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Fruit and vegetable biowaste as a source of functional nutritional components for animal feed

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The recovery of fruit and vegetable waste (FVW) from markets and processing plants should be considered a resource for functional feed ingredients since these wastes are rich in nutrients and valuable bioactive compounds. This study focused on FVW from the wholesale market in Milan, which is the largest in Italy, to evaluate the dietary fiber (DF), insoluble dietary fiber (IDF), soluble dietary fiber (SDF), total polyphenol content (TPC), and antioxidant activity (AA) of the FVW collected monthly over the course of a year. Compositional parameters were evaluated based on the month and season of collection (winter, spring, summer, and autumn). The samples collected each month were representative of the month and seasonality of harvesting and commercialization. The DF, IDF, SDF, TPC, and AA were statistically different ($p < 0.05$) based on the month and season, except for the TPC. Considering the seasonal pattern, the DF content was higher in the autumn and winter seasons (33.3 g/100 g dw and 30.8 g/100 g dw) than in the spring and summer seasons (19.9 g/100 g dw and 21.9 g/100 g dw). A similar trend was observed for the IDF content, which was higher in autumn and winter compared to spring and summer. The SDF content was higher in the summer (9.1 g/100 g dw) and autumn samples (8.1 g/100 g dw). The TPC was similar across the samples collected in different months (overall mean 2.4 $\pm$ 0.8 g/100 g dw), without significant differences based on the season of waste generation. The AA content was higher in the spring samples, albeit with high variability (34.4 $\pm$ 22.4 μmol TE/g dw). The overall mean solid content in the FVW samples was 10.8 $\pm$ 1.2 g/100 g. The results showed that FVW is a valuable source of functional compounds, which may improve the nutritional quality of animal feed. The major constraints in using FVW are the variability in the components from month to month, the presence of anti-nutritional components, and the water content, which compromises product stability. Future investigations are necessary for the recovery of this waste, given its potential added value as a functional feed ingredient.

KEYWORDS
food waste recovery, circular economy, functional feed, dietary fiber, antioxidants

1 Introduction

According to the Food and Agriculture Organization (FAO), minimizing food loss and food waste is essential for lowering production costs and increasing the efficiency of the food production system, thereby contributing to a sustainable food system (Bennett et al., 2022). Compared to other food categories, fruits and vegetables have the highest wastage rates (40–50%) (FAO, 2011), which occur during various production, post-harvest, and processing stages, before reaching retail and human consumption (Vilarino et al., 2017). The reduction or reuse of these losses is intrinsic to the concept of the circular economy (de Oliveira et al., 2021), which views this waste as a co- or by-product of other production processes. It also recognizes the economic value of these by-products due to the nutritional value and the possible biological functionality of some of their bioactive components. In this regard, fruit and vegetable waste (FVW) can be considered a valuable source of nutrients and bioactive compounds. Additionally, as an ingredient in animal feed, it has the potential to contribute to sustainable animal production (Garcıa et al., 2005; Angulo et al., 2012a; Sahoo et al., 2021; Tedesco et al., 2021; Sun et al., 2024; Yohannes et al., 2024a). The reuse of FVW can be challenging because of its high moisture content. This characteristic contributes to increased perishability, susceptibility to microbial contamination, loss of safety parameters, and difficulties in handling and storing processes. Being intended for human consumption, fruits and vegetables must meet safety requirements, which are retained during processing and while on the market; the quality and safety of FVW can be maintained if it is processed immediately. Another issue to address is the variability in the quantity and nutritional value of waste throughout the year due to the typical seasonality of fruits and vegetables, geographic location, and product demand (Angulo et al., 2012b). In any case, some components of these particular wastes can provide physiological benefits, such as enhanced disease resistance, stress tolerance, improved animal health and welfare, and increased growth rates. The potential of FVW may be attributed to its nutrient content and the presence of bioactive compounds, especially polyphenols and dietary fiber (DF) (Nirmal et al., 2023).

