Compositional and Nutritional Profiling of Fruit and Vegetable Wastes for Poultry Feed Development: A Comparative Study with Commercial Feeds

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Abstract

The current investigation evaluates the nutritional and functional potential of fruit and vegetable wastes (FVWs) as sustainable substitute to conventional poultry feed. The physical characterization of FVWs revealed optimal pH value (5.3-6.6), moisture content (9.7-12.7 %), and water holding capacity (76.3 %) highlighted favorable preservation, digestibility, and stability of the biomass. Biochemical analysis identified potato peels and banana foliage as rich sources of carbohydrates (65.76 %) and poor in lignin, respectively, enhancing their feed suitability. Likewise, pea pods showed the highest crude protein (19.8 %). Further, vitamin analysis revealed carrot pulp and pea pods as potent sources of vitamin A (1520 and 1011 IU/100 g). Fiber content ranged from 2.2 % to 20.6 %, with carrot pulp and apple pomace being the richest sources. Amino acid study highlighted banana foliage and pea pods as nutrient-dense biomass, rich in key amino acids *viz*., leucine, isoleucine, and lysine. The FVW-based feed showed 1.2-1.76 folds higher protein content in comparison to commercial local and branded feeds. Further, FVW-based feed revealed comparable or superior concentrations of essential amino acids like threonine and isoleucine in comparison to both commercial feeds. These findings underscores the inclusion of selected FVWs for poultry feed formulations, offering a cost-effective, nutritionally balanced, and environmentally sustainable alternative to conventional feed resources at an industrial scale.

Keywords: Fruits and vegetable waste; Poultry feed; Animal health; Protein; Carbohydrates; Compositional analysis

1. Introduction

Poultry farming possess a central role in global agriculture development especially in developing nations like India and other subcontinent region of Asia (Islam et al., 2022). It significantly contributing to food safety through supplying the protein enriched diet including meat and eggs (Bist et al., 2024). The ever-increasing insist of poultry products has entailed the development of sustainable, cost-effective, and nutrient-enriched feed formulations (Pesti & Choct, 2023). Poultry bird's performance extremely associated with balanced nutrition diet, which ensures their growth, reproductive efficacy, diseases resistance, and the quality of meat and eggs (Barszcz et al., 2024). Poultry feed characteristically constitutes grains, protein meals, minerals, vitamins, and essential amino acids. The dependency on conventional feed ingredients namely corn, soybean meal, wheat grains, fishmeal etc. has led to increase the competition among human and animal nutrition (Chisoro et al., 2023). According to a report by business plans (2024), the feed operating cost generally accounts for 60-70 % of total expenditure in poultry farming, and custom a considerable challenge for farmers, especially in low-income regions (https://businessplan-templates.com/blogs/running-costs/poultry-farm). Additionally, the harsh environmental impacts associated with the production and transportation of these feed ingredients emphasizes the urgency for sustainable substitutes (Chen et al., 2021). These potent challenges have governed the interest of researchers to search for alternative, inexpensive, and sustainable feed resources with optimal nutritional values (Sun et al., 2024). Among various approaches, inclusion of fruit and vegetable wastes (FWVs) into poultry feed formulations seems to be a viable solution to address these challenges (Dou et al., 2024).

Fruit and vegetable wastes are rich source of essential nutrients, carbohydrates, proteins, amino acids, vitamins (A, C, and E), fats, dietary fibers, minerals (potassium and magnesium), antioxidants, and other health beneficial bioactive compounds like polyphenols and flavonoid (Tsegay et al., 2024; Vicente et al., 2022). These byproducts including peels, seeds, pulps, stubs, and other residues are majorly generated during processing and consumption of foods (Kaur, 2023). Despite their nutritional values, these residues are majorly decomposed in landfills, which not only loss the valuable resources but also contributes to environmental manipulation through green house gases emissions (Noor et al., 2024). The inclusion of FVWs as feed ingredients renders several advantages including reduction in the cost and dependency on conventional feed ingredients; increase the capita of farmers by utilizing the food processing industries wastes; and aligns with global sustainability goals to promote circular economy practices by reducing food waste and environmental pollution simultaneously (Kumar Gupta et al., 2024; Michel et al., 2024).

Previous studies have explored the inclusion of various agro-wastes and food byproducts in poultry feed enhanced the animal growth, performance, and health by stimulating gut microbiota, boosting immunity, and mitigating oxidative stress (Ikusika et al., 2024; Malenica et al., 2023; Mnisi et al., 2022). FVWs including fruit peels of banana, citrus, apple, mango etc. and residues of vegetable like carrot, tomato, pea, cabbage etc. have been shown to improve growth performance and health in poultry owing to their high energy and nutrient content (Râpă et al., 2024). Despite their potent welfares, the supplementation of FVWs into poultry feed also features several challenges. One major obstacle is the variation in nutrient composition, which depends on the nature of waste, seasonal availability, and processing methods. Further, some FVWs also contain anti-nutritional factors, such as tannins and oxalates, which can hinder with nutrient absorption and reduce feed efficacy (Malenica et al., 2023; Muleta, 2024; Pesti & Choct, 2023).

