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Importance of Nutritional Properties of Fruit and Vegetable Wastes and By-Products in Livestock Feed Production: A Review

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***Abstract*—In a world grappling with the dual challenges of food security and sustainable agricultural practices, the innovative use of fruit and vegetable processing by-product as livestock feed has emerged as a promising solution. Every year, vast quantities of fruits and vegetables are discarded due to cosmetic imperfections or surplus production, contributing to both food waste and environmental concerns. However, recognizing the nutritional value of this waste stream and its potential to enhance livestock diets presents an opportunity to simultaneously reduce waste, alleviate pressure on natural resources, and improve livestock productivity. This paradigm shifts towards utilizing fruit and vegetable waste as livestock feed not only demonstrates a commitment to waste reduction but also holds the potential to transform the way we think about sustainable food systems. Moreover, many studies showed that incorporation of fruit and vegetable wastes into livestock feed can effectively improve the livestock diet thereby productivity of a farm. This review article focuses on the utilization of fruit and vegetable processing by-products to livestock feed, their nutritional values, feeding management, and the constraints.**

Keywords*—*By-product, fruit, vegetable, livestock, feed

I INTRODUCTION

The livestock sector encompasses dairy, poultry, swine, goat, and sheep subsectors. In 2021, this livestock sector played a vital role, contributing approximately 11 percent to the country's agricultural GDP and providing employment for approximately 600,000 individuals [1]. In numerous developing Asian countries, there is a significant deficit in livestock feed availability, primarily attributable to constraints such as limited land for fodder cultivation, urban expansion, and competition among food, feed, and fuel resources [2]. Furthermore, the rising costs of feed ingredients have created a situation where cost-effective feed formulations are crucial. By incorporating less expensive alternatives, the overall cost of feed production can be reduced.

Fruit and vegetable processing by-products consists of wastage from the various stages of processing industries. Therefore, utilizing them as livestock feed presents an opportunity to address the prevalent feed shortage in many developing nations [3, 4] as wastage from fruit and vegetable processing are often available at low cost or even no cost. Incorporation of variety of fruits and vegetable wastes and by-products in feed formulation can create a more balanced diet for livestock. Fruits and vegetable by-products can be a valuable source of macro and micronutrients, phytochemicals such as carotenoids, phenolics, and flavonoids which possess antioxidant, antimicrobial properties [4]. Such positive functional and nutritional attributes can improve the palatability of the feed while contributing to better animal growth and health.

On the other hand, utilizing fruit and vegetable waste as livestock feed is a promising solution to address the challenges of food waste, environmental sustainability, and livestock productivity [5]. By repurposing these discarded resources, we can reduce food waste, minimize environmental impact, and enhance the efficiency of our agricultural practices. This innovative approach not only tackles pressing global issues but also paves the way for a more sustainable and responsible approach to food production and waste reduction.

Therefore, use of fruits and vegetable wastes and by-products in feed formulation for developing countries like Sri Lanka, is a sustainable and economically sound approach. Annual fruits and vegetable production in Sri Lanka exceeds 900, 000 MT (metric tons) [6]. Sri Lanka annually produces 710,000 MT of vegetables and 540,000 MT of fruits. About 40% of this production is wasted due to post-harvest loss. Additionally, 19% of vegetables (approximately 221,955 MT) and 21% of fruits (approximately 290,151 MT) are wasted during transportation [6], [7]. In Sri Lankan scenario, these resources remain largely unexplored, and their efficient utilization can expand the available feed supply, increase feed availability, and reintegrate wasted food into the human food supply chain [8].

The objective of this review is to explore the potential sources of fruit and vegetable wastes and by-products and summarize how their nutritional properties are beneficial in livestock feed formulation.

II FRUIT AND VEGETABLE WASTE AND BY-PRODUCTS AS LIVESTOCK FEED

The fruits and vegetables waste that was accessible included unprocessed fruits and vegetables that were not suitable for human consumption, as well as their peels, seeds, stones, and leftovers [1]. Numerous studies have explored the viability of using various fruit and vegetable wastes as livestock feed. Tables 1 and 2 provide a summary of select fruit and vegetable wastes and by-products including seeds, stalks, pulp, peels etc. which can be used in feed formulation. Use of these materials in feed formulation have been studied considering their suitability, chemical

composition, nutritional values, moisture content, contaminations such as microbes, pesticides, toxins etc.