The Milan wholesale fruit and vegetable market (SO.GE.M.I. Spa) is the largest in Italy, handling over 1.000,000 tonnes of products per year. It serves as a hub for wholesalers and producers supplying individual retailers.[1] Every day, surplus fruits and vegetables that are still safe for human consumption but cannot be sold are donated to charitable organizations. If fruits and vegetables are spoiled or bruised, they are discarded at the waste collection site, placed in containers, and transported to biogas or composting plants (approximately 1700 tonnes/year). This waste is a valuable source of nutrients and, since it is intended for human consumption, it does not pose health or safety risks until it is disposed of at the collection point. The presence of heavy metals, pesticide and antibiotic residues, mycotoxins, and microbiological hazards was recently investigated and did not raise any safety concerns (Tedesco et al., 2021). However, it is important to consider that anti-nutritional factors (e.g., phytate, oxalates, tannins, saponins, and lectins) in fruit and vegetable waste are naturally occurring compounds that can interfere with nutrient absorption, digestion, or metabolism in animals (Bakshi et al., 2016; Pop et al., 2022; Yohannes et al., 2024b). As this waste consists of a mix of fruits and vegetables, the varying availability of individual fruit and vegetable wastes can help minimize the negative effects of anti-nutrients when the waste is used as a complementary functional feed ingredient.

In this context, vegetable waste from the wholesale market can serve as a safe raw material for conversion into feed ingredients and a source of functional components, such as dietary fiber and antioxidant compounds.

This study evaluated the functional nutritional characteristics of fruits and vegetables sourced from the Milan wholesale market, with the aim of exploring the possibility of using this waste as a functional feed ingredient. Dietary fiber (DF), soluble dietary fiber (SDF), insoluble dietary fiber (IDF), total polyphenol content (TPC), and antioxidant activity (AA) were evaluated in the FVW samples collected monthly over the course of a year. A statistical approach was applied to assess the variability in the composition of FVW in relation to the month and season during the 1 year of collection.

2 Materials and methods

2.1 Sample collection

Samples from the wholesale market were collected each month from the waste collection sites. At each sampling time, approximately 100 kg of various fruit and vegetable waste was collected, based on the ratio of each fruit and the daily wastage material. The samples were gathered in accordance with EU regulation (Regulation 152/2009, 2009). The monthly samples were then prepared by weighing each fruit and vegetable in the appropriate proportion, manually cutting them into small pieces, and thoroughly mixing them. From the mixed FVW, 12 samples of 300 g each were stored at −20°C until analysis. Seasonal samples were obtained by grouping the monthly samples into the following four seasons: summer (June, July, August), autumn (September, October, November), winter (December, January, February), and spring (March, April, May).

2.2 Total solid content (SC)

For each month, three samples were analyzed in triplicate ($n = 9$). The samples were partially thawed and homogenized. The total solid content (SC) was determined from subsamples dried at 65°C to constant weight for 24 h (AOAC, 2005). The results were presented as g/100 g. All other analytical results were expressed on a dry weight (dw) basis.

2.3 Dietary fiber (DF), insoluble dietary fiber (IDF), and soluble dietary fiber (SDF)

For each month, three samples were analyzed in triplicate ($n = 9$). The DF, IDF, and SDF contents were quantified using the enzymatic-gravimetric method (AOAC, 1995). Briefly, the samples underwent sequential enzymatic digestion with heat-stable α-amylase (Sigma Aldrich), protease VIII (Sigma Aldrich), and amyloglucosidase (Sigma Aldrich) to remove starch and protein, allowing for the extraction of the dietary fiber fractions. The IDF was recovered by filtration of the digested samples and then dried and weighed. The SDF was precipitated from the filtrate by adding a preheated solution of 95% ethanol. After precipitation, the SDF was dried and weighed. The TDF was determined by summing the IDF and SDF. The results were expressed as g/100 g dw.

1 https://www.sogemispa.it/mercati/mercato-ortofrutticolo

2.4 Total polyphenol content (TPC)

The total polyphenol content (TPC) was assessed using the Folin–Ciocalteu method (Singleton and Rossi, 1965). For each month, three samples were analyzed in triplicate ($n = 9$). Briefly, 10 g of each sample was finely shredded. Then, 100 mg was placed in a Falcon tube, to which 2 mL of methanol was added, and the mixture was incubated at room temperature for 48 h in the dark. The alcoholic extract was separated from the insoluble fraction by centrifugation at 6000 *g* for 5 min at room temperature. The assay was performed on each sample as follows: 25 µL of the extract solution was mixed with 1.5 mL of deionized water and 125 µL of Folin–Ciocalteu reagent (2 M). After 5 min, 0.5 mL of 15% Na_2CO_3 aqueous solution was added. The mixture was incubated in the dark for 2 h, and the absorbance was measured at 765 nm using a Jasco V-630 Spectrophotometer (UV-Vis/Vis, Thermo Fisher Scientific). Calibration curves were prepared with gallic acid (range 0–1 mg/mL) as the standard. The results were expressed as g GAE/100 g dw.

