sensory optimization. In principle, the torula yeast protein concept was rated positively. Interestingly, in this study, Icelanders seem to have more trust in food value chain actors than Swedes and Germans. In Germany, consumers rated the properties that measure transparency and communication in the food industry, as less expressed, these results being only evaluated as trends as they did not show significance. However, this could be an important signal for players in the German market that increasing attention should be given to communication and transparency to the consumer, considering especially marketing campaigns of developed products

containing new alternative proteins (Kornher et al., 2019; Tso et al., 2021).

Early versions of some alternative protein products faced criticism for their taste and texture (Malek et al., 2019; Tso et al., 2021). However, manufacturers made significant strides in improving the taste and quality of these products, making them more palatable to consumers. Cultural preferences, habits, and regional differences can influence how quickly these options become mainstream. Ongoing research, development, and consumer education will likely continue to shape the trajectory of alternative protein acceptance in the years to come (FSA, 2022). In the German market, several trends and factors are gathering efforts to contribute to the growth of the alternative protein sector (Zollman Thomas and Bryant, 2021).

As a result, food neophobia appears to have a strong impact on acceptance within this study. When individuals experience food neophobia, they tend to stick to familiar foods and avoid trying new ones, which can limit their exposure to diverse nutrients and flavors. It has been shown that Icelanders have been more neophobic than Germans and Swedes, regardless of age. It is clear that neophobia can be influenced by cultural norms and social pressures. If certain foods are considered unusual or unfamiliar within a particular culture or social group, individuals may feel even more reluctant to try them (Costa et al., 2020). Neophobic individuals might miss out on

experiencing the richness and diversity of global cuisines (Hopkins et al., 2023). This can hinder their ability to appreciate different flavors and culinary traditions.

The analysis revealed a fascinating interconnection between consumer acceptance and food neophobia. Participants with lower levels of food neophobia exhibited a more positive response to the innovative food products. The statement suggests that individuals who have lower levels of food neophobia tend to show a more positive response to innovative food products. This implies that individuals with lower levels of food neophobia are more likely to embrace and enjoy innovative food products. This positive response may manifest in terms of willingness to try, liking the taste, or overall acceptance of the new food items. Overall, this observation highlights a connection between an individual's openness to trying new foods (lower food neophobia) and their receptiveness to innovative food products. It aligns with the idea that people with a more adventurous or less neophobic attitude toward food are generally more willing to explore and enjoy novel culinary experience. Unfortunately, neither a correlation of food neophobia, trust, and trust toward the food industry with the overall impression of the products nor a linear correlation was able to identify a direct significant relationship. This part emphasizes the difficulty in establishing a direct and significant relationship between various factors (food neophobia, trust, and trust toward the food industry) and the overall impression of the products. The attempts were made to correlate these variables, but none of these attempts revealed a clear and statistically significant connection. Additionally, the mention of linear correlation suggests that we explored whether there was a linear trend or relationship between these variables and overall impression, but this analysis did not yield significant results.

This aligns with previous research suggesting that individuals open to new culinary experiences are more likely to embrace and appreciate novel food items (Jaeger et al., 2021; Siddiqui et al., 2022). The findings highlight the pivotal role of food neophobia as a determinant of consumer acceptance, emphasizing the need for tailored marketing strategies and product positioning to address potential barriers associated with higher levels of food neophobia. The interplay between these background variables suggests a complex web of factors influencing consumer acceptance. For instance, individuals with high trust in stakeholders may be more inclined to overcome initial hesitancy associated with food neophobia (Siegrist and Hartmann, 2020). Additionally, aligning innovative products with specific diet preferences can capitalize on existing consumer habits and preferences, fostering a more positive reception. Therefore, a nuanced analysis of the interplay between consumer acceptance and background variables provides valuable insights into both practitioners and researchers. Recognizing the multifaceted nature of factors influencing consumer behavior allows for more informed product development, marketing strategies, and interventions aimed at overcoming potential barriers to successful commercialization (Šostar and Ristanović, 2023). By considering the holistic context in which consumer decisions are made, stakeholders in the food industry can better tailor their approaches to meet the diverse and evolving needs of their target audience.

Several studies have explored the relationship between personality traits, particularly openness to experience and food preferences (Esposito et al., 2021; Golestanbagh et al., 2021; Pristyna et al., 2022). Individuals with higher levels of openness are generally more adventurous and curious, making them more inclined to explore diverse cuisines and try unfamiliar foods. Cultural factors, exposure to different culinary traditions, and the influence of social and environmental factors also play a role in shaping attitudes of individuals toward new foods (Geuens, 2023). Additionally, positive or negative experiences with trying new foods in the past can impact the willingness of a person to experiment with novel culinary options.

5 Conclusion

Two vegan spread powders, namely a "Leberwurst"-style variant with 14.7% protein and a "Balkan"-style variant with 9.7% protein, have been developed, enriched with high protein content and featuring torula yeast as an innovative alternative protein source. The consumer acceptance test indicated that both spreads received favorable rating, falling within the "like slightly" range. Notably, the "Balkan-style" spread garnered higher consumer preference compared with the "Leberwurst"-style variant. Both products meet the criterion of providing "at least 20% kcal from proteins of total product kcal," qualifying them as "high-protein" and eligible for such claims. Proteins derived from torula yeast are gaining significant attention due to their immense appeal. These proteins boast attributes of being highly scalable, efficient, and sustainable, with production costs that are notably economical in comparison to other sources.

Analysis of background variables revealed that Icelandic consumers exhibit higher neophobic characteristics compared with Swedish and German consumers. Despite higher neophobic characteristics, Icelandic consumers, in general, express more trust in the overall food value chain. This implies that, despite being cautious about trying new things, Icelandic consumers have confidence in the transparency, quality, or reliability of the food supply chain. Additionally, German consumers feel that transparency and communication are lacking in the food value chain. This suggests that there might be concerns or dissatisfaction among German consumers regarding how information about food products is communicated to them. These findings could have implications for businesses and policymakers in understanding and catering to the preferences and concerns of consumers in these respective countries. Understanding the unique characteristics and preferences of consumers in each country can guide businesses and policymakers in developing targeted strategies that address specific concerns and build trust within the food value chain. This approach can contribute to more successful market penetration and improved consumer satisfaction.

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.

Ethics statement

Ethics approval was not required for this study, the research has been part of an EU-funded project and the European Commission

provides information on the main ethical aspects that may arise in research and indicates how each topic might be addressed to ensure compliance at: http://cordis.europa.eu/fp7/ethics_en.html. We followed the Ethics Review and Food-Related Research as mentioned in the official document of European Commission: Guidance Note for Research on Food Issues (europa.eu) (https://ec.europa.eu/research/participants/data/ref/fp7/89847/research-food_en.pdf). As document specified Informed Consent and Data Protection and Privacy were applied. Potentially vulnerable populations were not targeted within this study. Research activities supported have respected the fundamental ethical principles, including those reflected in the Charter of Fundamental Rights of the European Union and take into account opinions of the European Group on Ethics in Science and New Technologies.

Author contributions

A-KG: Formal analysis, Investigation, Writing – original draft. IM: Formal analysis, Writing – review & editing. DG: Investigation, Writing – review & editing. SE: Data curation, Writing – review & editing. KS: Investigation, Writing – review & editing. JN: Formal analysis, Writing – review & editing. AR: Funding acquisition, Project administration, Visualization, Writing – review & editing.

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Conflict of interest

A-KG, DG, SE, AR were employed by Biozoon.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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