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Fruit and Vegetable Wholesale Market Waste: Safety and Nutritional Characterisation for Their Potential Re-Use in Livestock Nutrition

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Abstract: Compared to other food categories, fruits and vegetables are the most wasted. This leads to the squandering of economic, social, and environmental resources. The reallocation of fruit and vegetable waste (FVW) into animal feed contributes to the sustainability of livestock production, reducing the impact of feed production for land use. In this study, the fruit and vegetable waste from the General Wholesale Market of Milan was considered. FVW samples were collected for one year and were analysed for safety parameters and nutritional, vitamin, and mineral composition. Data showed that dry matter (DM) was on average 10.82 ± 1.21% and neutral detergent fibre (NDF) was on average 22.43 ± 4.52% DM. The presence of soluble sugars (30.51 ± 7.61% DM, on average) was also detected. However, the high moisture content of this waste makes it easily perishable, with detrimental effects on quality, storage, and transportation. A strategy was therefore proposed to reduce the water content of FVW by pressing. Overall, the results highlighted the significant nutritional value of FVW from the wholesale market and the need to develop appropriate technologies to maintain the food chain line safe.

Keywords: fruit vegetable wholesale market; waste; nutritional composition; feed safety; livestock

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1. Introduction

Every year one-third of the food produced worldwide for human consumption is lost or wasted. A reduction in these losses and waste may be part of a solution for future food availability. Compared to the other food categories, fruit and vegetable waste has the highest wastage rates (40–50%) [1]. Fruits and vegetables incur high levels of loss given their high perishability and limited shelf life. This food category is rich in highly nutritive elements, so its waste leads to a squandering of economic, social, and environmental resources. In Northern America and Europe, the impact factors on producing fruits and vegetables from a farm for retail are on average 1.5 tonne CO_2 equivalent/tonne, blue water usage 242.3 m^3/tonne, and land impact factors 0.1 ha/tonne [2]. The more food products move forward into the supply chain, the more they contribute to GHG (greenhouse gas) emissions. This implies that a unit of food lost or wasted at the wholesale stages has a larger carbon footprint than a unit lost on the farm [2].

As reported by Directive 2008/98/EC [3] on waste, food waste can be arranged in a hierarchical model to manage its reduction and reuse. The preferred actions of this model are "prevention and reduction" and "repurposing and recycling" to the least preferred, "disposal." Nowadays, food waste is mainly used in anaerobic digestion processes to produce biogas for energy generation [4–7]. Fruit and vegetable waste (FVW) is optimal feedstock for anaerobic digestion, making the anaerobic fermentation of this waste profitable. Asquer et al. [8] analysed the FVW from a general wholesale market in Sardinia and found that a correct mix of FVW can provide raw material balanced in macro- and micronutrients, which promotes anaerobic digestion. The production of biogas is even more profitable if the biofermenter is close to the place where the waste is produced. In this way, it is possible to reduce the cost and the CO_2 emission rising from the transportation of the waste to the biofermenter [4,5]. Besides, there are other valid alternatives to valorise these wastes. From FVW, several bioactive compounds such as phenolics, terpenes, fatty acids, dietary fibre, saponins, and phytoestrogens can be obtained that have beneficial health properties [4,9–13]. FVW can also be used as a growth substrate for terrestrial invertebrates, insects, or earthworms that, due to their high protein content, can be used for animal and human nutrition [14–18]. On the other hand, FVW is a good source of nutrients [19–21], making it suitable for the direct feeding of livestock. Besides, fruits and vegetables originally intended for food but then diverted to animal feed are no longer considered quantitative food loss or waste [2]. Therefore, reintroducing FVW into the production chain as a feed ingredient can valorise this waste in a more circular-economy concept. The waste from fruits and vegetables is generated in high amounts from wholesale markets, where they are sold in large quantities [22]. The recovery of FVW from plant-based industries and wholesale markets and its exploitation as animal feed would add economic value to this waste, albeit wholesalers, as recently reported, consider FVW management a low-utility task [23].