2.5 Antioxidant activity (AA)

The antioxidant activity (AA) of the samples was determined using the DPPH* (2,2-diphenyl-1-picrylhydrazyl) assay (Brand-Williams et al., 1995). For each month, three samples were analyzed in triplicate ($n = 9$). The assay was performed on clear methanol extracts, obtained as follows: each monthly sample (about 300 g) was partially thawed and finely shredded in a food mixer to obtain a well-homogenized sample. A total of 2 g of the homogenate was extracted with 20 mL of methanol:water mixture (60:40) in an ultrasonic bath for 30 min at room temperature. The mixture was centrifuged at 6000 *g*, the supernatant was separated, and the DPPH* assay (Sigma Aldrich) was performed, following the method previously described by Buratti et al. (2020). The method was calibrated by constructing a calibration curve with Trolox (6-hydroxy-2,5,7,8-tetra-methyl-chroman-2-carboxylic acid, Sigma-Aldrich, Italy), and the data were converted into Trolox equivalents (TEs). Both the extraction and the test were performed in duplicate ($n = 4$), and the results were expressed as µmol TE/g dw.

2.6 Statistical analysis

The DW, DF, IDF, SDF, TPC, and AA data were analyzed using a generalized linear model (GLM), employing the GLM procedure of the Statistical Product and Service Solutions (SAS) (version 9.4; SAS Institute Inc., Cary, NC), with the month of sampling as the main factor. The four seasons were considered by pooling data from summer (June, July, August), autumn (September, October, November), winter (December, January, February), and spring (March, April, May). Subsequently, the pooled data were analyzed to investigate the effect of season on the variability. The values were expressed as mean ± standard deviation (SD), and the differences were considered significant at a p-value of < 0.05.

3 Results

The monthly FVW samples from the wholesale market were characterized by their DF, IDF, SDF, TPC, and AA. Table 1 reports the mean values ± SD of all parameters evaluated and the effect of month and season on the variability of the data. The fruit and vegetable composition discarded from the wholesale market reflected the month of production and commercialization. Highly significant differences ($p \leq 0.001$) in all parameters were observed based on the month of collection. Concerning the season, the SC, DF, IDF, and SDF showed significant differences ($p \leq 0.005$), whereas the TPC and AA did not differ significantly ($p > 0.05$). The SC was relatively low and typical of the matrix (average value over the year, 10.8 ± 1.2 g/100 g). Similarly, the DF, TPC, and AA showed high values typical of fruits and vegetables (26.5 ± 6.3 g/100 g dw, 2.4 ± 0.8 g/100 g dw, and 24.6 ± 19.8 g/100 g dw, respectively). In particular, a high SDF average content was detected (7.0 ± 2.0 g/100 g dw).

The seasonal pattern of the DF, IDF, SDF, TPC, and AA in the FVW from the wholesale market is presented in Figures 1–4. The DF content (Figure 1) ranged from 19.9 (spring samples) to 33.3 g/100 g dw (autumn samples), with similarly higher values in autumn and winter samples and similar lower values in spring and summer ($p < 0.05$). The fiber composition was characterized by a high ratio of IDF (Figure 2), which ranged from 12.9 g/100 g dw in summer to 26.5 g/100 g dw in winter. As observed for the DF content, significantly higher values were detected in the autumn and winter samples compared to the spring and summer samples ($p < 0.05$).

The distribution of the SDF fraction showed a different pattern (Figure 3). The highest levels were observed in the summer and autumn samples (9.1 ± 0.8 g/100 g dw, 8.12 ± 1.02 g/100 g dw, respectively), while the lowest level was observed in winter (4.31 ± 0.5 g/100 g dw), with an intermediate value in spring (6.6 ± 1.0 g/100 g dw) ($p < 0.05$).

It should be noted that the TPC (Figure 4) of FVW was almost constant throughout the year, ranging from 2.1 g GAE/100 g dw (autumn) to 2.7 g GAE/100 g dw (spring), with no significant differences across the seasons ($p < 0.05$). In contrast, the AA (Figure 5) determined using the DPPH* assay showed significant differences across the seasons, with higher values in the spring samples, albeit with a high dispersion of the data. The AA ranged from 12.5 µmol TE/g dw in the summer samples to 34.4 µmol TE/g dw the spring samples.