Previously, most of the studies related to inclusion of FVWs in poultry feed fully focused on precise types of FVW without providing inclusive insights into the formulation and optimization of mixed FVW-based feeds (Afolabı et al., 2023; Peñaflor et al., 2023; Pereira Farias et al., 2021; Zhang et al., 2021). While other studies have explored the compositional analysis of FVWs or their general applications in animal feed, inadequate research has focused on their detailed utility in poultry feed formulation (Al-Sagheer et al., 2023; Castaldo et al., 2022; Kandemir & Bozbay, 2023; Yang et al., 2022). To the best of our knowledge, there is a lack of ample comparison between the nutritional profiles of FVWs-based feeds with commercial options, especially in terms of their proximate composition. Therefore, in the current investigation we have addressed these gaps by not only analyzing the compositional properties of FVWs but also formulating poultry feed that benefit these wastes as a sustainable substitute. By directly comparing the nutritional efficiency of the FVWs-based feed to commercial diet, this research provides crucial insights into their potential to reduce feed costs and sustainable development of poultry feed to meet the global goal of circular economy.

2. Materials and methods

2.1. Raw feedstocks and chemicals

Various FVWs were collected from a local market fruit and vegetable market, juice corner, and food courts from Bhiwani, Haryana, India. In details, apple pomace, mango kernel, and carrot pulp was collected from juice corner, while, potato peels and pea pods were collected from hotel kitchen, and banana foliage were collected from fruit and vegetable market. All chemicals and reagents used in this study were of the analytical and HPLC grade available commercially.

2.2. Preparation of FVWs

Fruit and vegetable wastes were manually sorted to separate the traces of plastic, paper, and organic waste by spreading them on a flat surface. The feedstocks were then chopped in coarse particles using a knife. The FVWs were dried in a solar tunnel dryer, a low-cost drying method that utilized the renewable solar energy to reduce the moisture content of the biomass. The feedstocks were then fed into the portable biomass shredder and power mixture grinder to attain a final average particle size of 1-2 mm. The biomass powders were stored in moisture free are in air-tight seal polybags, until further usage.

2.3. Physical properties analysis of different FVWs

The physical analyses of various FVWs were carried out to access their moisture content and pH by following the standard protocols of FSSAI manual for fruits and vegetables products (https://fssai.gov.in/upload/uploadfiles/files/Manual_Fruits_Veg_25_05_2016(1).pdf). The water holding capacity of the FVWs was determined by following the centrifugation method (Boulos et al., 2000). In brief, moisture content of the various FVWs was determined by placing the feedstocks in an hot air oven maintained at 105±2 °C for 2 h. The moisture content was calculated as;

$$\text{Moiture content (\%)} = \frac{\text{M1} - \text{M2}}{\text{M}} \times 100$$

M_1= weight of the dish with biomass before drying extraction

M_2= weight of the empty dish

M= weight of test specimen

pH of the FVWs were determined by adding deionized water (1:2 solid to liquid) and mixed thoroughly to attain a homogenized mixture. pH electrode was immersed in the sample and mixed gently until a constant pH reading was obtained.

2.4. Biochemical compositional analysis of FVWs

Biochemical compositional analysis of various FVWs was carried out to quantify holocellulose (total cellulose and hemicellulose content) and lignin by following the alkali and acid hydrolysis methods, respectively, as described elsewhere (Wise et al., 1946). The ash content of FVWs was accessed by burning the feedstocks at 450±10 ℃ for 5 h using a muffle furnace (Saini et al., 2023).

The composition of the various components was evaluated as;

$$\text{Component \%} = \frac{\text{W1} - \text{W2}}{\text{W}} \times 100$$

W_1= weight of the crucible with biomass after extraction

W_2= weight of empty crucible

W= weight of test specimen

2.5. Proximate analysis of FVWs and

Proximate analysis of FVWs was carried out to quantify various nutritional constituents of feedstocks including protein, dietary fiber, vitamins, and amino acids.

2.5.1. Estimation of total protein content in FVWs

The total protein content in selected FVWs were quantified following the standard protocol of kjeldahl method described in FSSAI manual for cereals and cereals products (https://www.fssai.gov.in/upload/uploadfiles/files/CEREALS_AND_PRODUCTS.pdf). In brief, 1.0 g of sample powder was placed in 500 ml kjeldahl digestion flask. About 15 g of K_2SO_4, 0.5 g of $CuSO_4$, and 40 ml of H_2SO_4 were added to the sample powder. The mixture was heated gently in initial stage followed by steady boiling for 2 h and allowed to cool down to room temperature. The slurry was mixed with 200 ml of double distilled water and 25 ml of 8.0 % (w/v) sodium thiosulphate solution. The solution was alkalized by mixing 110 ml of NaOH (45.0 % w/v). The digestion flask was connected with distillation apparatus and150 ml of distillate collected. 5 drops of methyl red indicator was added to distillate and titrated with 0.1 N NaOH. Blank titration was carried simultaneously and 1.0 ml of 0 .1 N H_2SO_4 = 0.0014 g N. The total protein content was quantified following the equation;

$$\text{Total protein} = \text{N} \times 6.25$$

2.5.2. Estimation of vitamins A and K in FVWs

The vitamin A and K content in the FVW were carried out at SFTS Laboratory Private Limited, Delhi, India using a HPLC apparatus (Agilent infinity II1260, USA) armed with UV-Visible detector and a C18 reversed-phase column (4.6 × 100 mm, 2.7 µm) chromatography column. Methanol:water (95:5, v/v) and Methanol:acetonitrile:water (70:20:10, v/v/v) were used as mobile phase for running vitamin A and vitamin K, respectively. For vitamins estimation, 0.5 µl of the hydrolyzed samples were loaded in a 5.0

µl sample loop at a constant flow rate of 0.4 ml/min. The column temperature was kept at 35 ℃. Concentration of vitamin A was checked at 325 nm, where for vitamin it was set to 248 nm. The retention time (RT) of the samples was compared with the vitamins standards.