The use of FVW as an ingredient for livestock feed can help meet the increasing demand for animal protein resulting from the expected population growth for 2050 [24–26]. Furthermore, FVW diverted into animal feed can contribute to the sustainability of livestock production and a reduction in land competition and water use [27]. The results from a large number of studies support the use of FVW as animal feed. For instance, cauliflower and cabbage are rich in proteins, soluble sugars, and macro- and microelements, and have good digestibility and dry matter intake [26]. Fresh carrot contains 88% water, and in dry matter content 10% crude protein, up to 60% sugars, and high levels of vitamin C and β-carotene [26].

The presence of nutrients, vitamins, minerals, fibre, and bioactive compounds makes FVW a valuable feed ingredient for livestock nutrition and the waste originated from food processing, plant-based industries, and general markets can be added to livestock's diet without any adverse effects on the animals [18,26–28]. On the other hand, the composition of FVW is variable and depends on the seasonality of harvesting. Therefore, one of the key aspects to be considered when evaluating the use of FVW as a feed component is its nutritional composition throughout the year, along with its safety.

In EU legislation, some food waste (e.g., catering waste or household waste) is prohibited to be fed to farm animals (Regulation (EU) No. 1069/2009 regarding animal by-products and Regulation (EC) No. 767/2009 on the placing on the market and use of feed, Annex III), which instead can be used for pet food [29]. Other foodstuffs manufactured for human consumption but no longer intended for human consumption and that do not present any health risks can be reintroduced in feed production as former foodstuffs since they are a non-hazard food (Commission Regulation (EU) No. 68/2013 on the Catalogue of feed materials). In this context, fruit and vegetable waste from wholesale markets is a safe resource to be converted into feed ingredients, being derived from fruits and vegetables intended for human use. When recycling food waste into animal feed, particular attention should be paid to the high moisture content and consequent easy spoilage, the variability of nutritional content, and the safety aspects that must be guaranteed [30]. As for the handling of fruits and vegetables, it should be remembered that they have a high moisture content, which can create safety issues. As a result, this waste has to be transported as soon as possible to the nearest suitable processing facility to prevent its decay [9]. Alternatively, dry feed should be produced directly where the waste originates, reducing in this way the post-processing transportation costs based on the distance and the weight of the transported material [4,7].

A potential strategy to prevent the rapid degradation of FVW and maintain safety aspects is the reduction of the water content. This can be easily obtained by mechanical pressing, which results in a significant decrease in the vegetative water content. This strategy can also contribute to a reduction in the environmental impact of transporting wastes with high water content. Indeed, 1 tonne of waste transported for 1 km has a global warming impact of kg CO_2 eq 0.174 [31], which is undoubtedly detrimental to the environment.

Based on the above considerations, the present investigation was conducted to assess the potential use of the FVW generated in large amounts from the General Wholesale Market of Milan as a feed ingredient. Different aspects were considered: (1) the nutritional components of fruit and vegetable waste during one year of sampling, (2) the evaluation of macro- and micronutrients, (3) the control of food safety, and (4) the feasibility of reducing the water content by a simple pressing technique.

2. Materials and Methods

2.1. Plant Material and Study Site

In this study, the fruit and vegetable waste from the General Wholesale Market (SO.GE.MI. S.p.a.) of the city of Milan, the largest in Italy, was considered, where fruits and vegetables are sold to retailers. Every day the unsold products that have lost their commercial value (perishable products in a wholesale market are not suitable for sale the following days because freshness cannot be guaranteed) but still perfectly edible, are collected and redistributed to charitable organisations that assist poor and needy people (about 1500 tonnes/year). On the other hand, unsold products damaged with spoils and bruises become waste (about 1700 tonnes/year) and are discarded at the waste-collecting site and dropped in containers, as showed in Figure 1.