4 Discussion

From the perspective of improving the sustainability of agri-food production and reducing food loss and food waste, the reuse of FVW

TABLE 1 Average values (mean value ± SD) and effects of the month and season of waste on the variability of the solid content (SC), dietary fiber (DF), insoluble dietary fiber (IDF), soluble dietary fiber (SDF), total polyphenol content (TPC), and antioxidant activity (AA) of the FVW from the wholesale market.

Item	Mean ± SD	Significance	
		Month p-value	Season p-value
SC (g/100 g)	10.8 ± 1.2	0.001	0.005
DF (g /100 g dw)	26.5 ± 6.2	< 0.0001	< 0.0001
IDF (g /100 g dw)	19.4 ± 6.9	< 0.0001	< 0.0001
SDF (g /100 g dw)	7.0 ± 2.0	0.0008	< 0.0001
TPC (g GAE/100 g dw)	2.4 ± 0.8	< 0.0001	0.6864
AA (µmol TE/g dw)	24.6 ± 19.8	< 0.0001	0.086

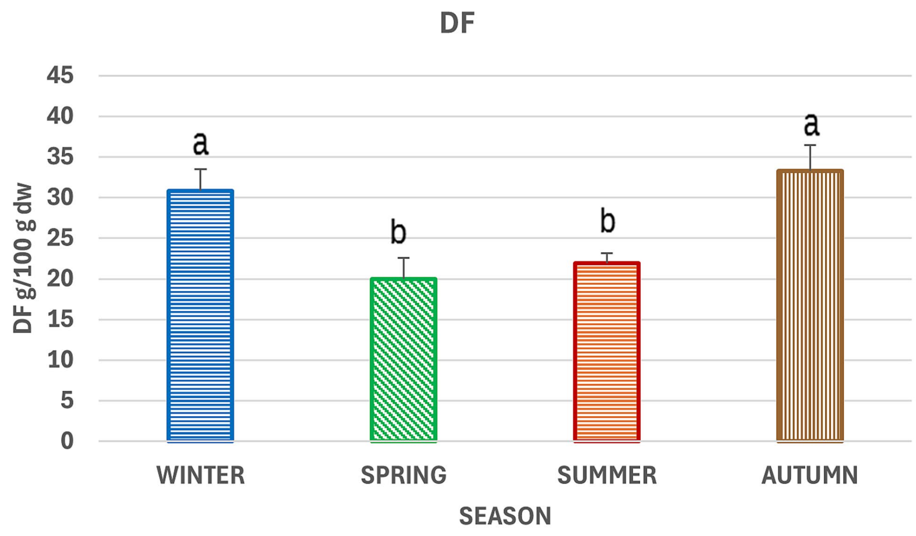

FIGURE 1
Seasonal content of the DF (g/100 g dw) in FVW from the wholesale market (means ± SD). The seasons were defined as follows: summer (June, July, August), autumn (September, October, November), winter (December, January, February), and spring (March, April, May). Different letters indicate statistically significant differences ($p < 0.05$).

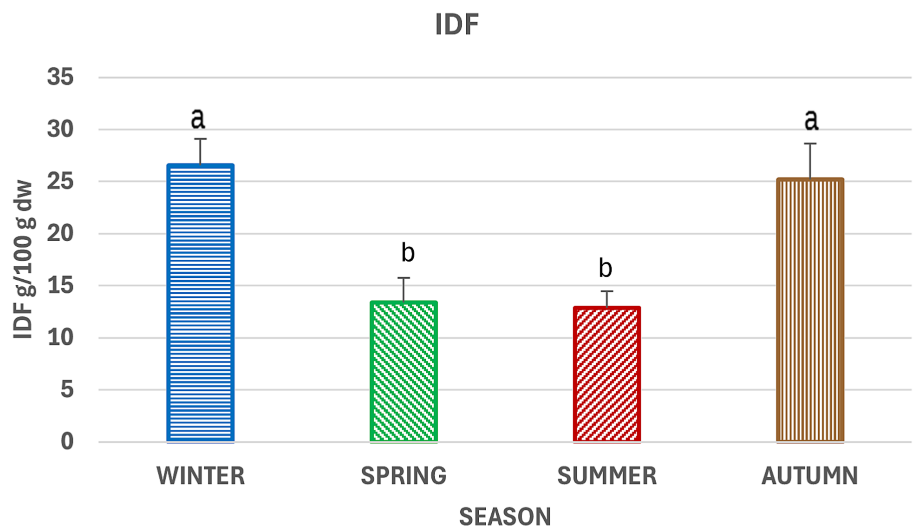

FIGURE 2
Seasonal content of the IDF (g/100 g dw) in FVW from the wholesale market (means ± SD). The seasons were defined as follows: summer (June, July, August), autumn (September, October, November), winter (December, January, February), and spring (March, April, May). Different letters indicate statistically significant differences ($p < 0.05$).