2.5.3. Estimation of crude fiber content in FVWs

The crude fiber content in selected FVWs were quantified using soxhlet apparatus following the methodology described in FSSAI manual for cereals and cereals products (https://www.fssai.gov.in/upload/uploadfiles/files/Manual_Cereal_08_07_2022.pdf). 2.5 of powdered sample were extracted with petroleum ether using soxhlet extractor extracted sample was transferred to a dry 1 L conical flask. 200 ml of the H_2SO_4 was added and connected with reflux condenser. The mixture was boiled for 30 min with intermediate rotation of the flask to ensure thorough mixing of the sample. The resulted slurry was filtered through double layered muslin cloth and washed with hot water (with 20 ml, 5 times) to remove the traces of acids. The sample was again transferred to digestion flask and mixed with 200 ml of NaOH solution. The slurry was boiled for 30 min and filtered through G_2 glass crucible. The solid residues was washed with hot distilled water (with 20 ml, 5 times) followed by final washing with ethyl alcohol. The solid residues were dried at 105 ± 3.0 °C for 6 hours and further at 575 ± 10.0 °C for 24 h in a muffle furnace. The following formula was used to quantify the crude fiber content.

$$\text{Crude fiber \%} = \frac{C1 - C2}{M} \times 100$$

C_1= weight of the crucible and contents before ashing

C_2= weight of the crucible and contents after ashing

M= weight of moisture free test specimen

2.5.4. Estimation of amino acids in FVWs

The total amino acids content in the FVW were carried out at SFTS Laboratory Private Limited, Delhi, India using a HPLC apparatus (Agilent infinity II1260, USA) armed with VWD and a C18 (4.6 × 100 mm, 2.7 µm) chromatography column. The chromatographic conditions employed were in accordance with the methodology as described elsewhere, with slight modifications (Jajić et al., 2013). Mobile phase A, consisted 1.4 g of anhydrous Na_2HPO_4 and 3.8 g of $Na_2B4O_7 \cdot 10H_2O$ per liter of water. The pH was adjusted to 8.2±0.2 with concentrated HCl, and then filtered through 0.45 µm cellulose membranes. The mobile phase B was acetonitrile–methanol–water (45:45:10, v:v:v). For amino acids estimation, 0.5 µl of the hydrolyzed samples were loaded in a 5.0 µl sample loop. Samples were run with solvent gradient (0 min, 0 % B, 1.9 min, 0 % B, 18.1 min, 57 % B, 18.6 min, 100 % B, 22.3 min, 100 % B, 23.2 min, 0 % B and 26 min, 0 % B) at a constant flow rate of 0.2 ml/min. The column temperature was kept at 40 ℃. The retention time (RT) of the samples was compared with the amino acids standards.

2.6. Preparation of FVWs-based poultry feed

The preparation of poultry feed from FVWs involved a systematic process to ensure its safety and nutritional parameters. The finely grinded and dried FVWs were namely apple pomace, mango kernel, carrot pulp, potato peels, pea pods, and banana foliage were mixed in an equal ratio solid to solid. The mixed FVWs were than assimilated with equal volume of distilled water and lightly cooked in a kitchen pressure cooker for 40 mint to enhanced the digestibility and eliminate potential pathogens. The mixture was again dried using solar tunnel dryer and powered using a power mixture grinder. The prepared FVWs- based feed was analysed for its physical, biochemical composition, and proximate analysis by following the methodology discussed above, and compared with commercial local (unbranded) and branded (ABIS Poultry Feed, IB Group, Indamara, Rajnandgaon, Chhattisgarh) poultry feed.

2.7. Statistical Analysis

All experiments were performed in several replicates, and the data was presented as a mean ± SD.

3. Results and discussion

3.1. Physical properties analysis of different FVWs and poultry feed

The functional properties of FVWs are strongly associated with the physico-chemical properties, which basically have a direct relation by color, particle size, pH, moisture content, water holding capacity (WHC) etc. (Dias et al., 2020). The physical properties of various FVWs are stated in Table 1.

The pH is an important physical parameter, as it as it directly impacts nutrient accessibility and digestibility, preservation, and microbial stability. An optimal pH range guaranteed better preservation of feed additives by inhibiting microbial growth, enhances nutrient digestion, and improves palatability for poultry (Adedokun & Olojede, 2019). No significant differences ($P < 0.05$) were observed in pH of various FVWs. The pH value ranged from 5.3 to 6.6 for various FVWs **(Table 1)**. Further, the pH of commercial local and branded feed was found 6.1, whereas, the pH of FVWs-based feed was observed to be 6.5 **(Table 1)**. Previous studies have reported that the optimal pH for poultry feed ranges from 5.5 to 6.5, which corroborates with the current study (Cox et al., 2013; Kim et al., 2006).

Moisture content also an important physical parameter, determine the quality, stability, and nutritional efficiency of poultry feed. Earlier studies have revealed the ideal moisture content of poultry feed is range from 10 % to 12 %, on dry weight basis (Ahmed et al., 2022; Preethi et al., 2021). In the current investigation, the moisture content of various FVWs along with FVWs-based feed, commercial local and branded feed ranged from 9.7 % to 12.7 % **(Table 1)**. This range typically minimizes the risk of microbial contamination and spoilage while preserving the physical and nutritional veracity of the feed.

Similarly, WHC can directly affect the nutrient digestibility and feed texture. A high WHC can improve gut health by slowing down feed course through the digestive territory, improving nutrient assimilation (Huting et al., 2021). On the other hand, low WHC may result in quicker feed passage, limiting nutrient absorption. The WHC of the FVWs (76.3 %) was found to be somewhat similar to that of commercial local and branded feed (86.2 % and 84.2 %, respectively) **(Table 1)**.

