

# From field to feed: Evaluating herbs and horticultural by-products for agricultural characteristics and nutritional values in Bulukumba Regency, South Sulawesi

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## ABSTRACT

This study aimed to evaluate locally available agricultural by-products and herbs as alternative feed resources for ruminants. A total of 15 plant species, including horticultural by-products, conventional forages, and herbs, were initially assessed based on palatability, availability, bioactivity, and toxicity. Primary data were collected from local cattle farmers (n=50) in the district of Rilau Ale, Bulukumba regency and the field officers (n=5) of the department of horticulture from Bulukumba regency. The 15 initial plants were ranked on the basis of palatability, availability, potential as feed sources, history as herbal medicine and toxicity. From then, six candidates were selected: banana stem, rambutan peel, vegetable waste, rice bran, ginger, and turmeric were selected for further study. The analysis revealed the presence of terpenoids, phenolics, sugars, fatty acids, and nitrogenous compounds, which are known for their antioxidant, antimicrobial, and anti-inflammatory properties. Nutritional evaluations showed that vegetable waste had the highest crude protein (21.26%) and ginger had the highest total digestible nutrients (TDN) at 59.63%. Banana stem, although low in protein (1.73%), was rich in fiber and available year-round. Rambutan peel exhibited high tannin content (10.29%). Rice bran provided high ash and energy but contained undissolved ash, possibly reducing digestibility. The findings suggest that these materials, if processed and combined properly, offer potential as sustainable, cost-effective cattle feed. Additionally, their year-round availability and functional bioactive compounds may contribute to improved animal health and reduced environmental waste.

## Introduction

Livestock farming plays an important role in supporting food security and rural livelihoods. However, one of the biggest challenges in animal production is the high cost and limited availability of quality feed. In many areas, farmers rely on conventional forages that are limited due to the conversion in land use and low quality forages that mainly depends on the less predicted seasons recently. On the other hand, herbs and horticultural by-products are potential feed ingredients that are often overlooked. These materials are widely available in farming areas and are usually considered waste.

Bulukumba is one of the potential regencies for agricultural and livestock in the province of South Sulawesi. The cattle population is increasing 1.5% for the past five years (Saputra and Syam, 2024). The growth of the cattle's population has not yet been supported by the nutritious feed availability. It is necessary to provide alternative sources other than conventional forage to fulfill this gap.

In Bulukumba Regency, there are many herbs and horticultural crops are grown, producing by-products that are often thrown away or left to rot. This not only wastes valuable resources but can also cause environmental problems, such as greenhouse gas emissions and pollution. As the example, the production of banana trees in 2022 was 2.205.400 kg and in 2023 it was 2.830.900 kg (Saputra and Syam, 2024). The by-product particularly the stem is approximately up to 70% of a whole banana tree. Despite the high water content, banana stem is a good source of fibre for the ruminants (Kumar *et al.*, 2022; Shrestha *et al.*, 2021).

The incorporation of herbs and horticultural by-products derived from local agricultural systems into livestock feed formulations offers a strategic solution to multiple challenges. Environmentally, it can contribute to the reduction of organic waste accumulation and minimize potential ecological harm. Economically, it provides an avenue for lowering feed-related expenditures, which in turn supports improved profitability

and long-term resilience in livestock enterprises. Prior to recommending these materials for feeding purposes, it is critical to assess their agronomic characteristics—including adaptability, growth rates, and biomass production—as well as their chemical properties, with particular attention to nutrient composition. This investigation evaluated selected botanical species and horticultural residues from Bulukumba Regency, analyzing their production traits and nutritional attributes to identify feed resources that align with both ecological sustainability and economic feasibility.

## Materials and methods

### Materials

This research was conducted in January-May 2025 in the district of Rilau Ale, Bulukumba, South Sulawesi, Indonesia. The samples were collected from different villages and were analyzed for the molecular volatile compounds using LC-MS in the laboratory of Biofarmaka, Institut Pertanian Bogor, West Java. The samples are banana stem, rambutan peel, vegetable waste, rice bran, ginger, turmeric. The other materials that were used in this study were: large sized plastic bags to collect the fresh samples, small sealed bags to keep the grinded substrate, chopper, grinder 1 mm size, gloves, masks.

### Information collection and survey methodology

Primary data were collected from local cattle farmers (n=50) in the district of Rilau Ale, Bulukumba regency, South Sulawesi, the field officers (n=5) of the department of horticulture from Bulukumba regency. The information from this survey was supplemented with research report from different resources. 15 initial plant species including horticultural by-products, conventional feed sources and herbs were ranked on the basis of palatability, availability, potential as feed sources, history as herb-

al medicine and toxicity. This information was used to rank the potential feed sources and select six candidates that have desirable properties for further testing for the volatile compounds including secondary compounds that might be antinutritional compounds.