TABLE I. STUDIED FRUIT WASTES AND BY-PRODUCTS THAT CAN BE USED AS LIVESTOCK FEED

Fruits	**Wastes and By-products**	**References**
Grapes	Pomace, Seeds, stalk	[40], [41],[42], [43]
Citrus fruits	Peel, Pulp, Ensiled Citrus pulp, Citrus molasses	[9], [10], [41], [42], [43]
Pomegranate	Seeds, Peel, Pulp	[43]
Apple	Peels, Core, Seeds, Stems	[41], [42], [43], [45]
Banana	Peels, Leaves, young stalks and Pseudo stems, Damaged banana	[3], [9], [42]
Muskmelon	Peels	[10]
Watermelon	Peels	[10]
Mango	Peels, Seed kernels	[9], [42]
Pineapple	Bran, Skin, Crown, Cannery waste, Pomace	[9], [42], [45]
Avocado	Peels	[42]

TABLE II. STUDIED VEGETABLE WASTES AND BY-PRODUCTS THAT CAN BE USED AS LIVESTOCK FEED

Vegetables	**Wastes and By-products**	**References**
Lettuce	Leaves	[3], [9], [23], [40]
Cabbage (red and green)	Leaves	[19], [21], [22], [23], [24], [26], [40], [42], [46]
Cauliflower	Leaves, inflorescence	[19], [20], [21], [22], [23], [24], [25], [40], [46]
Tomato	Pomace, Seed, Skin, Cull tomatoes	[41], [42], [43], [47]
Carrot	Peel, Pulp, Tops	[9], [10], [41], [43], [45], [48]
Soybean	Seeds	[41]
Potato	Peel	[40], [41], [42]
Sunflower	Seeds	[41]
Pumpkin	Peel, Pulp, Seeds, Seed flour	[28]
Pea	Empty pods	[9], [10]
Baby corn	Husk, Fodder	[9]
Bottle gourd	Pulp	[9]
Sugar beet	Leaves, Pulp	[9]
Radish	Leaves	[9]
Sweet potato	Whole or chopped cull sweet potato, Peels, Cannery waste	[44]

III NUTRITIONAL ATTRIBUTES OF FRUIT AND VEGETABLE BY-PRODUCTS THAT CONTRIBUTES TO THEIR UTILITY IN FEED FORMULATION

The characteristics of fruit and vegetable wastes and by-products such as nutrient density, diverse compositions, and cost effectiveness enable feed formulators to create nutritionally balanced, economically feasible, and environmentally friendly feeds for different animal species.

Nutrient density is a key contributing factor on the nutritional value of animal feed. Dried apple pomace which is a by-product left after apple have been processed is found to contain 7.7% crude protein (CP), 5.0% fat, and offers 1.86 Mcal metabolizable energy per kg of dry matter [9]. The same study has also shown that for lactating dairy cows, it provides 1.06 to1.12 Mcal net energy per kg of dry matter, with the best feed conversion observed at a 15% incorporation in their diet. Moreover, apple pomace can be valuable component in broiler rations as a partial replacement for maize [42] stated that in broiler rations, it can replace 10-20% of maize without negatively impacting broiler production [9].

Ripen banana peels contain approximately 8% crude protein, 6.2% fat, 13.8% soluble sugars, and 4.8% total phenolics [9, 10]. They are rich in trace elements, especially Fe, Cu, and Zn, surpassing safe intake levels for ruminants. Therefore, it is advisable not to feed banana peels ad libitum but to supplement them in the ruminant's diet as a source of organic minerals [9]. Several studies have suggested that in tropical areas, ripen banana peels can be utilized as an additional dietary resource for ruminant animals as it is readily available in many tropical areas being a cost-effective resource [9, 11, 12, 13]. Moreover, these studies have stated as banana peel contains significant amount of dietary fiber it is beneficial for ruminants which could be supporting proper microbial fermentation in the rumen.

Raw pineapple waste, on a dry matter basis, typically contains 4 to 8% crude protein, 60 to 72% neutral detergent fiber (NDF), and 40 to 75% soluble sugars which can contribute to the overall nutritional value of feed. However, it lacks minerals [9, 14, 15], necessitating supplementation with protein and minerals to prevent adverse effects on animal productivity and health [9].