originating from wholesale markets or transformation plants is particularly promising. Both strategies—reducing the amount of FVW and valorizing FVW as a source of nutritionally relevant compounds—can be implemented (Sagar et al., 2018; Cassani and Gomez-Zavaglia, 2022). A critical consideration is related to the safety of reusing this waste as an ingredient for animal feed. Animal feed manufacturers should use sustainable, secure, and safe resources. Fruits and vegetables intended for human consumption are subjected to strict regulations to ensure an adequate hygienic profile. Therefore, at the original point where fruits and vegetables are discarded, safety issues are not highlighted, such as the presence of heavy metals, pesticides, antibiotic residues, mycotoxins, or microbiological hazards (Tedesco et al., 2021).

Bioactive compounds are commonly found in vegetable products (Wadhwa et al., 2015). The health-promoting effects of these compounds are mainly mediated through biochemical and cellular interactions, which further prevent susceptibility to diseases, promote animal health, and improve the quality or quantity of their products (Durmic and Blache, 2012). FVW in the livestock feed sector can be considered a valuable source of bioactive compounds (Bakshi et al., 2016).

The content of DF in the waste generated over a year from the wholesale market averaged 26.5 ± 6.3 g/100 g dw. From a nutritional

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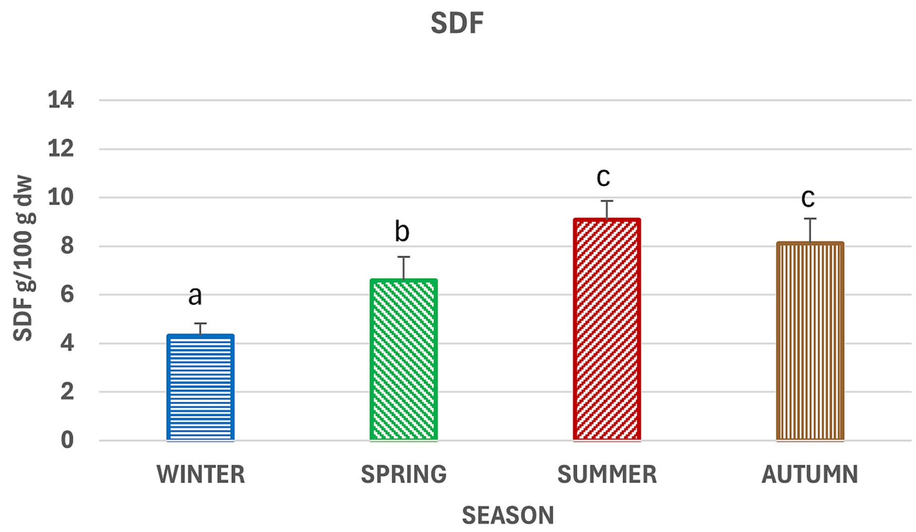

FIGURE 3
Seasonal content of the SDF (g/100 g dw) in FVW from the wholesale market (means ± SD). The seasons were defined as follows: summer (June, July, August), autumn (September, October, November), winter (December, January, February), and spring (March, April, May). Different letters indicate statistically significant differences ($p < 0.05$).