#### Samples collection

All six (6) candidates that were selected from the 15 initial plant species, were collected from 18-25 March 2025, 5kg fresh weight each, and were stored in separate plastic bags. The samples were collected from various villages in the districts of Rilau Ale, Bulukumba regency :

Banana stem, collected from Padangloang village.

Rambutan peel, collected from Tokombeng village.

Vegetable waste (cabbage, bok choy, eggplant, beans, carrot, cucumber), collected from traditional market at Cekkeng village.

Ginger, collected from Padangloang village.

Tumeric from Sempang village.

Rice bran, collected from Padangloang village.

Upon collection, the samples were sun-dried and chopped then were grinded to 1 mm size. All samples were kept in labelled sealed bags prior to send them to the laboratory of Biofarmaka, IPB for the metabolomic analysis using LC-MS and the laboratory of Feed Biochemistry, Faculty of Animal Science, Unhas .

#### Data analysis

The data for the samples secondary compounds were analyzed using a multivariate statistical approach comprising Principal Component Analysis (PCA) and biplot visualization to assess chemical and inter-treatment variability. The results were visualized through biplots that illustrated the separation of compounds according to treatment type, with the significance level set at  $\alpha = 0.05$ . Data analysis was conducted using both RStudio 4.2.2. and Python 3 to ensure cross-platform consistency and optimal data visualization.

#### Results

##### Agricultural characteristics

Assessing the agricultural charactersitics is beneficial as the preliminary stage in selecting the feed candidate for the further test. As there are numerous sources of potential plants that came up from the farmers opinion, it is necessary to rank them particularly based on the availability, accessibility and toxicity.

Table 1 showed the 15 species of plants: including conventional forage, horticultural by-products and herbal plants. The species based on the anecdotal evidence were found to have potential as feed sources

Table 1. Initial data on the characteristics of 15 local plants (conventional forage, plant's by-product and herbal plants) for ruminants in Bulukumba regency, Indonesia.

| No | Plants/By-product                           | Nutritive values                                                                                                                                 | Availability                                                                | Bioactivity                                                                                | Reference                                          |
|----|---------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------|
| 1  | <i>Pennisetum purpureum</i>                 | Dry matter 18,65-19.9%; Fiber 34.2%; Crude protein 8,87%; Crude Fiber 42,97% Ash11.20%; Fat 1.6%; NDF 73,71%; ADF 39,50%; Hemicellulose 34,21%   | Available all seasons, majorly dried and hard stem, easy growth             | No reports                                                                                 | (Lounglawan <i>et al.</i> , 2014)                  |
| 2  | <i>Leucaena leucocephala</i>                | DM 320g/kg; Ash 64%; NDF 31.6%; CP 20,5%                                                                                                         | Less available                                                              | Toxic (mimosine) if fed to excess                                                          | (Halme-mies-Beauchet-Filleau <i>et al.</i> , 2018) |
| 3  | Rice straw                                  | DM 93,25%; CP 4%; FAT 1,12%; CF 32,14%                                                                                                           | Less available, require fermentation                                        | No reports                                                                                 | (Suningsih <i>et al.</i> , 2019)                   |
| 4  | Coconut waste                               | CF 14,6-31,6%; Fat 16,3-35,3%; CP 5,6-9%; Ash 2,6%                                                                                               | Less available, high fat content                                            | vitamin A < 0,5 IU/100 grams, vitamin D 4,93 µg/100 gram, and vitamin E < 0,1 mg/100 gram. | (Yetti, 2020)                                      |
| 5  | Lemongrass ( <i>Cymbopogon citratus</i> DC) | CP 5,72-7,72%; CF 25,73-34%; Fat 2,30%; energy 3353 ccal/GE/kg; ligning 37%                                                                      | Available at any time; require fermentation                                 | Antioxidant, anti-pathogenic microorganisms, anti-inflammation, anti-mouth ulcer           | (Astuti <i>et al.</i> , 2023)                      |
| 6  | Tumeric                                     | CP 11,87%; Ash 6,77%; Fat 2,89%; CF 12,52%                                                                                                       | Available at any time                                                       | Curcumin and atsiric oil increase appetite                                                 | (Badrussalam <i>et al.</i> , 2020)                 |
| 7  | Corn straw                                  | CP 5,56%; CF 33,58%; Fat 1,25%; Ash 7,28%                                                                                                        | Less available, require fermentation                                        | No reports                                                                                 | (Trisnadewi <i>et al.</i> , 2017)                  |
| 8  | Vegetable waste                             | CP 8,72-23,83%; CF 52,73%; energy 3474-4266 KKal/kg                                                                                              | Available any time, require treatments because of high moisture             | No reports                                                                                 | (Nurhaita. <i>et al.</i> , 2022)                   |
| 9  | Tofu waste                                  | CP 23-29%; Fat 4,9%-18,3%; CF 7,11%-24,43%; Phospor 0,14%-0,29%; Ca 0,19%-0,88%; Fe 0,04%                                                        | Available only at certain time, require treatments because of high moisture | No reports                                                                                 | (Sari and Barrera, 2016)                           |
| 10 | Ginger                                      | CP 2,3%; Fat 0,9%; Minerals 1-2%; Fiber 2-4%; Carbohydrates 12,3%                                                                                | Available at any time                                                       | Antioxidant, anti-inflammatory, anti-cancer, neuroprotection, anti-diabetic                | (Mao <i>et al.</i> , 2019)                         |
| 11 | Guava leaves                                | Organic acids: acetic acids, ascorbic acids, citric acids, malonic acids.                                                                        | Available only at certain time, limited use because of high tannins         | Anti-microbials, anti-inflammatory                                                         | (Stella and2020)                                   |
| 12 | Banana stem                                 | Fat 1,11%; CP 3,6%; ash 6,75%; CF 24,33%; total carbohydrate 81,60%; minerals and vitamins                                                       | Available at any time                                                       | Antioxidant; therapeutic agents                                                            | (Suhaimi <i>et al.</i> , 2020)                     |
| 13 | Durian peel                                 | Flavonoids, phenolic acids, tannins, carotenoids, ascorbic acids; fat 3,10 – 5,39 gr/100g, 1,40 – 2,33 gr/100gr; 134-162 kcal; lignin 3,39-7,69% | Available any time, require treatment due to high lignin                    | Anti-microbials, anti-inflammatory, antidiabetic                                           | (Aziz and Jalil, 2019)                             |
| 14 | Rice bran                                   | CP 11-17%; Fat 12-22%; Fiber 6-14%; vitamins, γ-oryzanol, tocotrienols, and tocopherols                                                          | Available at any time                                                       | Anti-microbials, anti-inflammatory, antidiabetic                                           | (Manzoor <i>et al.</i> , 2023)                     |
| 15 | Rambutan peel                               | Fat 10,2gr/100gr; CP 5,25gr/100gr                                                                                                                | Available at any time                                                       | Anti-microbials, antidiabetic antiviral, anti-inflammatory, and anti-hypoglycemic          | (Le Xuan <i>et al.</i> , 2022)                     |