Table 1. Physical properties of various fruits and vegetable wastes and poultry feed

Sample	Description	pH	Moisture content (%)	Water holding capacity (%)
Apple pomace	Brown granular powder	6.6	9.8	73.6
Mango kernel	Light green granular powder	5.3	10.4	78.9
Carrot pulp	Light red granular powder	6.2	9.7	88.3
Potato peels	Whitish granular powder	5.3	12.5	83.2
Pea pods	Light green granular powder	6.2	10.1	53.6
Banana foliage	Yellow granular powder	6.3	12.6	86.0
FVWs-based feed	Light red granular powder	6.5	10.9	76.2
Commercial Local feed	Light red granular powder	6.1	11.2	86.2
Commercial	Light red	6.1	10.5	84.2

branded feed	granular powder

3.2. Biochemical compositional analysis of FVWs

Biochemical composition analysis of FVWs is an essential step for developing FVW-based poultry feed as it provides clear idea about their nutritional profile, including carbohydrates and identifies anti-nutritional factors (lignin and ash content) enables proper balancing with other feed components (Supriya et al., 2023). Biochemical compositional profiles of various FVWs have been highlighted in figure 1. Among the various FVWs, potato peels have the highest level of holocellulose (65.76 %) **(Figure 1d)**, whereas, the minimum holocellulose content was observed in banana foliage (32.09 %) **(Figure 1f)**. On the other hand, maximum lignin content was reported from mango kernel (21.46 %), defines its hard nature among the various FVWs **(Figure 1b)**. The minimum lignin content i.e., 8.79 % was observed from carrot pulp describes its fluffy nature **(Figure 1c)**. Compositional profile of various FVWs observed in the current investigation was close to the value observed in previous studies, for instance 53.12 % in apple pomace (Ahmed et al., 2022), 32.34 % to 76.81 % in mango kernel (Mwaurah et al., 2020), 24.21-27.41 % in carrot pulp (Akhter et al., 2024), 65.46- 78.30 % in potato peels (Dusuki et al., 2020; Helal et al., 2020).

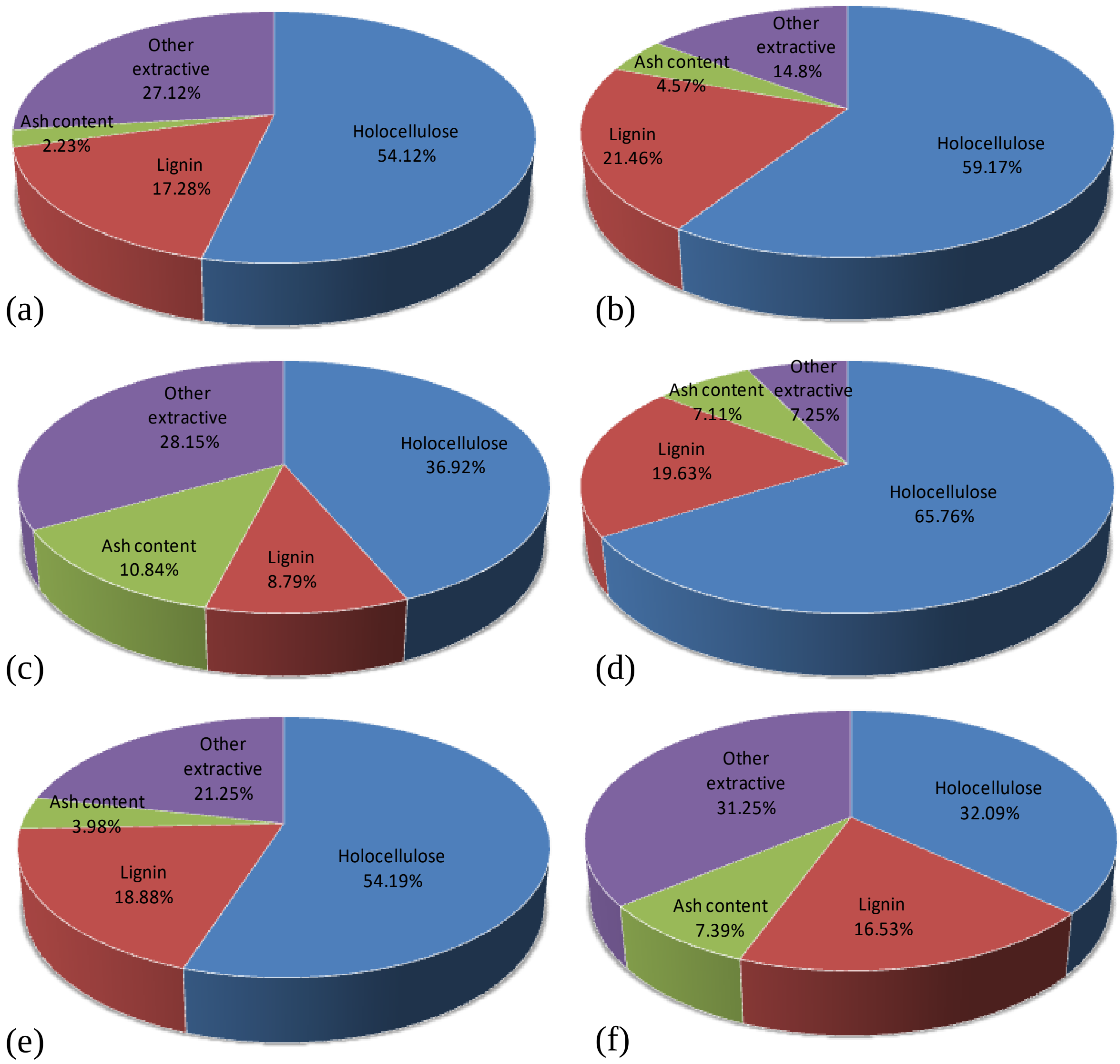

Figure 1. Biochemical compositional analysis of various FVWs. (a) Apple pomace, (b) Mango kernel, (c) Carrot pulp, (d) Potato peels, (e) Pea pods, and (f) Banana foliage.

