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Research Article

Nutritional and Anti-Nutritional Evaluation of Alternative Feed Ingredients for Sustainable Poultry Farming in Central and Southern Ethiopia

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Abstract | The search for sustainable and cost-effective alternative feed sources for poultry production has led to the evaluation of various unconventional feed ingredients. This study investigated the utilization practices of alternative poultry feed ingredients in smallholder farms across the Wolaita and Gamo zones of southern Ethiopia and the Hadiya Zone of central Ethiopia, with three specific objectives: (1) assessing the nutritional composition of selected alternative feed ingredients, (2) identifying and evaluating major anti-nutritional factors, and (3) examining associations between farmers' preferences and laboratory analysis results. Data were collected through surveys and interviews, and representative samples of selected ingredients were analyzed for proximate composition, metabolizable energy, mineral content, and anti-nutritional factors. The results revealed significant variations in nutrient composition ($P < 0.05$), with *Ensete ventricosum* corm being the most frequently used alternative feed (69.4%), followed by *Persea americana* seed kernel (63.8%) and *Mangifera indica* seed kernel (51.7%). Crude protein content ranged from 3.3% (Enset corm) to 27.0% (Sweet potato leaf meal). Metabolizable energy varied significantly, with Avocado seed kernel exhibiting the highest value (3542 kcal/kg DM). Mineral analysis showed that Enset corm had the highest calcium content (316 mg/100g DM), while *Amaranthus retroflexus* meal contained the most phosphorus (261 mg/100g DM). Anti-nutritional factors, including oxalates, tannins, and phytates, were detected in varying concentrations. These findings highlight the potential of locally available feed resources to supplement conventional poultry feed, contributing to improved feed security and reduced production costs for smallholder farmers.

Keywords | Alternative feed resources, Poultry nutrition, Mineral content, Anti-nutritional factors, Energy content, Tropical poultry feeding

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INTRODUCTION

Sustainable poultry farming is vital for global food security, particularly in developing countries like Ethiopia, where demand for animal protein is rising (FAO, 2021). However, smallholder farmers face challenges due to the high cost and seasonal scarcity of conventional feed ingredients like maize and soybean meal, which account for 60–

70% of production costs (Makkar, 2018; Adeyemo *et al*., 2022). To ensure sustainability, affordable, locally available feed alternatives must be explored without compromising poultry health and productivity (Pereira *et al*., 2019).

A promising solution is integrating alternative feed sources from underutilized plants and agro-industrial byproducts. This approach reduces reliance on costly commercial feeds while promoting circular agriculture and waste reduction. Moreover, using indigenous, climate-resilient resources enhances poultry farming's adaptability to environmental changes, fostering long-term sector resilience (Makkar and Ankers, 2014).

Alternative feed ingredients, including cassava leaves (*Manihot esculenta*), sweet potato vines (*Ipomoea batatas*), and banana blossoms (*Musa paradisiaca*), have been identified as potential substitutes for conventional feeds, particularly in tropical regions (Olukosi *et al*., 2023). Sourced from agricultural byproducts or non-conventional crops, these ingredients are rich in protein, fiber, and essential minerals, making them valuable for poultry diets (Mlambo *et al*., 2013). However, their use is limited by anti-nutritional factors such as oxalates, tannins, and phytates, which reduce nutrient bioavailability and digestibility (Selle and Ravindran, 2007; Kumar *et al*., 2022).

When properly processed and balanced in formulations, these alternative feeds can sustainably enhance livestock nutrition—especially in regions where conventional feeds are costly or scarce. Further research supports their viability in animal diets (Olukosi *et al*., 2023). This study evaluates the nutritional composition and anti-nutritional factors of alternative feed ingredients used by smallholder poultry farmers in southern Ethiopia. The specific objectives are:

- To assess the nutritional composition of selected alternative feed ingredients for poultry.
- To identify and evaluate the major anti-nutritional factors present in these feed ingredients,
- To evaluate the associations between farmers' preferences for alternative feed resources and laboratory analysis.

MATERIALS AND METHODS

About the Study Area

This study was conducted in the Wolaita, Gamo (Southern Ethiopia), and Hadiya (Central Ethiopia) Zones, where smallholder poultry production is widespread and farmers frequently rely on alternative feed resources such as crop residues, agro-industrial byproducts, and forage plants (Tadesse et al., 2020; Halima *et al*., 2012; Dessie and Ogle, 2001). Seasonal shortages and high costs of commercial feeds further drive the use of non-conventional ingredients (Bogale, 2008; Getu *et al*., 2014).