or feed components to cattle, with 3 of them were already fed to the local cattle in Bulukumba regency (rice bran, Leucaena, Elephant grass). The other two (Turmeric and Guava leaves) were reported from anecdotal evidence that has evidence for medicinal use for cattle. Six species are considered as suitable and available to be used as feed component for cattle at any time and reported to have comparable values in agronomic properties and protein content compared to the conventional forage that was usually fed to the local cattle in Bulukumba regency. The detailed of the initial of 15 list of plant species is presented on table 1. We then narrowed down to 6 list based on the availability/accessability and the record of toxicity and or bioactivities based on the literatures and anecdotal evidence.

#### Frequently detected compounds

Fig 1. showed the frequently detected compounds in the six selected candidates that were analysed in LC-MS. The figure presents a bar chart showing the frequency of detection for various molecular formulas, offering insight into the most commonly identified compounds in a particular chemical analysis. The most frequently detected compound is  $C_{15}H_{22}O$ , appearing 28 times, followed closely by  $C_{15}H_{20}O$  (26 times) and  $C_9H_{10}$  (25 times). Further down the list, several other compounds also show relatively high frequencies of detection. For example,  $C_7H_{14}O_8$  and  $C_6H_{12}O_6$  were each detected 20 times,  $C_{15}H_{24}$  and  $C_{15}H_{22}$  (detected 19 and 18 times, respectively). The appearance of  $C_{18}H_{30}O_3$  and  $C_{18}H_{32}O_3$  with 17 and 16 detections respectively. A variety of other molecular formulas with moderate detection frequencies include compounds such as  $C_5H_{11}NO_2$  (14 detections) and  $C_8H_8O_2$  (12 detections). A group of molecular formulas detected 10 to 11 times such as  $C_7H_{10}O_5$ ,  $C_6H_{12}O_7$ ,  $C_4H_6O_4$ ,  $C_{15}H_{22}O_2$ , and  $C_{17}H_{24}O_3$  suggests a diverse chemical presence even among the less frequently occurring compounds.

#### Nutritive values

Other important component to be investigated is the nutritive values for the selected candidates. We analyzed the nutritional content on the wet chemical procedure and all the six candidates might complement

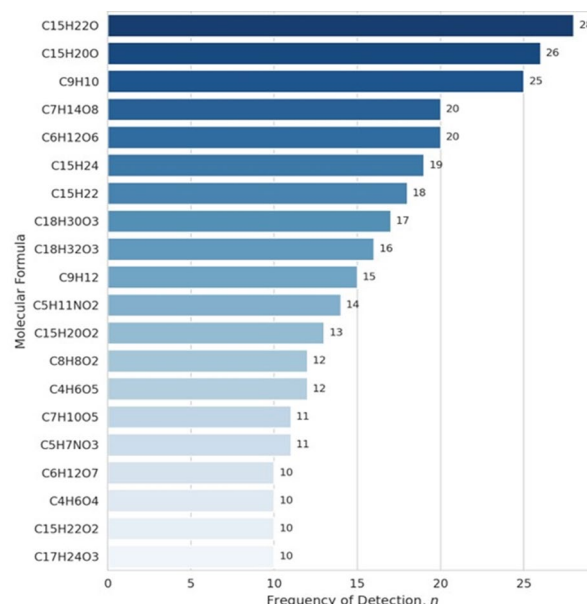


Fig 1. Frequently detected molecular component in all samples.

each other.