(**a**) (**b**) (**c**)

Figure 1. The collection site of fruit and vegetable waste in the General Wholesale Market: crates of vegetables discarded (**a**), manually dropped in the containers (**b**), and a representative mix of fruit and vegetable waste discarded in the containers (**c**).

Each month for one year, fruit and vegetable waste from the crates at the waste-collecting site was classified and the fruit and vegetable composition discarded was classified. Table 1 reports the variable composition of the fruit and vegetable waste for each month, following the seasonality and the commercial distribution.

Table 1. Composition of fruit and vegetable waste collected over the course of the year from the wholesale market of Milan.

Season	Month	Fruit and Vegetable Waste Composition
Summer	June, July, August	Cauliflower, celery, eggplant, fennel, leeks, melons, peaches, pears, peppers, pineapples, American potatoes, Italian potatoes
Autumn	September, October, November	Apricots, chicory, eggplant, grapes, green beans, melons, onions, parsley, peaches, pears, peppers, plums, rocket, salad, strawberries, tomatoes, turnip greens
Winter	December, January, February	Apples, artichokes, courgettes, eggplant, grapefruit, khakis, kiwis, lemons, mangos, mapo, melons, oranges, peppers, pineapples, pomegranates, radishes, salad, tomatoes, turnip greens
Spring	March, April, May	Artichokes, bananas, broccoli, carrots, celery, chicory, coriander, courgettes, cucumbers, fennel, garlic, grapes, leeks, oranges, pomegranates, peppers, plums, pumpkins, pumpkin flowers, purple cabbage, radishes, rocket, salad, savoy cabbage, spring onions, strawberries, tomatoes, turnip greens

Before FVW was discarded in the container, representative samples were randomly collected from the crates in proportion to the fruits and vegetables wasted, following the methods of sampling for the official control of feed (Commission Regulation (EC) No. 152/2009 laying down the methods of sampling and analysis for the official control of feed. The FVW was immediately transported to the laboratory, where each type of fruit and vegetable was weighed, cut manually, and thoroughly mixed. From the mixed FVW, samples were collected for the specific assessments. To simulate the reduction of water content in FVW at the collection site, before transport to the disposal facilities (Figure 2) water extraction was conducted in the laboratory with a fruit press machine. The press deployed was a manual stainless steel home fruit press. It consists of a manual pressing plate inside a bucket (5 L capacity) provided with a small tap on the bottom to gather resulting liquids. The mixed FVW was weighed and pressed up to a 50% reduction of the waste weight. After that, the residual waste remaining from the pressing was weighed and sampled for the subsequent analysis. All samples were prepared and analysed in triplicate.

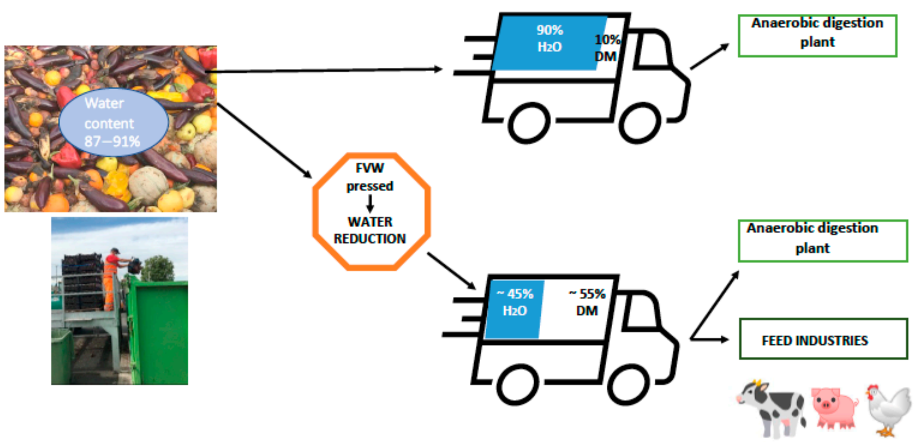

Figure 2. Representation of different approaches to handle and use fruit and vegetable waste from the wholesale market. One approach considers the actual transportation and usage of FVW to a biogas plant, whereas the other considers how the FVW can be transported and used after undergoing the pressing process.