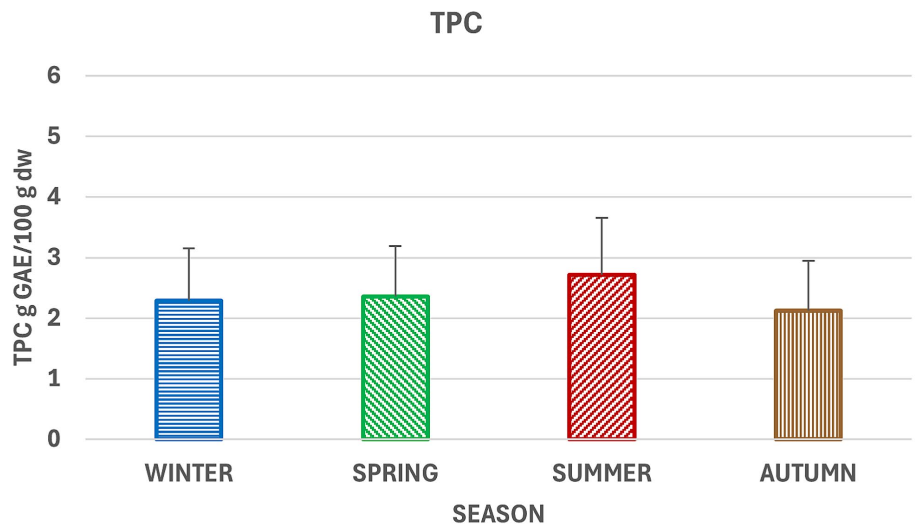

FIGURE 4
Seasonal values of the TPC (g GAE/100 g dw) in FVW from the wholesale market (means ± SD). The seasons were defined as follows: summer (June, July, August), autumn (September, October, November), winter (December, January, February), and spring (March, April, May).

perspective, DF is defined as non-digestible carbohydrates and lignin resistant to mammalian digestive enzymes (Trowell, 1976). Interest in DF has grown due to its beneficial physiological effects on the gastrointestinal tract (Hipsley, 1953). Based on its interaction with water, dietary fiber comprises two fractions: the insoluble fraction, which includes cellulose and lignin, and the soluble fraction, which includes pectins, beta-glucans, hemicelluloses, gums, and galactans (Van Soest et al., 1991; Davidson and McDonald, 1998). DF can be digested by both rumen microbiota and gut microbiota. In monogastric animals, one crucial function of DF is to act as a prebiotic, modifying the types and functions of gut bacteria. The health-beneficial effects of DF on the microbiota and immune system are well-reported (Hooper et al., 2012; Jha et al., 2019). The positive effect of fiber consumption might be associated with modifications in the physicochemical properties of the digesta, enhanced fermentation capacity in monogastric animals, and the colonization of beneficial commensal microbiota that competitively blocks the adhesion of pathogenic bacteria to the gastrointestinal tract mucosa (Molist et al., 2014). Soluble fiber, primarily found in fruits, legumes, and oats, is known to lower LDL cholesterol and may aid in the regulation of blood sugar levels (Slavin, 2013).

Insoluble fiber contributes to appetite control and the prevention of constipation (Yang et al., 2012). High-fiber diets have been linked to a lower incidence of several diseases. Benefits include boosting the volume

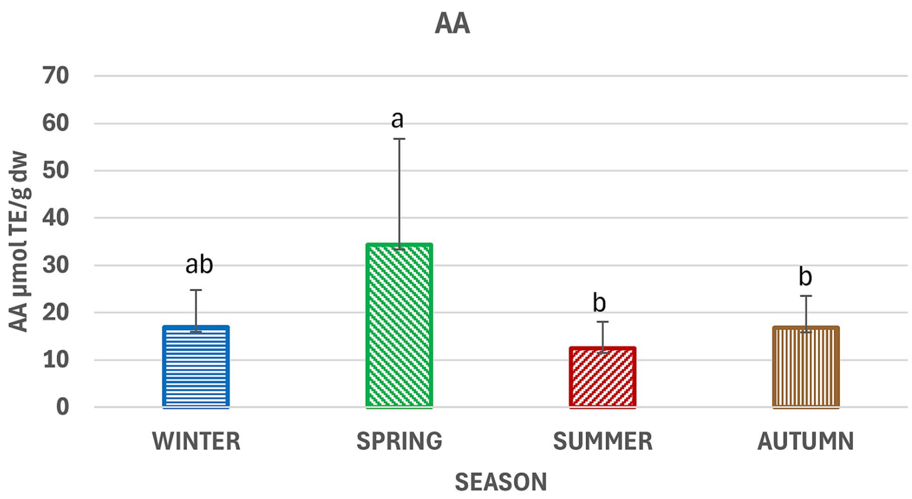

FIGURE 5
Seasonal AA (µmol TE/g dw) in FVW from the wholesale market (means ± SD). The seasons were defined as follows: summer (June, July, August), autumn (September, October, November), winter (December, January, February), and spring (March, April, May). The whiskers represent the upper and lower values of the data. Different letters indicate statistically significant differences ($p < 0.05$).