Table 3 showed the nutritional contents of the six selected candidates for further feed formulation. Crude Protein (CP) content varies widely among the materials. Vegetable waste has the highest CP at 21.26%, which suggests it is the richest protein source among the six. Ginger and rice bran follow with moderate protein levels at 7.35% and 7.30%, respectively. Rambutan peel (4.94%) and turmeric (4.24%) are lower, while banana stem is the poorest in protein (1.73%), indicating it may need to be supplemented if used as primary feed. Crude Fat (CF) is highest in turmeric (8.55%) and ginger (6.34%), suggesting they may be useful for energy supplementation. The other ingredients have much lower fat content, with banana stem at 1.21%. Ash content, which reflects mineral concentration, is highest in rice bran (14.66%) and vegetable waste (14.40%), indicating good mineral contribution. Turmeric also has relatively high ash (12.02%), while banana stem has the lowest (9.91%). Total Digestible Nutrients (TDN), which indicate energy value, are highest in

Table 2. The antinutritional and bioactivity of the compounds in the feed sources from Bulukumba regency.

| No | Compounds (Formula)                              | Bioactivity                                            | Feed safety relevance                                              |
|----|--------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------------------|
| 1  | Nootkatone ( $C_{15}H_{22}O$ )                   | Insecticidal, antimicrobial                            | Generally safe in low doses; used in essential oil blends          |
| 2  | Hexyl cinnamaldehyde ( $C_{15}H_{20}O$ )         | Antimicrobial, antifungal                              | Safe in flavoring levels; avoid high doses due to rumen irritation |
| 3  | Indane ( $C_9H_{10}$ )                           | Antioxidant potential                                  | Limited data; no reported toxicity in feed                         |
| 4  | Glucosaminic acid ( $C_7H_{14}O_8$ )             | Prebiotic, antioxidant                                 | Non-toxic sugar acid; used in mineral chelation                    |
| 5  | Hex-2-ulose ( $C_6H_{12}O_6$ )                   | Metabolic intermediate                                 | Neutral; similar to reducing sugars                                |
| 6  | $\alpha$ -Farnesene ( $C_{15}H_{24}$ )           | Plant defense, insect repellent                        | Considered safe; no anti-nutritional effects reported              |
| 7  | Cuparene ( $C_{15}H_{22}$ )                      | Anti-inflammatory (associated with $\alpha$ -curcumin) | Bioactive terpene; safe in trace amounts                           |
| 8  | Hydroxylinolenic acid ( $C_{18}H_{30}O_3$ )      | Anti-inflammatory fatty acid                           | Potentially beneficial; not anti-nutritional                       |
| 9  | L-Valine ( $C_5H_{11}NO_2$ )                     | Essential amino acid                                   | Vital nutrient; not anti-nutritional                               |
| 10 | Costunolide ( $C_{15}H_{20}O_2$ )                | Anti-inflammatory, antitumor                           | Safe at low concentrations in phytochemical additives              |
| 11 | Malic acid ( $C_4H_6O_5$ )                       | Energy metabolism, rumen buffer                        | Common feed additive; enhances propionate production               |
| 12 | Cyclohexanecarboxylic acid ( $C_7H_{10}O_3$ )    | Rare organic acid                                      | Limited data; no known toxicity                                    |
| 13 | Pyroglutamic acid ( $C_5H_7NO_3$ )               | Glutamate derivative, antioxidant                      | Safe; present in plant proteins and milk                           |
| 14 | Gluconic acid ( $C_6H_{12}O_7$ )                 | Prebiotic, mild acidifier                              | Used in feed to improve mineral bioavailability                    |
| 15 | Succinic acid ( $C_4H_6O_4$ )                    | TCA cycle intermediate                                 | Natural fermentation product; feed-safe                            |
| 16 | Valerenic acid ( $C_{15}H_{22}O_2$ )             | Sedative (Valeriana sp.)                               | Safe in herbal extract form; monitor for behavioral effects        |
| 17 | Shogaol ( $C_{17}H_{24}O_3$ )                    | Antioxidant, anti-inflammatory                         | Active ginger compound; safe in functional feed blends             |
| 18 | Coronaric acid (isoleukotoxin) $C_{18}H_{32}O_3$ | Cytotoxic, pro-inflammatory                            | Can damage rumen epithelium; leukotoxin activity                   |
| 19 | Cumene (isopropylbenzene) $C_9H_{12}$            | Volatile solvent, industrial use                       | Toxic; not suitable for feed use due to liver toxicity risk        |
| 20 | Phenylacetic acid ( $C_8H_8O_2$ )                | Aromatic compound, antimicrobial                       | Can disrupt rumen flora in high doses; monitor dosage carefully    |