3.3. Proximate analysis of various FVWs and poultry feed

Proximate analysis of FVWs perform a central role in poultry feed development by emphasizing an inclusive assessment of the feed's nutritional composition, including crude protein, crude fat, and crude fiber. This profiling helps in determining the energy and nutrient content of feed ingredients, ensures that nutritional requirements are met for optimal poultry growth and productivity (Siwach et al., 2025).

3.3.1. Protein profiling of FVWs and poultry feed

Protein is a fundamental component of poultry diet, catering essential amino acids crucial for growth, muscle development, egg production, and overall better health of birds. It has been shown to regulate the key physiological processes such as enzyme and hormone synthesis, immune function, and tissue repair (Kelley et al., 2007). Among the various FVWs, pea pods have the highest level of crude protein content (19.8 %), followed by mango kernel (8.1 %), highlighting their suitability for poultry feed development **(Figure 2)**. On the other hand, apple pomace has the lowest level of crude protein content i.e., 4.5 %. A systematic comparison between FVWs-based and commercial feed showed that protein content of FVWs-based feed was 1.20-fold and 1.76-fold higher in comparison to commercial local and branded feed, respectively. Previous studies have highlighted that optimum protein content in nutritious bird's diet ranges 8 % to 25 % depending on type and age of birds viz., broilers, layers, and starter feed (Barekatain & Swick, 2016).

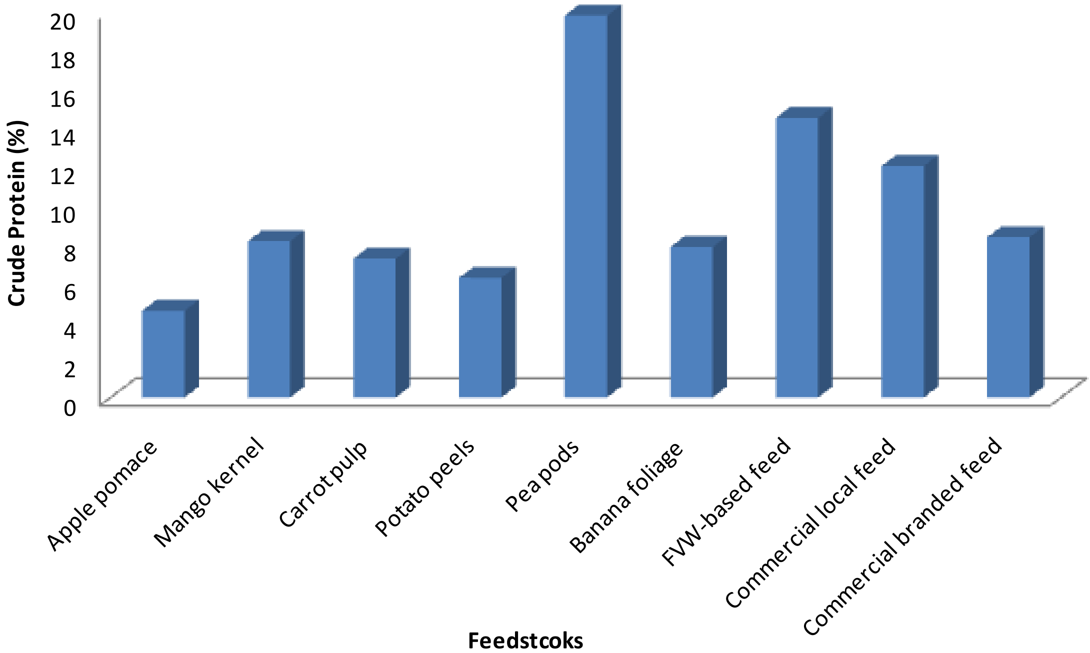

Figure 2. Crude protein content of various FVWs, FVWs-based feed, and commercial local and branded poultry feed

3.3.2. Vitamin profiling of FVWs and poultry feed

Vitamins A and K are two major essential micronutrients for poultry feed, which have decisive roles in maintaining health and physiological functions of birds. Vitamin A is prominent for vision, immune stimulation, skin health, and cellular growth. It also helps in the expansion of the respiratory and digestive tracts (Huang et al., 2018). The vitamin A content across the selected FVWs varies extensively, with the highest levels observed in carrot pulp (1520 IU/100 g) and pea pods (1011 IU/100 g). On the other hand, apple pomace (8.7 IU/100 g), mango kernel (15.27 IU/100 g), and potato peels (17.3 IU/100 g) revealed considerably lower vitamin A levels **(Figure 3)**.