of fecal bulk, reducing the duration of intestinal transit, lowering cholesterol and glycemic levels, and encouraging the growth of the intestinal flora (Hooper et al., 2012; Jha et al., 2019). Considering the content of DF and its insoluble and soluble fractions, the FVW analyzed in this study can be considered a good source of fiber, even for monogastric animals that need low fiber quantities to stay healthy. However, the composition of the FVW varied over time; this can pose problems in the formulation of feed using FVW as an ingredient. Nevertheless, its potential as a functional, fiber-rich ingredient should be exploited.

Phenolic compounds are secondary plant metabolites that represent a major class of bioactive compounds. The intake of polyphenols from fruits and vegetables is nutritionally important due to their biological activities, including antioxidant, anti-inflammatory, immunomodulatory, and antimicrobial effects, as well as their positive influence on intestinal morphology and nutrient absorption, especially in monogastric animals (Kamboh et al., 2015; Lipiński et al., 2017). The role of polyphenols is well-recognized in animal nutrition. Supplementation with polyphenols has shown an improvement in animal health, growth performance, and the quality of products (Hashemi and Davoodi, 2011; Serra et al., 2021; Budiarto et al., 2024). Studies have reported that feeding fruit waste (such as grape pomace, orange/Citrus pulp, etc.) rich in polyphenols to chickens, laying hens, and ruminants improves the meat and egg quality, increases polyunsaturated fatty acids concentrations, and reduces lipid peroxidation due to increased radical scavenging activity (Goñi et al., 2007; Goliomytis et al., 2018; Tayengwa et al., 2020; Arend et al., 2022). Similarly, in pigs and rabbits that were fed fruit and vegetable waste rich in polyphenols, meat analysis revealed an increase in polyunsaturated and monounsaturated fatty acids concentrations, along with a reduction in thiobarbituric acid reactive substances and improved oxidative stability (Hossain et al., 2012; Dal Bosco et al., 2012; Tian et al., 2023; Blasi et al., 2024).

Despite the variable monthly composition of other parameters, the FVW collected in this study showed a constant level of polyphenols throughout the year, with an average content of 2.4 ± 0.8 g GAE/100 g dw. Numerous studies in the literature have reported the TPC values referring for individual types of fruit or vegetable waste. Studies have reported that apple pomace and peel, for example, contain TPC values of 10.2 mg GAE/g dw and 28.3 mg GAE/g dw, respectively (Sudha et al., 2007; Henríquez et al., 2010). Regarding white grapes, red grape pomace, tomato pomace, and kiwi juice pomace, TPC has been reported to range from 11.6 to 15.8 mg GAE/g dw, 21.4 to 26.7 mg GAE/g dw, 55.1 mg GAE/g dw, and 1.30 to 4.87 mg GAE/g dw, respectively (Deng et al., 2011; Azabou et al., 2020; Carbone et al., 2020). Of peel waste, *Citrus* species were reported to exhibit a TPC range of 14.8–8.4 mg GAE/ g dw (Budiarto et al., 2024). Furthermore, in a study conducted by Ahmadi et al., (2020), a waste mix (onion, lemon, potato, tomato, plum, etc) showed an overall TPC value of 10.1 mg GAE/g dw. Compared to the data in the literature, the FVW analyzed in this study possessed a similar or higher level of TPC, which was scarcely influenced by the period of collection. Therefore, this waste represents a rich source of untapped, potentially readily available polyphenols that could be used in animal feed. Polyphenols present in FVW are likely to have good bioavailability due to the presence of associated saccharides, especially in fruits (Sieminska-Kuczer et al., 2021). These saccharides increase the secretion of digestive enzymes, bile, and mucus and enhance the phenolic bioavailability, particularly in the small and large intestines (Chiva-Blanch and Visioli, 2012; Brenes et al., 2016).