Table 3. The nutritional values of the by-products and herbs in Bulukumba regency, South Sulawesi.

| No | Nutritive values/<br>Fibre fraction | Composition (% DM) |               |                 |        |         |           |
|----|-------------------------------------|--------------------|---------------|-----------------|--------|---------|-----------|
|    |                                     | Banana Stem        | Rambutan Peel | Vegetable Waste | Ginger | Tumeric | Rice Bran |
| 1  | Crude Protein                       | 1.73               | 4.94          | 21.26           | 7.35   | 4.24    | 7.3       |
| 2  | Crude Fat                           | 1.21               | 1.78          | 1.38            | 6.34   | 8.55    | 3.9       |
| 3  | Ash                                 | 9.91               | 10.54         | 14.4            | 8.09   | 12.02   | 14.66     |
| 4  | TDN                                 | 46.6               | 51.66         | 56.35           | 59.63  | 50.03   | 44.6      |
| 5  | Tannins                             | 0.66               | 10.29         | 1.36            | 1.87   | 1.57    | 0.47      |
| 6  | ADF                                 | 25.66              | 20.69         | 27.57           | 17.5   | 23.39   | 46.4      |
| 7  | NDF                                 | 37.3               | 23.65         | 33.27           | 36.56  | 49.35   | 57.98     |
| 8  | Cellulose                           | 18.35              | 15.34         | 17.16           | 10.97  | 10.98   | 25.65     |
| 9  | Hemicellulose                       | 11.64              | 2.97          | 5.7             | 19.07  | 25.96   | 11.59     |
| 10 | Lignin                              | 5.87               | 5.03          | 8.78            | 6.18   | 10.82   | 14.25     |
| 11 | Undissolved Ash                     | 1.45               | 0.32          | 1.65            | 0.35   | 1.58    | 6.51      |

ginger (59.63%) and vegetable waste (56.35%), making them the best energy sources among the six. Banana stem and rice bran have lower TDN values (46.60% and 44.60%, respectively). Tannin levels, which can reduce digestibility, are extremely high in rambutan peel (10.29%), which may limit its use unless treated. Other ingredients show lower tannin content, especially rice bran (0.47%) and banana stem (0.66%). For fiber fractions, ADF (Acid Detergent Fiber) and NDF (Neutral Detergent Fiber) reflect feed digestibility and bulkiness. Rice bran has the highest ADF (46.40%) and NDF (57.98%), suggesting it has lower digestibility. In contrast, ginger and rambutan peel have relatively low ADF and NDF, indicating higher digestibility. Cellulose and Hemicellulose are structural carbohydrates. Turmeric has high hemicellulose (25.96%), while banana stem has a balance of cellulose (18.35%) and hemicellulose (11.64%). These values affect fiber quality and energy release. Lignin, which is indigestible, is highest in rice bran (14.25%) and turmeric (10.82%), suggesting these are less digestible. Rambutan peel and banana stem have lower lignin values, which can be more favorable.

## Discussion

Table 1 presents a comprehensive overview of various plant species, plant's by-products and agro-industrial by-products with potential as alternative feed resources for cattle and the herbs that offers health-promoting bioactivities. From the prospective of agricultural characteristics, several agricultural by-products and plants have different levels of availability throughout the year. One of the most available feed resources is *Pennisetum purpureum*. It is available in all seasons and grows easily, making it a reliable and consistent source of forage for livestock. However, its stems are often hard and dry, which may affect digestibility unless processed properly. *Leucaena leucocephala*, although high in protein, is less available compared to other plants. The cultivation and supply of certain feed resources are constrained by geographic and seasonal factors, which limit their reliability as consistent inputs for livestock production. Rice straw, for instance, is only obtainable during or shortly after harvest periods. Its seasonal nature reduces its suitability for continuous use, and it often requires fermentation to improve its nutritional quality. Coconut by-products such as coconut meal and husk are similarly subject to fluctuating availability, as their production is dependent on the operational schedules of coconut processing facilities, which may not run consistently throughout the year. In contrast, lemongrass (*Cymbopogon citratus*) can be harvested year-round, although it must undergo fermentation before being safely incorporated into livestock diets. Turmeric and ginger, both perennial species, offer the advantage of continuous cultivation and harvest, providing farmers with reliable and accessible feed supplements. Conversely, corn straw remains less available, limiting its potential as a long-term feed source. This pattern of availability is also evident in other agricultural residues. Some feed materials share with rice straw the lim-