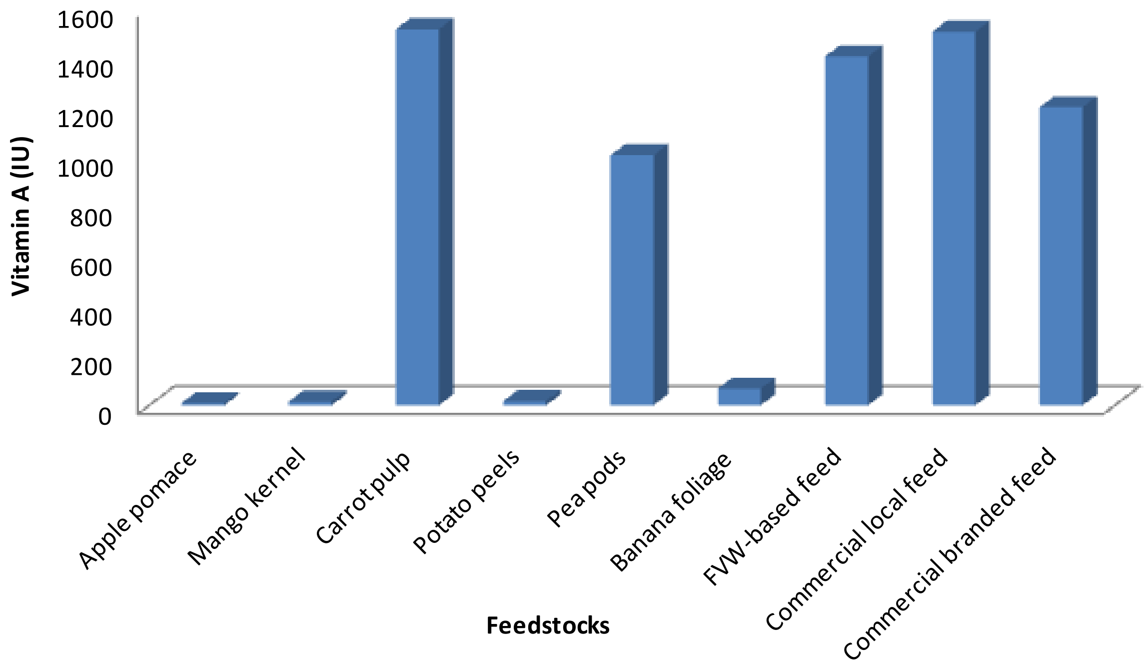

Figure 3. Vitamin A content in selected FVWs, FVW-based feed, and commercial unbranded and branded feed ((in IU/100 g dry weight)

The highly diversification in vitamin A levels denotes the significant impact of the intrinsic properties of the raw material, as well as potential variations due to the treatment and processing of these residues. The observation emphasizes the potential of carrot pulp and pea pods as potent contributors to the vitamin A requirements in poultry diets. The optimum values for vitamin A in poultry feed has been shown within a range of 600 to 1000 IU/100 g. Further, the compositions of vitamin A in the most of the FVWs were found identical to previous reports described elsewhere. To evaluate the efficiency of FVW-based feed to pour poultry nutritional requirement, its vitamin A content was compared to with commercial unbranded and branded feeds. The vitamin A content of the FVW-based feed (1410 IU/100 g) was found comparable to that of commercial unbranded feed (1510 IU/100 g) and higher that of commercial branded feed (1205 IU/100 g) **(Figure 3)**. These results advocate that FVW-based feed can present as a possible substitute to conventional feeds. However, the levels of vitamin K from various FVWs and FVW-based feed were found below level quantification **(data not shown)**.

3.3.3. Fiber profiling of FVWs and poultry feed

Fiber in poultry feed possess a vital part in maintaining gut health, enhancing digestion, and supporting the growth of beneficial gut microbiota. It also improves gut motility, helps in nutrient absorption, and prevents digestive disorders (Jha & Mishra, 2021). Previous reports on poultry feed have identified optimal fiber content is usually ranged from 3 % to 5 %, depending on the bird's age and type (J. Tejeda & K. Kim, 2021; Mateos et al., 2012). Exceeding the fiber content in diet may have some adverse effect because poultry have limited ability to digest fiber due to their simple digestive systems (Jha & Mishra, 2021). The fiber content of selected FVWs was analyzed to evaluate their latent for inclusion in poultry feed formulations. The results discovered significant variations in fiber levels, where, carrot pulp exhibited the highest fiber content (20.6 %) followed by apple pomace (16.16 %). While mango kernel (2.8 %) and potato peels (2.2 %) had the lowest fiber contents **(Figure 4)**. These differences can be recognized to the inherent botanical composition, with high-fiber by-products derived from fibrous plant structures like pulp and peel. The fiber content of FVW-based feed found to be higher (11.0 %) in comparison to both commercial unbranded feed (9.9 %) and branded feed (7.9 %) **(Figure 4)**. Previous studies have reported that high fiber content have negligible or limited effect on birds health and performance (Desbruslais et al., 2021; Singh & Kim, 2021).