Numerous studies have demonstrated that dried citrus pulp serves as a safe and effective alternative to cereals in the diets of animals on high-concentrate, low-roughage regimens, particularly high-yield dairy cows. Its nutrient content, fiber-rich nature, sustainability, and cost-effectiveness make it a feasible choice for livestock feed. It

can replace up to 20% of the concentrate in dairy cattle diets, up to 30% in lactating cow's diets, and up to 50% in gestating and lactating sow's diets [9]. Moreover, it can be included at levels of 20 to 30% in rabbit diets and 5 to10% in poultry diets [9]. When ensiled dried citrus pulp with wheat or rice straw in a 70:30 ratio, it produces excellent silage [9]. Importantly, these substitutions do not negatively impact essential factors such as dry matter intake, rumen metabolites, digestibility, milk production, or milk protein and fat content [9, 10, 16, 17, 18].

Numerous studies have consistently highlighted the potential of leafy vegetable waste materials as an excellent and cost-effective source of essential nutrients for livestock feed. For example, these studies consistently report a significant amount of crude protein (CP) in leafy vegetable waste, typically falling within the range of 14.4% to 24.1% [9, 19, 20, 21, 23]. The low-fat content of certain vegetable by-products provides a valuable option for feed formulators to control the overall fat content in animal feeds. Cabbage waste stands out for its relatively low levels of fat, which range from 0.5% to 2.3% [19, 22, 23]. This lower fat content is advantageous for ruminant diets, as high fat content can adversely affect rumen chemistry and biology [23]. Furthermore, research indicates varied levels of total ash content in different leafy vegetables. For example, the total ash content of cauliflower ranges from 7% to 16.7% [20, 21, 24, 25], cabbage from 2.3% to 17.2% [24, 26], and lettuce at 24.7% [23]. In addition, acid detergent fiber content (ADF), and NDF in vegetable by-products can offer several advantages in feed formulation especially for ruminants supporting digestive health. ADF is a measure of non-digestible components primarily composed of cellulose fibers and lignin [23] whereas NDF measures total fiber content consists of cellulose, hemicellulose, lignin, and other complex carbohydrates. Studies have reported ADF values for cabbage and cauliflower in the range of 22.9% to 23% and 20% to 29.3%, respectively [21, 22, 23, 24]. NDF is a crucial factor in animal diets, affecting both the amount of dry matter consumed by animals and the duration of their rumination. Moreover, NDF content in feeds is inversely related to their energy concentration [23]. For example, various studies have reported NDF values for cabbage ranging from 20.9% to 34%, while cauliflower had a NDF content of approximately 28% to 29% [19, 22, 23, 24]. These findings highlight the potential of utilizing leafy vegetable waste as a livestock feed, given its high crude protein content, low levels of fat, fiber, ADF, and NDF.

In a study by [9], fresh carrots were found to be rich in water (88%), crude protein (10%), and sugars, making them a valuable feed option for various animals. When incorporated into the diets of dairy cows, carrot by-products can enhance reproductive performance, including a reduced calving interval, fewer inseminations required for successful fertilization, and an increased calving rate and as carrots being a rich source of metabolizable energy (ME) , at 3.29 Mcal/kg DM and net energy (NE) , at 1.94 Mcal/kg DM can be fed at levels of up to 20 to 25 kg/day to lactating dairy cows and young bulls to a well body maintenance, growth, and lactation [8, 9]. Dehydrated carrots are popular as treats for laying hens; the addition of 4 to 8% dried carrot meal improves yolk color without affecting egg production. Carrot pomace, containing 64.3% soluble sugars, holds promise for providing nutritional value to animals [9]. A study conducted by [42] explored a variety of vegetable and fruit waste suitable for poultry diets. The findings indicate that culled carrots and carrot tops can enhance yolk color at inclusion levels of 4% and 15%, respectively.

Additionally, empty pea pods are also a valuable feed source for ruminants, owing to its high crude protein content (19.8%), soluble sugars, phenolics, and essential macro- and micro-elements. In addition, bottle gourd pulp waste can also be recommended at a level of 50% in the concentrate mixture for adult ruminants [9], [27].

The study done by [28] highlighted that research on the use of pumpkin seeds in animal feed such as for broiler chickens [29, 30, 31], laying hens [32, 33], turkeys [34], dairy cows [35], and pigs [36]. These studies have identified a range of bioactive compounds in pumpkin seeds and pulp, including antioxidants, antifungal, antiparasitic, antimicrobial, and anti-inflammatory substances. This suggests that the inclusion of pumpkin in animal diets has the potential to enhance the health, productivity, and overall well-being of livestock.