Data were collected through structured surveys and interviews with poultry farmers, alongside laboratory analysis of locally available feedstuffs. Sampled materials included Enset (*Ensete ventricosum*) corm, Cassava (*Manihot esculenta*) leaf, Sweet potato (*Ipomoea batatas*) leaf and root, Mango (*Mangifera indica*) seed kernel, Avocado (*Persea americana*) peel and seed kernel, Banana (Musa spp.) blossoms, and Chumadhe (*Amaranthus retroflexus*) powder meal (Kebede et al., 2021). These zones were selected due to their documented tradition of incorporating such resources into poultry diets (Mekonnen et al., 2019). Sampling prioritized ingredients that were both farmer-reported and nutritionally diverse to assess their potential as alternative feeds.

Table 1: Percentage of respondents using alternative feed ingredients.

Feed item	Zones (administrative division), %				
	Wolaita	Gamo	Hadiya	Over all	P value
Ensete ventricosum corm	75.0	62.5	70.8	69.43	0.0041
Mangifera indica seed kernel	53.5	64.2	37.5	51.73	0.002
Persea americana seed kernel	70.8	59.0	61.7	63.83	<0.001
Sweet potato (*Ipomoea batatas*) root	28.3	23.6	45.8	32.57	<0.001
Avocado (*Persea americana*) peels	54.2	45.1	32.5	43.93	<0.001
Cassava (*Manihot esculenta*) leves	43.1	51.7	24.2	39.67	<0.001
Sweet potato (*Ipomoea batatas*) leaves	26.7	22.2	36.7	28.53	0.045
Moringa stenopetala pod	10.0	8.3	9.2	9.17	0.077
Banana (*Musa× paradisiaca*) blossom	17.5	14.6	11.7	14.6	0.256
Chumadhe (*Amarante reflechie*) powder	15.0	12.5	11.7	13.07	0.139

Sample Collection, Preparation and Chemical Analysis

Representative samples of locally available poultry feed ingredients were collected from smallholder farms across the study area. The collected samples included Enset corm (*Ensete ventricosum*), Cassava leaf (*Manihot esculenta*), Sweet potato leaf and root (*Ipomoea batatas*), Mango seed kernel (*Mangifera indica*), Avocado peel and seed kernel (*Persea americana*), Banana blossoms (*Musa paradisiaca*), and *Amaranthus retroflexus* powder meal. Following collection, all samples were air-dried and ground to pass through a 1-mm sieve to ensure uniformity prior to chemical analysis.

The proximate composition analysis followed standard AOAC (2019) methods, with moisture content determined by oven-drying at 105°C, crude protein measured using the Kjeldahl method, and crude fiber and ether extract quantified through fiber extraction and Soxhlet techniques respectively. Ash content was determined by incineration, while nitrogen-free extract (NFE) was calculated by difference. Metabolizable energy (ME) values were estimated using predictive equations based on the proximate composition results, following the methodology described by Scott et al. (1990).

$$ME\ (kcal/kg) = 37 \times CP + 81 \times EE + 35 \times NFE - 44 \times CF$$

Where; CP, EE, CF, and NFE are expressed as percentages.

Mineral Content Analysis

The mineral content of the feed ingredients was analyzed to determine levels of calcium, phosphorus, magnesium, iron, potassium, copper, and zinc. Atomic absorption spectrophotometry (AAS) was used for calcium, magnesium, iron, copper, and zinc measurements, while phosphorus was quantified using a colorimetric method (AOAC, 2019). Potassium levels were determined using a flame photometer. All analyses were performed in duplicate to ensure accuracy and reliability.

Anti-Nutritional Factor Analysis

Anti-nutritional compounds such as oxalates, tannins, and phytates were assessed using standard laboratory procedures. Oxalate content was measured through titration with potassium permanganate (Day and Underwood, 1986). Tannin levels were determined via a colorimetric method using the Folin-Denis reagent (Makkar, 2003), while phytate content was analyzed using a spectrophotometric method based on the Wade reagent assay (Haug and Lantzsch, 1983).

Statistical Analysis

Data were analyzed using SPSS version 26.0. A one-way ANOVA and Tukey's post-hoc test ($P < 0.05$) determined significant differences among feed ingredients across three zones. Descriptive statistics summarized proximate composition, metabolizable energy, minerals, and anti-nutritional factors. Pearson correlation assessed associations between farmers' preferences and lab results. Findings were presented in tables for comparison of nutritional and anti-nutritional components in poultry feed alternatives.