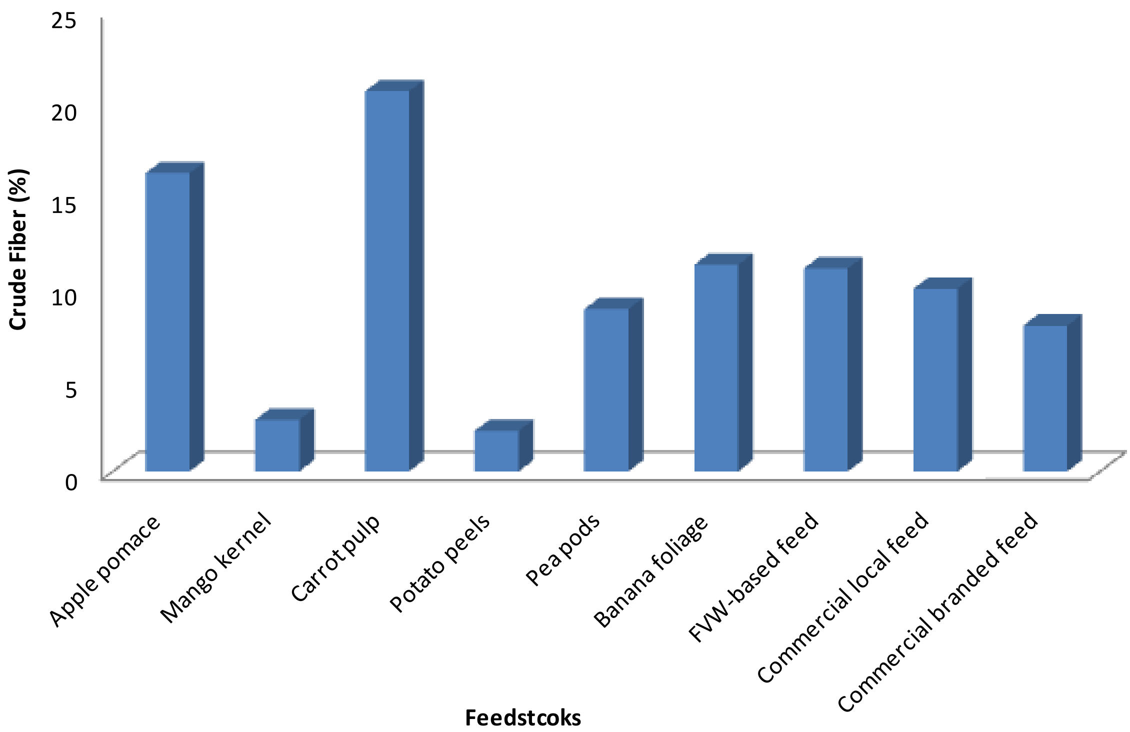

Figure 4. Fiber content in selected FVWs, FVWs-based feed, and commercial unbranded and branded feed

3.3.4. Amino acids profiling of FVWs and poultry feed

Amino acids are fundamental components of poultry feed required for birds growth, muscle development, and egg production, serving as the building blocks of proteins. Essential amino acids viz., lysine, methionine, and threonine improve feed efficiency, immune function, and feather formation (Alagawany et al., 2021). Their balanced inclusion in feed supports optimal health, productivity, and reproductive performance (Lee et al., 2023). The amino acids of profiling selected FVWs revealed significant differences in both the concentration and variety of amino acids **(Table 2)**. Among the various FVWs, banana foliage found to be most nutrient-dense material, exhibiting the highest values for several key amino acids including leucine (10.31 mg/100 g), isoleucine (9.20 mg/100 g), lysine (7.16 mg/100 g), and phenylalanine (9.50 mg/100 g). This is probably due to its green leafy nature, which usually supports higher photosynthetic and nitrogen assimilation activity, leading to superior protein biosynthesis and storage. Likewise, potato peels showed a notably high content of tryptophan (8.2 mg/100 g), likely due to the presence of active metabolic compounds and residual enzymatic proteins in the periderm tissue of tubers, which tend to be more biochemically active than inner storage tissues. Similarly, pea pods revealed a high lysine content (7.4 mg/100 g), might be due to their leguminous origin, which typically grooms synthesis of lysine-rich storage proteins such as globulins and albumins. On the other hand, apple pomace, mango kernel, and carrot pulp showed comparatively lower amino acid variety and concentration. For instance, methionine was lowest in apple pomace (1.30 mg/100 g) and leucine was least in carrot pulp (4.0 mg/100 g). These differences could be due to the fruit-based origin of these wastes, where the primary nutritional focus is on carbohydrates and fiber rather than protein.

The comparative analysis of amino acid profiling revealed that FVW-based feed offers a competitive nutritional profile relative to both commercial local and branded poultry feeds **(Figure 5)**. Particularly, threonine which is essential for birds immune function and gut health was found at a slightly higher concentration in FVW-based feed (18.5 mg/100 g) compared to local (17.2 mg/100 g) and nearly equal to branded feed (18.6 mg/100 mg). Similarly, isoleucine (6.5 mg/100 g) was also observed highest in FVW-based feed. Further, concentration of phenylalanine, tyrosine, and methionine, tryptophan were observed somewhat similar among all the feeds. On the other hand, leucine, lysine, and valine were slightly lower in FVW-based feed than in commercial feeds, the differences were marginal (e.g., leucine: 4.2 vs. 4.7 mg/100 g in branded).

Table 2. Amino acids profiling of selected fruits and vegetable wastes

Amino acids	Apple pomace (mg/100 g)	Mango kernel (mg/100 g)	Carrot pulp (mg/100 g)	Potato peels (mg/100 g)	Pea pods (mg/100 g)	Banana foliage (mg/100 g)
Threonine	2.81	-	18.0	2.80	-	2.81
Isoleucine	3.19	-	6.0	2.70	-	9.20
Leucine	7.50	6.2	4.0	5.02	-	10.31
Lysine	4.21	3.3	4.9	4.32	7.4	7.16
Methionine	1.30	3.40	2.0	1.90	1.8	2.52
Phenylalanine	3.20	6.0	2.8	2.73	-	9.50
Tryptophan	-	-	3.7	8.2	1.0	7.30
Tyrosine	-	-	3.0	-	-	-
Valine	2.31	4.20	4.0	3.09	-	2.01