Polyphenols have the ability to counteract reactive oxygen species (ROS) production, which, especially during oxidative stress, triggers degenerative and inflammatory diseases (Gessner et al., 2017; Artuso-Ponte et al., 2020). The presence of phenolic compounds is mainly responsible for the antioxidant activity of fruits and vegetables (Wijngaard et al., 2009). In our study, the overall value of antioxidant activity was 24.6 ± 19.8 µmol TE/g dw and the highest antioxidant capacity was measured in the spring samples (34.4 ± 22.4 µmol TE/g dw). This high value may be due to the presence of products particularly rich in ascorbic acid in the waste. Among the most common FVW evaluated in the above-cited studies, *Citrus* peel showed an antioxidant capacity ranging from 8.7 to 15.1 µmol TE/g dw (Budiarto et al., 2024). Grape seed pomace showed the highest antioxidant potential, with an antioxidant capacity of 160.9 µmol TE/g dw (Costa et al., 2019). In contrast, orange and apple juice showed DPPH* scavenger activities of 26.3 and 35.4 µmol TE/100 mL, respectively (Šeregelj et al., 2024). An appreciable amount of polyphenols can remain in the solid residues of digested food, where they can be absorbed by dietary fiber. Considering that the microflora in the digestive tract can disrupt the DF matrix, these polyphenols can be released and metabolized, producing molecules with health benefits (Fulgencio, 2011).

As fruit and vegetable wastes and by-products represent a potential source of valuable compounds, tapping into their full potential would contribute positively to the circular economy by adding value through the development of "innovative" products (Laufenberg et al., 2003). The main limitation is the high moisture content, which is responsible for the rapid deterioration of this waste. The first step in implementing the use of FVW as a feed ingredient is to reduce the moisture content, ensuring the maintenance of safety requirements during storage and use. FVW could be dehydrated using methods such as sun-drying, vacuum/connective-drying, freeze-drying, or infrared-drying (Sogi et al., 2013; Wang et al., 2022). Given the large quantities of waste that need to be dried, the application of these technologies is rather complicated and cost-prohibitive. Moreover, due to the rapid deterioration of FVW biomass, companies or vegetable markets should deliver it to the processing plant within a short time. As an alternative to dehydration, ensiling is a sustainable and biological method for storing large amounts of FVW, which could be used directly on-site without excessive costs. Ensiling is a storing technique with a low environmental impact, which is widely used for ruminant feed production. It relies on the activity of lactic acid bacteria in anaerobic conditions, which leads to a reduction in pH, preserving forages and optimizing the nutritional and microbial quality of the feed (Mejía-Avellaneda et al., 2022; Ma et al., 2023). Due to the composition of FVW, ensiling should be combined with co-ensiled crop residue biomass to help reduce moisture (Duo et al., 2018). Additionally, using probiotic bacteria inoculum (i.e., *Lactobacillus plantarum*, *Lacticaseibacillus casei*, *L. rhamnosus*, etc) can inhibit the growth and metabolism of pathogenic microorganisms, thereby improving the ensiling quality (Keshri et al., 2018).

Another challenge is the nutritional variability of FVW observed throughout the year, which complicatesfeed formulation. The use of rapid NIR spectroscopy to evaluate the nutritional composition before adding FVW to a diet could help address this problem (Tedesco et al., 2021). In addition, the potential presence of anti-nutritional components must be considered; however, the variable presence of individual fruits and vegetables containing anti-nutritional factors in a multi-component mixture can minimize the negative effects of anti-nutritional factors. This risk is further reduced by including FVW as a complementary ingredient in the animal's diet.

5 Conclusion

This study indicates that FVW from a wholesale market is a valuable source of nutritional compounds that can be valorized in the food chain by producing functional feed ingredients. The major constraints in the reuse of FVW are its high moisture content and its variable composition throughout the year. Since the waste from fruits and vegetables is constantly increasing, its reallocation to animal feed can contribute to sustainable livestock production. Efforts are needed to improve processing technologies that make this waste reusable in animal nutrition. In addition, further investigations are needed to fully characterize this particular waste to exploit its potential added value as a functional feed ingredient.

The results from this study only pertain to the FVW obtained from the Milan wholesale market over 1 year. However, we can assume that similar data would be obtained from wholesale markets in regions with similar food habits and that yearly variability should not significantly affect the general results. Research should be expanded to include markets representing different dietary patterns to establish the composition of their FVW and assess its potential use as a feed ingredient.

Data availability statement

The datasets presented in this article are not readily available because data will be made available on request only after authorization from the company where the assessment was carried out. Requests to access the datasets should be directed to doriana.tedesco@unimi.it.

Author contributions

DT: Writing – original draft, Writing – review & editing. AG: Writing – original draft, Writing – review & editing. GG: Writing – original draft, Writing – review & editing.

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Conflict of interest

The 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.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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