itation of seasonal production and the need for treatment to enhance feeding value. Vegetable waste, however, presents a contrasting case; it is generated continuously from households, markets, and the food service sector, ensuring year-round supply. Despite this advantage, its high moisture content accelerates spoilage and increases susceptibility to microbial contamination, necessitating processing or preservation before use in animal diets. Similarly, tofu residue can serve as an alternative feed input, yet its availability is constrained by the scale and frequency of tofu production, making it less dependable as a consistent resource. Guava leaves, though beneficial in small quantities, are only available in specific seasons and are limited in use due to the presence of tannins, which can interfere with nutrient absorption in animals. Banana stems are available any time and are widely accessible in regions where bananas are grown. Since banana harvesting occurs throughout the year, the stems are constantly produced and often discarded, making them a cheap and sustainable feed resource. Similarly, durian peel is usually available during the durian fruit season, but in areas with continuous or overlapping fruit cycles, it can be collected regularly. Although it needs to be treated due to high lignin content, its availability is considered good. Rice bran, a by-product of rice milling, is generally available year-round in rice-producing regions. It is one of the most common feed ingredients due to its steady supply. Finally, rambutan peel is another agricultural waste product that is readily available during rambutan harvests. In many regions, rambutan is widely grown, and the peels are often thrown away, making them a good candidate for feed use when collected and treated properly.

From the prospective of nutritional content and bioactivity of the 15 initial by-products and plant species in table 1, the nutritive values, availability, and bioactivity profiles of these materials demonstrate significant variability, which has important implications for their inclusion in livestock diets. For instance, *Pennisetum purpureum* (Napier grass), a commonly used forage, shows moderate crude protein content (8.87%) and high fiber fractions (NDF 73.71%; ADF 39.5%), making it suitable as a basal roughage source (Tedeschi *et al.*, 2023). Its year-round availability and adaptability enhance its value in sustainable feeding systems. However, generally, grass and legumes are hardly recognized of their bioactive compounds. *Leucaena leucocephala* offers a higher crude protein content (20.5%) and low fiber, thus representing a valuable protein supplement. Nevertheless, the presence of mimosine, a toxic amino acid, necessitates cautious use to avoid adverse effects on animal health (Hifziah *et al.*, 2018; Stifkens *et al.*, 2021). Agricultural residues such as rice straw and corn straw are characterized by low protein content and high fiber levels, indicating lower nutritive quality without further processing such as fermentation or supplementation (Trisnadewi *et al.*, 2018; Hu *et al.*, 2020). Similarly, coconut waste, although rich in fat (up to 35.3%), presents challenges due to variability in nutrient composition and limited seasonal availability. Ginger is rich in various beneficial compounds and contains carbohydrates (12.3%), small amounts of protein (2.3%), and fiber. More

importantly, it has antioxidant and anti-inflammatory properties, which may help improve animal health and reduce disease. Turmeric has higher protein content than ginger (about 11.87%) and contains oils and compounds such as curcumin, which can help increase appetite and improve digestion in animals. These properties make turmeric a potential natural supplement in animal feed. Rambutan peel also contains useful nutrients, such as protein (5.25%) and fat (10.2 g/100 g). It is known to have antimicrobial and antidiabetic effects, which could support animal health when included in their diet. Rice bran is already used in many animal diets and is known for its good nutritional value. It contains protein (11–17%), fat (12–22%), and fiber (6–14%). In addition to these nutrients, rice bran has antioxidant compounds that may help improve immunity and prevent cell damage in animals. Vegetable waste also shows potential, with protein levels ranging from 8.72% to 23.83% and a high fiber content. Although it has high moisture, it can be preserved or processed to extend its use, one alternative is through sun-dried and grounded (Shinali *et al.*, 2024; Wadhwa and Bakshi, 2013).

For further study, we selected banana stem, rambutan peel, vegetable waste, rice bran, turmeric and ginger, because these materials are available throughout the year, which is important for ensuring a stable supply of feed for livestock. Seasonal availability can often be a challenge in animal production, so using feed ingredients that are always available helps maintain consistent feeding practices without interruption.

Fig 1. shows the compounds that frequently detected in the feed samples. The figure indicated that the compounds are possibly derived from agricultural waste, biomass residues, or fermentation by-products. The most frequently observed compounds, including  $C_{15}H_{22}O$ ,  $C_{15}H_{20}O$ , and  $C_{15}H_{24}$ , are consistent with the chemical formulas of terpenes and terpenoids, a class of compounds well-known for their bioactive properties. Terpenoids are widely distributed in essential oils and resins of aromatic plants and are valued for their antimicrobial, antioxidant, and anti-inflammatory activities. Recent research indicated that the potential of terpenoids as natural growth enhancers in livestock feed, serving as effective alternatives to synthetic antibiotics by promoting better gut health and feed conversion efficiency (Masyita *et al.*, 2022). Additionally, compounds such as  $C_9H_{10}$ ,  $C_9H_{12}$ , and  $C_8H_8O_2$  suggested the presence of aromatic hydrocarbons and phenolic substances, which likely resulted from the breakdown of lignin or secondary plant metabolic processes. These compounds were commonly produced during the decomposition of woody plant matter, fruit rinds, or foliage, and had been investigated for their antioxidant and antimicrobial properties. Phenolic compounds had demonstrated potential in optimizing rumen fermentation, mitigating methane production, and enhancing the utilization of nutrients (Nastoh *et al.*, 2024).