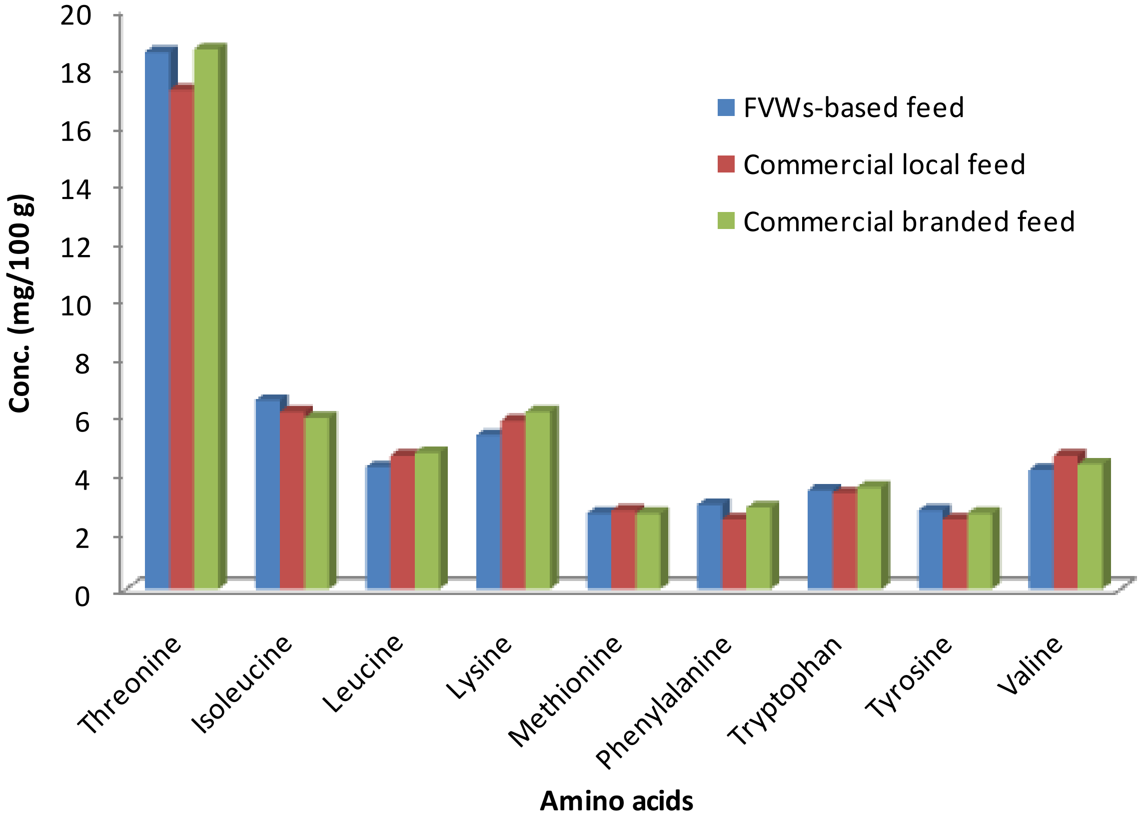

Figure 5. Comparative analysis of amino acid content in FVW-based feed, commercial local feed, and commercial branded feed

4. Conclusion

The present study systematically evaluated the potential of various fruit and vegetable wastes (FVWs) as feasible ingredients for developing nutritionally balanced poultry feed. The physical, biochemical, and proximate analyses provided compelling support for the suitability of FVWs in feed formulations, based on parameters such as pH, moisture content, water holding capacity, crude protein, carbohydrates, fiber, vitamin, and amino acid content. The pH values of FVWs and FVW-based feeds observed within the optimal range (5.3-6.6), ensuring better feed preservation, microbial safety, and improved nutrient digestibility. Other physical properties like, moisture content and WHC also supported their functional applicability by ensuring feed stability and enhanced nutrient assimilation. Biochemical profiling revealed that certain FVWs, particularly potato peels, mango kernel, and apple pomace have high carbohydrates and low lignin content, indicating favorable digestibility and reduced anti-nutritional factors. The proximate composition revealed pea pods as a rich protein source (19.8 %), and overall, the FVW-based feed demonstrated higher protein content in comparison to commercial feeds. Further, carrot pulp and pea pods were found to be excellent sources of vitamin A, meeting or exceeding recommended dietary levels, while vitamin K was below detectable limits. Furthermore, fiber and amino acid profiling established an important nutritional contribution from FVWs. Carrot pulp and apple pomace contributed high fiber, while banana foliage and pea pods provided essential amino acids such as lysine, isoleucine, and threonine, which play critical roles in growth, immunity, and metabolic function. Finally, comparative evaluation with commercial feeds revealed that FVW-based formulations offer a competitive or superior nutritional profile, particularly in terms of protein and essential amino acids. In conclusion, the present investigation demonstrates that the strategic utilization of selected FVWs can offer a sustainable, cost-effective, and nutritionally enriched alternative to conventional poultry feeds. Their inclusion into poultry diets not only encounters feed cost and resource sustainability but also supports waste valorization and circular bioeconomy principles. Further in vitro and in vivo feeding trials and optimization studies are suggested to validate the long-term benefits and performance efficiency of FVW-based poultry feed.

CRediT author contributions

Ankita Siwach:- Data curation; Formal analysis; Investigation; Methodology; Software; Validation; Visualization; Writing - original draft. **Sangeeta Bhoria:-** Data curation; Formal analysis; Investigation; Methodology; Software; Validation; Visualization; Writing - original draft. **Anil Kumar:-** Conceptualization; Formal analysis; Funding acquisition; Investigation;

Resources; Supervision; Validation; Visualization; Writing - review & editing. **Amrita kumari:-** Review & editing.

Conflict of interests

The authors declare that they have no conflict of interest with contents of this article.

Availability of data and materials: All the data related to the present study is provided within the manuscript.

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