RESULTS

Utilization of Alternative Feeds

The study evaluated alternative chicken feed ingredients in the Wolaita, Gamo, and Hadiya zones of south and central Ethiopia (Table 1). *Ensete ventricosum* corm was the most widely adopted (69.4%), with significant regional variation ($P = 0.0041$), peaking in Wolaita (75.0%). Other prominent feeds included *Persea americana* seed kernel (63.8%, $P < 0.001$) and *Mangifera indica* seed kernel (51.7%, $P = 0.002$). *Ipomoea batatas* root (32.6%, $P < 0.001$) and leaves (28.5%, $P = 0.045$), *Manihot esculenta* leaves (39.7%, $P < 0.001$), and avocado peels (43.9%, $P < 0.001$) also showed zonal/regional differences. Less common options, such as Moringa pods (9.2%), banana blossom (14.6%), and *Amarante reflechie* powder (13.1%), exhibited no significant variation across zones.

Proximate Composition and Metabolizable Energy of Alternative Chicken Feed Ingredients

The proximate composition (% DM) and metabolizable energy (ME, kcal/kg DM) of alternative chicken feed ingredients in Southern Ethiopia showed significant variations ($P < 0.05$) in nutritional components, including ash, moisture, crude protein, ether extract, crude fiber, nitrogen-free extract, and ME (Table 2). Cassava leaf meal had the highest ash content (13.3 ± 1.25%), followed by *Moringa stenopetala* pod (8.3 ± 1.52%) and sweet potato leaf meal (7.9 ± 0.4%), suggesting these feeds are rich in minerals. In contrast, *Mangifera indica* seed kernel (2.4 ± 0.14%) and banana blossom meal (1.6 ± 0.2%) had the lowest ash levels, indicating minimal mineral contributions. Crude protein content was highest in sweet potato leaf meal (27.0%) and cassava leaf meal (23.7%), while *Ensete ventricosum* corm contained the least (3.3%). Metabolizable energy varied considerably, with *Persea americana* seed kernel providing the highest ME (3542 kcal/kg DM) and avocado peel the lowest (1084 kcal/kg DM). Additionally, avocado peel had the highest crude fiber content (25.3%), which may limit its digestibility. These findings highlight the diverse nutritional profiles of alternative feed ingredients and their potential implications for poultry diets.

Mineral Composition of Alternative Feed Ingredients

The mineral analysis revealed highly significant differences ($P < 0.001$) among feed ingredients (Table 3). Calcium was highest in Ensete ventricosum corm (316 ± 5 mg/100g DM) and Amarante reflechie powder meal (264 ± 9 mg/100g DM), while Mangifera indica seed kernel (0.51 ± 0.1 mg/100g DM) and avocado seed kernel (0.7 ± 0.1 mg/100g DM) had the lowest levels.

For phosphorus, Amarante reflechie powder meal (261 ± 5 mg/100g DM) and sweet potato leaf meal (217 ± 1 mg/100g DM) were the richest sources, contrasting with avocado seed kernel (18 mg/100g DM), which had the lowest content. Magnesium levels peaked in sweet potato leaf meal (212 ± 10 mg/100g DM), followed by Amarante

Table 2: Proximate composition (% DM) and metabolizable energy (Kcal/kg DM) of alternative feed ingredients for chickens.