2.1.1. Nutritional Analyses

Monthly samples from the FVW and the residual FVW waste after pressing were evaluated in triplicate to analyse their nutritional composition. Dry matter (DM) percentage was determined on subsamples dried at 65 °C to a constant weight and ground [32]. Total ash content was determined by incinerating the samples at 550 °C for 6 h [32]. Carbon and nitrogen contents were quantified according to the Dumas method [33] using a CHN elemental analyser (Carlo Erba, Milano, Italy). Total carbohydrates were determined after acid hydrolysis (2.5 M HCl for 30 min) by anthrone colourimetric method using a UV–Vis spectrophotometer (LAMBDA 365, Perkin Elmer, Milano, Italy) [34]. Water-soluble carbohydrates were evaluated by anthrone colourimetric method using a UV–Vis spectrophotometer (LAMBDA 365, Perkin Elmer, Milano, Italy) [34]. Neutral detergent fibre (NDF) was evaluated according to the method of Goering and Van Soest [35] using a manual crude fibre analyser (Fibertec FOSS, Denmark). Crude protein percentage was calculated by estimating nitrogen content by the Dumas method [33]. The ether extract was determined by solvent extraction in a Soxhlet apparatus with petroleum ether for 8 h [32].

2.1.2. Vitamin and Mineral Determination

On monthly samples of FVW, vitamins C and E were determined according to ISTISAN report 1996/34 [36] and β-carotene according to the EN 12823-2:2000 standard method. Other vitamins, including thiamin, riboflavin, niacin, pantothenic acid, vitamin B6, folic acid, and biotin, were determined by a microwell photometer using a microbiological test (VitaFast®-Biopharm; R-Biopharm, Darmstadt, Germany). Minerals (potassium, sodium, calcium, phosphorus, magnesium, iron, aluminium, silicate, chloride, zinc, bromide, manganese, copper, iodine, nickel, barium, chromium, cadmium, and lead) were detected with inductive coupled-plasma mass spectrometry (ICP-MS) analyses [37].

2.2. Chemical and Microbiological Analyses

All parameters analysed are reported in Table 2. The analyses were carried out according to validated and standardised methods on samples of FVW collected each month for one year from the waste-collecting site.

2.3. Statistical Analysis

Data were analysed using the GLM procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC, USA) with the month and season of sampling as the main factors. Data are expressed as the mean ± SD. Statistical significance was set at $p < 0.05$.

Table 2. Chemical and microbiological hazards evaluated in fruit and vegetable waste from the wholesale market.

	Investigated Parameters	Reference Methods
Pesticides	Atrazin, azinphos-ethyl, azinphos-methyl, azoxystrobin, benalaxyl, bitertanol, bupirimate, buprofezin, cadusafos, chlorfenvinphos, cyproconazol, cyprodinil, diazinon, ethoprophos, ethoxyquin, fenamiphos, fenarimol, fludioxonil, flusilazole, furalaxyl, kresoxim-methyl, malathion, metalaxyl, methidathion, oxadixyl, paraoxon-methyl, phosalone, piperonyl butoxide, pirimicarb, pirimiphos-ethyl, pirimiphos-methyl, profenophos, propachlor, propargite, pyrazophos, quinalphos, simazine, tetrachlorvinphos, tetraconazole, triazophos	[38,39]
Antibiotics	Amoxicillin, ampicillin, cloxacillin, dicloxacillin, benzylpenicillin, oxolinic acid, nalidixic acid, cefalexin, cefquinome, ciprofloxacin, enrofloxacin, lomefloxacin, marbofloxacin, florfenicol, florfenicol-amine, chloramphenicol, flumequine, chlortetracycline, doxycycline, oxytetracycline, tetracycline, lincomycin, sulfathiazole, sulfadimidine, sulfadiazine, sulphadimethoxin, trimethoprim, erythromycin, tylosin, thiamphenicol	[40]
Mycotoxins	Aflatoxin B1, B2, ochratoxin A	[41]
E. coli		ISO 16649-2:2001
Listeria monocytogenes		AFNOR BRD 07/10-04/05
Salmonella spp.		AFNOR BRD 07/06-07/04