A considerable proportion of the identified molecules, including  $C_6H_{12}O_6$ ,  $C_7H_{14}O_8$ , and  $C_6H_{12}O_7$ , belong to the categories of simple sugars and sugar acids, which are characteristic of carbohydrate-dense plant materials such as fruit and vegetable waste. Glucose and its derivatives are crucial as energy substrates in fermentation processes and are integral to the formulation of fermented or silage-based animal feeds.

Recent studies had highlighted the importance of agricultural by-products rich in fermentable sugars in the production of probiotics and bioactive metabolites, which contribute to improved animal health and reduced feed costs (Nath *et al.*, 2023; Nastoh *et al.*, 2024). Long-chain, oxygenated compounds like  $C_{18}H_{30}O_3$  and  $C_{18}H_{32}O_3$  are consistent with the molecular structure of polyunsaturated fatty acids or oxidized lipids, commonly found in oil-rich biomass, such as seed waste, kernel husks, or coconut-derived residues. These fatty acids not only provide energy but also fulfill key structural and functional roles in metabolic processes. Furthermore, polyunsaturated fatty acids have been shown to enhance reproductive performance, immune function, and milk composition in ruminant livestock (Castro *et al.*, 2019).

Nitrogenous compounds such as  $C_5H_{11}NO_2$ ,  $C_7H_7NO_3$ , and  $C_{17}H_{24}O_3$ , which correspond to amino acids, amines, or alkaloid derivatives, indicate

the presence of protein-rich biomass, likely originating from legumes, leaves, or microbial sources. Amino acids play a pivotal role in feed formulations, promoting growth, reproduction, and tissue regeneration. Additionally, certain nitrogenous plant metabolites have demonstrated potential as natural dewormers and immune enhancers in ruminant livestock systems (Charlier *et al.*, 2022). The characteristics of the molecular compounds that were identified in this study suggested that the sample material holds substantial promise for value-added applications, especially in the sustainable livestock feeding system and the bioproduct development. According to Seguí and Barrera (Seguí and Barrera, 2025), the synergistic presence of terpenoids, sugars, fatty acids, and amino acid derivatives reinforces the concept that plant-based residues can be transformed into functional feed ingredients, fermentation substrates, or bioactive feed additives. These compounds have the potential to improve animal performance while reducing reliance on synthetic inputs, in line with the principles of circular agriculture and green biotechnology.

Table 3 provides a comparison of six agricultural by-products: banana stem, rambutan peel, vegetable waste, ginger, turmeric, and rice bran; based on their nutritional composition and fiber fractions, which are essential factors in evaluating their potential as cattle feed. Crude protein (CP) is a key nutrient in cattle nutrition, playing a vital role in supporting growth, muscle development, and overall health. Xia *et al.* (Xia *et al.*, 2018) stated that to maintain optimal ruminal microbial activity, the diet should include a crude protein (CP) content at least 7% DM. Among the materials assessed, vegetable waste showed the highest crude protein content at 21.26%, indicating a valuable ingredient for livestock feed. Ginger and rice bran also contain moderate levels of crude protein (7.35% and 7.30%, respectively), which can support maintenance and moderate growth in cattle. In contrast, banana stem has a very low protein content (1.73%), suggesting that it should not be used as a sole feed source but could be included in a ration that is supplemented with more protein-rich ingredients.

Crude fat content contributes to the energy value of feed and can improve palatability. Both turmeric and ginger have relatively high fat contents (8.55% and 6.34%, respectively). Castro *et al.* (2019) suggested that the fat content in the cattle's diet should be limited to no more than 6–7% of dry matter to prevent adverse effects on digestion. However, due to the secondary compounds in turmeric and ginger that may be beneficial for the cattle's immunity and feed consumption so it is necessary to decide the best way to incorporate the turmeric and ginger in to the diet. Whereas banana stem, rambutan peel, and vegetable waste have lower fat levels, potentially necessitating supplementary energy sources.

In terms of the ash content, the vegetable waste and rice bran showed the highest ash contents (14.40% and 14.66%, respectively), indicating their capacity to provide various minerals essential for metabolic processes. However, a high ash content does not necessarily refer to the mineral quality or bioavailability. It is also crucial to assess the presence of undissolved ash, particularly in rice bran, which contains 6.51%. This may indicate the contamination from indigestible substances such as sand or silica, which could impair digestion or decrease feed efficiency (Manzoor *et al.*, 2023).

Total Digestible Nutrients (TDN) is a measure of the energy available from the feed, which is crucial for cattle growth and lactation. Ginger (59.63%) and vegetable waste (56.35%) are energy-rich and can significantly support cattle performance. Banana stem and rice bran have lower TDN values (46.60% and 44.60%), indicating a lower energy contribution and reduced suitability as the primary energy source. As emphasized by Wilson *et al.* (2021), high TDN feed improves animal weight gain and productivity.