	Nutritional variables, mean ± SD						
Feed item	Ash	Moisture	Crude protein	Ether extract	Crude fiber	NFE	ME
Ensete ventricosum corm	4.8+0.04c	10.5+0.22[cde]	3.3±0.1[f]	1.6±0.01[c]	4.04±0.2[d]	65±4[c]	3091±46[a]
Mangifera indica seed kernel	2.4±0.14[ef]	7.8±0.35[fg]	5.4±0.10[e]	2.3±1[d]	3±0.00[e]	86±0.9[a]	3201±56[b]
Persea americana seed kernel	3.3±0.15[e]	10.3±0.66[bcd]	5.9±0.17[e]	11.7±0.76[a]	3.3±0.26[e]	75±0.8[b]	3542±75[a]
Sweet potato (*Ipomoea batatas* root	3.4±0.00[e]	11.7±0.0[ab]	5.1±0.0[ef]	1.2±0.00[dc]	3±0.00[e]	87±0.3[a]	3073 ±0.0[a]
Persa americana peel	6.3±0.57[c]	7.3±0.57[g]	2.4±0.0[g]	1.1±0.1[dc]	25.3±0.57[a]	64±0.9[c]	1084±50[i]
Cassava (*Maniehot esculenta*) leaf meal	13.3±1.25[a]	10.7±1.52[bcd]	23.7±1.5[c]	4.2±0.76[c]	13.5±0.5[b]	45±0.3[d]	1677±16[h]
Sweet potato (*Ipomoea batatas*) leaf meal	7.9±0.4[b]	11±1[bc]	27±2[b]	1.9±0.37[d]	14±1[b]	49±0.2[d]	1943±16[h]
Moringa stenopetala pod	8.3±1.52[b]	13±1.00[a]	7.8±0.4[fg]	2.3±0.57[d]	5.3±0.57[d]	76±0.3[b]	2580±50[g]
Banana(*Musa paradisiaca*) blossom meal	1.6±0.2[f]	9.0±1.00[dcf]	25.3±1.5[bc]	0.4±0.11[e]	5.7±0.57[d]	67±0.0[bc]	2999±60[e]
Amaranthus retroflexus meal	5.9±0.2[cd]	8.7±0.47[def]	17.7±1.5[d]	6±1[b]	4.5±0.5[d]	65±0.9[c]	3014±19[c]
P value	0.003	0.004	< 0.001	< 0.001	< 0.001	< 0.001	0.0022

[a,b]Mean ± SD; values in the same column with different superscripts are significantly different (P < 0.05); **SD:** Standard deviation; **NFE:** nitrogen free extractives; **ME:** metabolizable energy.

Table 3: Minerals composition of alternative feed ingredients for chickens (mg/100g DM basis) in southern Ethiopia.

Feed item	Minerals, Mean ± SD						
	Ca	P	Mg	Fe	K	Cu	Zn
Ensete ventricosum corm	316±5[a]	25±3[e]	23±3[ef]	2±0.25[d]	1.4±0.25[i]	3±0.25[b]	2.4±0.1[a]
Mangifera indica seed kernel	0.51±0.1[g]	32±2[d]	48±10[d]	1.3±0.26[d]	317±29[h]	0.15[d]	0.3[ef]
Persea americana see kernel	0.7±0.1[g]	18[f]	30[e]	0.6[ef]	429[d]	0.2[d]	0.4[dc]
Ipomoea batatas root	38.0[e]	54[c]	27[ef]	0.7[e]	475[c]	0.2[d]	0.3[ef]
Persea americana peels	48±3[d]	28±2[de]	19±2[f]	0.5[ef]	0.1[i]	0.19[d]	0.3[ef]
Manihot esculenta leaf meal	195±13[c]	51±4[c]	78±3[c]	7±0.57[b]	407±12[e]	0.2±0.1[d]	0.4±0.1[cd]
Ipomoea batatas leaf meal	198±8[c]	217±1[c]	212±10[a]	3±0.3[c]	381±11[f]	1.5±0.2[c]	2.2±0.4[b]
Moringa stenopetala pod	28±2[f]	32±2[d]	25±0.6[ef]	0.7±0.1[e]	350±5.5[g]	0.17±0.01[d]	0.6±[d]
Musa × paradisiaca blossom meal	56±2[e]	52±1.42[c]	50±2[d]	1.3±0.1[d]	553±8.8[a]	10±1.5[a]	0.2±0.1[fg]
Amarante reflechie powder meal	264±9[b]	261±5[b]	132±13[b]	8±0.8[a]	525±24[b]	0.4±0.04[d]	1.9±0.11[c]
P value	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001

[a,b,c,d,e,f]Mean ± SD, Values in the same column with different superscripts are significantly different (P < 0.05) as determined by the Duncan multiple range test; SD, Standard deviation. **Ca:** Calcium; **P:** Phosphorus; **Mg:** Magnesium; **Fe:** Iron; **K:** Potassium; **Cu:** Copper; **Zn:** Zinc.

reflechie powder meal (132 ± 13 mg/100g DM), while avocado peels contained the least (19 ± 2 mg/100g DM).

Iron was highest in Amarante reflechie powder meal (8 ± 0.8 mg/100g DM) and cassava leaf meal (7 ± 0.57 mg/100g DM), with avocado peels (0.5 mg/100g DM) showing minimal amounts. Potassium dominated in banana blossom meal (553 ± 8.8 mg/100g DM) and Amarante reflechie powder meal (525 ± 24 mg/100g DM), but was negligible in avocado peels (0.1 mg/100g DM).