3. Results

3.1. Nutritional Evaluation

In Table 3 the nutritional compositions of the FVW collected monthly for one year from the wholesale market of the city of Milan are reported. All nutritional parameters evaluated showed significant differences determined by the different months of collection of the FVW ($p < 0.05$). The DM content across the year was 10.82 ± 1.21 (mean ± SD), with significant differences considering the season of sampling ($p < 0.05$). However, there was no significant difference among NDF, soluble sugars, or carbon content when the seasonal effects of sampling were evaluated ($p > 0.05$) (Table 3).

Table 3. Nutritional composition (% dry matter) of fruit and vegetable waste from the wholesale market and its monthly and seasonal effects.

Item	Mean ± SD	Month *p*-Value	Season *p*-Value
Dry matter	10.82 ± 1.21	0.001	0.005
Crude protein	12.37 ± 2.4	<0.0001	0.002
NDF [a]	22.43 ± 4.52	<0.0001	0.072
Ash	8.12 ± 1.8	<0.0001	<0.0001
Soluble sugars	30.51 ± 7.61	<0.0001	0.524
Carbon	43.73 ± 2.4	<0.0001	0.097
Nitrogen	1.97 ± 0.38	<0.0001	0.002

[a] NDF = neutral detergent fibre.

The season variability of the nutritional component of the FVW is shown in Table 4.

Table 4. Mean scores of nutritional composition (% dry matter) of fruits and vegetables from the wholesale market across the seasons.

	Seasons			
Item	**Autumn**	**Winter**	**Spring**	**Summer**
Dry matter	10.35 ± 0.43	10.47 ± 1.37	10.11 ± 0.76	12.36 ± 0.47
Crude protein	13.53 ± 0.65	12.42 ± 1.61	13.92 ± 3.06	9.63 ± 0.78
NDF [a]	22.17 ± 2.04	26.24± 6.69	19.69 ± 1.61	21.61 ± 3.93
Ash	9.67 ± 0.45	7.44 ± 1.02	9.22 ± 1.9	6.13 ± 0.66
Soluble sugars	32.13 ± 9.16	33.38 ± 10.29	29.28 ± 2.08	27.25 ± 6.67
Carbon	42.54 ± 2.9	43.16 ± 1.68	43.49 ± 2.53	45.76 ± 1.36
Nitrogen	2.16 ± 0.1	1.98 ± 0.26	2.22 ± 0.49	1.54 ± 0.12

[a] NDF = neutral detergent fibre.

On average, FVW from the wholesale market had the highest DM content in summer (12.36 ± 0.47%), whereas during the other seasons of the year the DM ranged from 10.11% to 10.47%, showing to be more stable. Interestingly, soluble sugars showed similar content in all seasons, with levels ranging from 27.25% to 33.38%.

The FVW was evaluated for the content of vitamins and minerals during the year of sampling. Table 5 shows the range of vitamin content throughout the seasons of sampling. FVW had a wide range of vitamins, the most present of which were β-carotene and riboflavin, with levels ranging from 2040 to 4246 μg/100 g and from 3.4 to 4.94 mg/100 g, respectively. Among the minerals, potassium was shown to be present in a good quantity, ranging from 2467 to 2763 mg/100 g (Table 6).

Table 5. Range content of water-soluble and fat-soluble vitamins present in fruit and vegetable waste from the wholesale market across the seasons.