Fresh cull tomatoes which are removed during the packaging process due to damages are rich in protein (14 to 20% crude protein), fat (11 to13%), soluble sugars (90 to 95%), and pectin (5 to 10%) [9, 37, 38]. They can be fed to male goats alongside hay without digestive issues [9, 38]. Another study has shown that dried cull tomatoes can replace alfalfa meal for broilers as it contains 19 to 22% crude protein and 11 to 13% fat) [9]. Further, ground tomato pomace can fully replace concentrates in the diet of male buffaloes without affecting feed intake, nutrient digestibility, or rumen function, as shown in multiple studies [9, 39]. Dried tomato pomace (20%) and tomato seed (15%) are suitable additions, while cooked potatoes and sweet potato meal (up to 40%) and peeled sweet potatoes (up to 15%) are viable options [42].

In a 2012 study conducted by (40), an analysis of fruit and vegetable waste from a Colombian marketplace has been performed, focusing on nutritional aspects. The study revealed that FV contained approximately 10% CP, 36.6% NDF, and 29.6% ADF. Moreover, it exhibited high ruminal degradability at 87.8% within 24 hours, possessed an energy content of 3657 kcal/kg, and contained 0.59% calcium (Ca^{2+}) and 0.21% phosphorus (P). These findings strongly highlight the potential of FV as a promising feed option for bovine nutrition.

Utilizing waste from the fruit and vegetable processing industry in formulating animal feed can be a successful practice for a variety of farm animals, including poultry, ruminants, and non-ruminants. Incorporating these by-products into animal diets can lead to significant improvements in animal growth, performance, reproduction, and the quality of products such as meat, milk, and eggs. These improvements are attributed to the antioxidant and antimicrobial properties of the ingredients, positive changes in fatty acid composition, enhanced yolk color, and improved milk fatty acid composition. Furthermore, peels, pomace, and seeds are potent reservoirs of bioactive compounds, including flavonoids, tannins, polyphenols, and antioxidants. These compounds not only modulate ruminal processes but also exert positive effects on ruminant health, bolstering immune systems and enhancing milk production [21, 43]. Importantly, it has been observed that the inclusion of fruit and vegetable by-products/wastes in livestock diets

does not have any adverse effects on animal performance. Therefore, as the review summarized, fruit and vegetable by-products can be considered as a sustainable alternative to conventional animal feed. Nevertheless, it is essential to handle feed formulation carefully to promote both sustainable animal production and improved nutrition.

IV Challenges

The utilization of fruit and vegetable waste as feed for livestock poses several obstacles. One major challenge is the perishable nature of these waste materials. Fruits and vegetables can quickly spoil [49], which makes it difficult to store and use them as consistent feed sources for livestock. Additionally, there is the issue of heterogeneity [49], meaning that these by-products can vary in composition and quality, making it challenging to provide a uniform and balanced diet for the animals.

The next dominant challenges associated with using these products as livestock feed are elevated moisture levels and the presence of contaminants, predominantly pesticides and their residues. It is imperative to establish a monitoring system for assessing the levels of pesticides, pesticide residues, mycotoxins, heavy metals, and antinutritional factors before incorporating vegetable products into animal diets [3, 8]. This precautionary step is crucial to ensure the safety and nutritional quality of the feed and, consequently, the health and productivity of the livestock. Supporting this report by [51] highlighted that, collecting and storing fruit and vegetable waste for livestock feed face challenges due to the diverse sources, seasonal variability, perishability, space constraints, and the need for hygiene and contamination control.

To encourage food-waste producers and the livestock industry to actively promote and implement change, it will be essential to establish legislation rooted in scientifically sound research. This legislation can serve as a powerful incentive, providing a structured framework for reducing food waste and optimizing the use of waste materials as livestock feed [50]. By ensuring that these regulations are well-informed by rigorous research, they can effectively drive the necessary changes in both sectors, fostering more sustainable practices and reducing overall waste in the food supply chain.

V Conclusion

In summary, this review highlights the significant potential of fruit and vegetable wastes and by-products as a sustainable resource in livestock feed. It emphasizes the importance of nutritional value and sound feeding management, revealing the role of fruit and vegetable by-products in promoting economic and ecological sustainability in the livestock industry. While using these waste materials helps reduce food waste and enhances animal nutrition and herd health, it must be cautious about any possible toxic chemicals, heavy metals, and pesticide residues in fruit and vegetable by-products. Therefore, careful assessment and handling of these materials are vital. By addressing these concerns, benefits of fruits and vegetable by-products can be enhanced while minimizing potential risks and continue working toward a more responsible and sustainable future in livestock production.

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