Tannins are secondary compounds that can reduce protein digestibility by binding to it, but they also possess anti-parasitic benefits in small amounts. Rambutan peel contains very high levels of tannins (10.29%), which may impair rumen function and reduce protein absorption unless treated or included at low inclusion rates. Banana stem and rice bran,

in contrast, have low tannin contents (0.66% and 0.47%), making them safer and more digestible. Besharati (Besharati *et al.*, 2022) suggested that tannin levels above 5% can significantly reduce rumen fermentation efficiency and should be carefully managed. Fiber fractions such as Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF), and cellulose affect feed digestibility and intake (Tedeschi *et al.*, 2023). Rice bran (46.40%) and vegetable waste (27.57%) have high ADF levels, reducing their digestibility. NDF indicates total cell wall content and affects the bulkiness of feed. Materials like rice bran (57.98%) and turmeric (49.35%) may reduce voluntary intake when fed in large quantities. On the other hand, ginger has a relatively balanced fiber profile (ADF 17.50%, NDF 36.56%), which may enhance both digestibility and intake. Cellulose, a major component of ADF, is less digestible than hemicellulose. Ginger and turmeric contain lower cellulose levels (10.97% and 10.98%), which favors digestibility. Conversely, rice bran (25.65%) and banana stem (18.35%) are higher in cellulose, reducing the energy availability from their fiber. Hemicellulose is a more digestible fiber and can serve as a good energy source for ruminants. Turmeric and ginger again show superior profiles with high hemicellulose contents (25.96% and 19.07%), while rambutan peel (2.97%) and vegetable waste (5.70%) are low in hemicellulose and may provide less fermentable fiber. Wilson *et al.* (2021) have noted that hemicellulose is a valuable component of dietary fiber because it breaks down more easily in the rumen. Lignin is an indigestible component that acts as a barrier to fiber degradation. Feeds with high lignin contents, like rice bran (14.25%) and turmeric (10.82%), have significantly lower digestibility. Materials like rambutan peel (5.03%) and banana stem (5.87%) are more favorable from this perspective. Lignin content above 8% dry matter could dramatically reduce the digestibility of other fiber components, making it an important factor to consider in ration formulation. Undissolved ash may indicate the inorganic contamination (Raffrenato *et al.*, 2017). Rice bran in this study showed the highest undissolved ash content (6.51%), suggesting that it is probably contaminated by soil, sand, or silica from the rice husks, which may influence the nutrient absorption or lead to gastrointestinal discomfort. In comparison, ginger (0.35%) and rambutan peel (0.32%) have lower levels of undissolved ash, indicating they are cleaner and more easily digestible.

In terms of fibre, the microbial population in the rumen ferments the cell wall components, primarily cellulose and hemicellulose, breaking them down into volatile fatty acids (VFAs) such as acetate, propionate, and butyrate, which are the primary energy sources for the animal. However, the high presence of lignin in the plant cell wall can inhibit this digestion. Lignin, a complex aromatic polymer, tightly bonds with cellulose and hemicellulose, making it difficult for rumen microbes to access and degrade these fibers (Tedeschi *et al.*, 2023). As the lignin content in the feed increases, both digestibility and energy availability decrease.

Tannins content in the diet has been recently studied as it is valuable to reduce methane emissions from cattle and it plays an important role in supporting the cattle's health. In lower quantities, tannins may offer beneficial effects, such as decreasing methane emissions or protecting dietary protein from rumen degradation, thereby allowing it to be absorbed in the intestines. However, in high concentration, tannins bind to proteins and digestive enzymes, reducing their availability for microbial fermentation and absorption. According to Besharati *et al.* (2022) when tannin levels exceed safe limits (generally above 5% of dry matter), they can suppress rumen microbial activity, reduce feed intake, and disrupt the digestion in rumen.

## Conclusion

As a summary, the several agricultural by-products have good potential to be used as animal feed. Based on the agricultural characteristics: banana stem, rice bran, rambutan peel, ginger, turmeric, and vegetable waste are easily accessible and are available throughout the year. Some of these by-products contain useful bioactive substances that may sup-

port animal health. However, some compounds may need special treatment to reduce possible negative effects before being given to animals. All of the by-products show different levels of crude protein, fat, ash, and total digestible nutrients (TDN). Some ingredients such as vegetable waste and ginger have high protein and energy content, which is useful for improving animal growth and production. The fibre fractions also varied and it requires specific treatment to reduce the undigestible lignin content. The utilization of these agricultural wastes as feed can help reduce environmental problems and feed costs for local cattle farmers in Bulukumba regency, South Sulawesi. Future research should focus on improving processing methods and testing how animals respond to these feed materials in real farming conditions.

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## Conflict of interest

The authors certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organization related to the material discussed in the manuscript.

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