	Seasons			
Vitamins	**Autumn**	**Winter**	**Spring**	**Summer**
Water-soluble				
Ascorbic acid, mg/100 g	0.7–2.5	0.5–1.7	0.5–1.5	0.6–2.0
Thiamin (B1), mg/100 g	0.69–0.71	0.69–0.72	0.69–0.70	0.69–0.71
Riboflavin (B2), mg/100 g	3.58–4.94	3.61–4.38	3.40–4.37	3.49–4.75
Niacin (B3), mg/100 g	1.0–1.3	1.1–1.3	1.2–1.5	1.0–1.4
Pantothenic acid (B5), mg/100 g	1.93–2.12	1.91–2.08	1.95–2.08	2.02–2.15
Vitamin B6, mg/100 g	0.25–0.34	0.25–0.30	0.27–0.33	0.29–0.35
Folic acid (B9), μg/100 g	1.21–1.98	1.58–2.70	1.82–2.29	1.50–2.46
Biotin (H), μg/100 g	1.57–2.15	1.40–1.93	1.65–2.07	1.88–2.12
Fat-soluble				
β-carotene μg/100 g	3473–4246	2310–3441	2192–2991	2040–2220
Vitamin E μg/100 g	0.3–0.5	0.2–0.4	0.2–0.5	0.3–0.4

3.2. Evaluation of Safety Aspects

The FVW samples were analysed considering their safety aspects (Table 2). No residue of antibiotics, pesticides, or mycotoxins were detected. The microbiological results are expressed as CFU/g, whereas the *Salmonella spp*. and *Listeria monocytogenes* results are expressed as present or absent in 25g of sample. The results showed that *E. Coli* was <10 CFU/g in all samples evaluated and *Salmonella spp*. and *Listeria monocytogenes* were absent in 25 g. Considering the heavy metals of concern for safety aspects, they were all under the limits of quantification (LOQ), as reported in Table 6.

Table 6. Range of mineral content present in fruit and vegetable waste from the wholesale market across the seasons.

	Seasons			
Minerals	**Autumn**	**Winter**	**Spring**	**Summer**
Aluminium, mg/100 g	5.16–7.22	3.41–6.15	3.20–4.6	2.54–5.55
Calcium, mg/100 g	344.5–509.7	290.8–538.0	2502–440.8	241.3–335.4
Total chromium, mg/100 g	0.11–0.22	0.11–0.15	0.09–0.15	0.11–0.18
Iron, mg/100 g	4.41–5.39	3.77–4.80	3.20–4.33	3.92–4.56
Magnesium, mg/100 g	124.5–137.2	117.4–145.1	135.3–159.8	129.5–144.4
Manganese, mg/100 g	1.85–2.19	2.10–2.61	1.97–2.28	1.98–2.34
Potassium, mg/100 g	2578–2702	2437–2669	2515–2634	2631–2763
Copper, mg/100 g	0.51–0.63	0.66–0.76	0.59–0.71	0.70–0.73
Silicon, mg/100 g	20.1–23.7	18.5–22.7	14.1–19.2	12.7–16.5
Sodium, mg/100 g	55.7–73.2	45.9–66.7	41.7–75.6	30.9–65.7
Arsenic, mg/100 g [(a)]	<0.005	<0.005	<0.005	<0.005
Cadmium, mg/100 g [(a)]	<0.001	<0.001	<0.001	<0.001
Mercury, mg/100 g [(a)]	<0.005	<0.005	<0.005	<0.005
Nickel, mg/100 g [(a)]	<0.013	<0.013	<0.013	<0.013
Lead, mg/100 g [(a)]	<0.001	<0.001	<0.001	<0.001

[(a)] Detected in the lower limit of quantification (LOQ).

3.3. Nutritional Evaluation after a Pressing Treatment

Since one of the aims of the study was to consider the reduction of water content at the collection site, the residue remaining after the pressing of the FVW was analysed for its principal nutritional constituents (Table 3). The aqueous content removed after FVW pressing was on average 44 $\pm$ 3.96%, with an increase in the DM content from 10.82 $\pm$ 1.21% to 55 $\pm$ 1.91%. The nutritional parameters of the residual waste remaining after the water reduction showed a similar nutritional composition of FVW before treatment (Table 7).

Table 7. Nutritional composition of fruit and vegetable residual waste from the wholesale market after pressing. The results are expressed in (% dry matter basis).

Item	Mean $\pm$ SD
Dry matter	55 $\pm$ 1.91
Crude protein	11.9 $\pm$ 1.98
NDF [a]	25.6 $\pm$ 4.48
Ash	8.04 $\pm$ 2.01
Soluble sugars	25.9 $\pm$ 6.87
Carbon	42.8 $\pm$ 2.03
Nitrogen	1.84 $\pm$ 0.29

[a] NDF = neutral detergent fibre.

4. Discussion

This study was conducted to evaluate the nutritional composition of the fruits and vegetables discarded from the wholesale market of Milan over a one-year sampling period. The results clearly indicate that FVW has an interesting nutritional value, although some differences in composition were found in the 12 months of sampling due to the variability of the waste composition.

The amount and characteristics of these wastes vary from market to market and from season to season of sale and/or production, due to the typical seasonality of fruits and vegetables, the geographic location, and the demand for these products. All of these factors could influence the nutritional characteristics of the discarded products [20]. To define and evaluate the best strategy for reusing this waste as animal feed, according to Angulo et al. [20], it is necessary to know the nutritional value of FVW as well as its possible variations over time. For instance, on waste originating from fruit shops where the fruit was always similar, Esteban et al. [42] did not find seasonal variability. Furthermore, its reuse for productive purposes should be aimed at obtaining a tangible and direct advantage, responding to the demand for the valorisation of agricultural and processing waste throughout the fruit and vegetable supply chain sector (OCM—Ortofrutta Stategia Nazionale 2018–2022, version annexed to DM 27/09/2018 n. 9286). The variable nutrient composition in this waste throughout the year thus needs to be considered. However, it is a particular waste, because as an ex-food it has nutritional value. Its reuse as feed preserves the food chain line. Large quantities of this waste are generated daily by wholesale markets and food industries. For large quantities of FVW, and being aware of the nutritional variability that can occur, it may be useful to use rapid NIR spectroscopy to assess its nutritional composition before adding it to animal diets.

On average, the FVW tested in this study had a dry matter content of 10.82 ± 1.21. Its high perishability is the main problem faced when proposing this waste as a feed ingredient. Although some authors propose either using it as is, without treatment, and including it in rations immediately, or with the addition of sodium metabisulfite to prevent microbial spoilage [43,44], others dehydrate the waste material to 10–16% moisture [22] or propose ensiling it with dry by-product feeds after treatment with sodium metabisulfite [45].

From the perspective of nutritional value, however, its applications as a feed ingredient could be important. In our study, crude protein was on average 12.37% DM, slightly higher than that reported by Angulo et al. [20] and by Song et al. [44], but similar to that obtained by Das et al. [46] and by Esteban et al. [42]. The NDF content was low, as these wastes consisted of whole fruit and vegetables. NDF contains cellulose, hemicellulose, and lignin as the major components [47]. The NDF value accounts for the cell wall fraction not digested by endogenous enzymes. It is used by ruminal microorganisms and in monogastric animals by intestinal microorganisms to produce energy as short chain fatty acids (SCFA). Whereas in ruminants fibrous feed is the basic ingredient in the diet, in monogastrics it reduces nutrient and energy digestibility. However, in monogastric animals, despite the lower digestibility and related negative effects on the digestibility of other nutrients, fibre and SCFA promote the growth of beneficial gut bacteria, supporting intestinal integrity, gut health, and proper immune function [48,49]. The richness in soluble sugars was constant throughout the year. Soluble sugars are an important source of energy, as they can be rapidly used. These sugars are fermented in the rumen to produce acetate and butyrate as main products [50]. The carbohydrate characteristics of this waste further contributed to supporting recycling it as a feed ingredient for livestock. Among micronutrients, FVW was rich in vitamins and minerals, which are important for animal health. In particular, among water-soluble vitamins, riboflavin (B2) and pantothenic acid (B5) were well represented, whereas among the fat-soluble ones β-carotene was the most significant. Some important minerals like calcium, magnesium, and potassium were well represented. Moreover, micro minerals such as iron, zinc, copper, and manganese were detected in a significant amount for the animal feed ratio.

Of course, since the aim of this investigation is to reintroduce this waste into the food chain as a feed ingredient, the safety aspects needed to be clearly assessed. In-depth analyses on safety aspects were conducted that considered heavy metals, pesticides, and antibiotic residues; mycotoxins; and microbiological hazards, which did not highlight safety issues. Since FVW was collected from the wholesale market of Milan, where the fruits and vegetables were earmarked for human consumption, their safety is an essential prerequisite. Accordingly, they were subjected to strict controls to ensure an adequate hygienic-sanitary profile. In our evaluation, the safety parameters were maintained until the collection point where the unsold fruits and vegetables are discarded. However, it is important to remember that FVW is damaged when spoilt and bruised. Furthermore, it is a fresh and perishable waste with high water content. These conditions can lead to contamination risks due to the growth of microorganisms after its collection. Since this waste is meant to be reintroduced into the food production chain as a feed ingredient, safety must be preserved to maintain the quality and the nutritional value and prevent spoilage. To this end, effective intervention strategies need to be implemented promptly to keep the food chain line safe. Among these, water reduction and the addition of preservative agents should be considered [20,44]. Reducing the water content of FVW is a possible strategy to better preserve the safety of this waste. In addition, lighter biomass resulting from partial water removal can reduce the number of trips to the feed facility or the biogas plant [7]. Furthermore, considering that 1 tonne of waste transported for 1 km has a global warming impact of 0.174 kg CO_2 eq [31]. It is evident that reducing the number of trips will decrease the environmental impact of transport. Even by a simple waste pressing to increase DM to 55%, the biomass will maintain mostly the same nutritional characteristics, and the transportation time will be greatly decreased. In addition, to ensure biosecurity, it should be sent as soon as possible to feed industries for the drying process or to farms for use (Figure 2). When this is not possible or economically feasible, alternative processing strategies should be considered. For example, recent advances in green extraction technologies have shown that bioactive compounds present in fresh plant materials such as tomatoes [51], artichokes [52], and coffee residues [53] can be easily recovered and used to enrich food or feed products. Besides, the components in the liquid removed after pressing FVW can be valorised in a complete biorefinery approach to be investigated in future research.

Therefore, to ensure high quality and safety levels, appropriate practices should be devised for handling FVW. As reported by Abadi et al. [23], the use of technology, facilities, and infrastructures can help improve FVW management. Hence, equipping wholesale markets with high technologies can greatly improve the quality of FVW management and the processed amounts.

5. Conclusions

This study aimed to assess the possibility of reallocating FVW into livestock nutrition based on the nutritional analysis carried out on a full year of evaluation and considering the seasonal variability and safety aspects.

Preliminary tests done at the wholesale market showed that for such big centres, the nutritional values were very close to their annual mean. The obtained results showed that the FVW generated from the General Wholesale Market of Milan is a safe waste and can be reintroduced into the food production chain. In particular, FVW is rich in nutrients that can be easily processed into animal feed ingredients. Since the waste from fruits and vegetables is constantly increasing, its reallocation to livestock feed can also contribute to sustainable livestock production. Moreover, using rapid NIR spectroscopy to evaluate nutritional composition before adding FVW to the diet can overcome problems originating from its variable composition across the year.

This study can lay the groundwork for creating collection points in markets and industries that generate high amounts of FVW, a material that can be effectively used for feed production, after an accurate control of its water content, which is a key factor for safety and economic considerations.

Furthermore, assessing opportunities to reintroduce this FVW in the food chain can represent a contribution to reaching the Sustainable Development Goals. In particular, it can be well-positioned in the framework of ensuring sustainable consumption and production (12th SDG), minimizing production waste in a circular-economy approach.

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