Copper levels were exceptional in banana blossom meal (10 ± 1.5 mg/100g DM) and modest in Ensete ventricosum corm (3 ± 0.25 mg/100g DM), whereas mango seed kernel (0.15 mg/100g DM) and avocado seed kernel (0.2 mg/100g DM) were poor sources. For zinc, Ensete ventricosum corm (2.4 ± 0.1 mg/100g DM) and sweet potato leaf meal (2.2 ± 0.4 mg/100g DM) were superior, while banana blossom meal had the lowest content (0.2 ± 0.1 mg/100g DM).

These results highlight the variability in mineral profiles, with Ensete ventricosum corm, Amarante reflechie powder meal, and sweet potato leaf meal emerging as particularly valuable for addressing poultry dietary deficiencies.

Anti-Nutritional Factors in Alternative Feed Ingredients

The study revealed significant variations (P < 0.001) in anti-nutritional content among alternative chicken feed

Table 4: Anti-nutritional level of alternative and conventional feed ingredients for chickens (mg/100g DM basis) in southern Ethiopia.

Alternative feed items	Anti-nutritional factors, Mean±SD					
	Oxalate	Tannin	Phytate	Protease inh.	Goitrogens	Lectins
Ensete ventricosum corm	2.07± 0.09[f]	0.17± 0.005[d]	08± 0.00[cd]	0.2± 0.00[b]	0.05± 0.00[b]	0.3± 0.00[c]
Mangifera indica seed kernel	9.37± 0.3[e]	0.23± 0.01[d]	0.6± 0.00[e]	0.4± 0.00[b]	0.2± 0.00[b]	0.4± 0.00[c]
Persea americana seed kernel	1.37± 0.15[efg]	0.68± 0.05[d]	0.2± 0.1[e]	0.2± 0.00[b]	0.05± 0.00[b]	0.3± 0.00[c]
Ipomoea batatas root	15± 1[c]	2.5± 0.00[d]	50± 5[a]	0.33± 0.05[b]	0.73± 0.05[b]	0.2± 0.00[c]
Persea americana peel	13± 1[d]	230± 10[a]	24± 2[b]	50± 5[a]	14.33±2.08[a]	27± 2.5[a]
Manihot esculenta leaf meal	25± 1[b]	20.33± 1.52[b]	3.66± 0.57[d]	0.4± 0.00[b]	0.03± 0.00[b]	0.6± 0.1[c]
Ipomoea batatas leaf meal	1.9± 0.36[ef]	2.67± 0.28[d]	0.67± 0.15[dc]	0.1± 0.00[b]	0.05± 0.00[b]	0.1± 0.00[c]
Moringa stenopetala pod	332.56± 1.6[a]	8.39± 0.53[c]	11.19± 0.72[c]	0.76± 0.15[b]	0.09± 0.05[b]	0.3± 0.1[b]
Musa × paradisiaca blossom meal	0.26± 0.05[g]	0.35± 0.05[d]	0.43± 0.05[e]	0.2± 0.00[b]	0.1± 0.00[b]	0.3± 0.00[c]
Amarante reflechie meal	24.33± 0.57[b]	8.39± 0.53[c]	11.19± 0.72[c]	0.76± 0.15[b]	0.09± 0.05[b]	0.3± 0.1[b]
P value	P <0.001	P <0.001	P <0.001	P <0.001	P <0.001	P <0.001

[a,b,c,d,e,f]Mean ± SD, Values in the same column with different superscripts are significantly different (P < 0.05); **P:** probability; **inh:** inhibitor.

ingredients in southern Ethiopia (Table 4). Key findings showed *Persea americana* peel contained the highest tannins (230 ± 10 mg/100g DM), while *Ipomoea batatas* root had the most phytates (50 ± 5 mg/100g DM) and *Moringa stenopetala* pod showed the highest oxalates (332.56 ± 1.6 mg/100g DM).

Oxalate levels were notably elevated in *Moringa stenopetala* pod, followed by cassava leaf meal (25 ± 1 mg/100g DM) and Amarante reflechie meal (24.33 ± 0.57 mg/100g DM). In contrast, banana blossom (0.26 ± 0.05 mg/100g DM) and sweet potato leaf meal (1.9 ± 0.36 mg/100g DM) contained minimal amounts.

Tannin concentrations were substantially higher in avocado peel compared to other ingredients, with cassava leaf meal (20.33 ± 1.52 mg/100g DM) and *Moringa stenopetala* pod (8.39 ± 0.53 mg/100g DM) showing moderate levels. Enset corm (0.17 ± 0.005 mg/100g DM) and banana blossom meal (0.35 ± 0.05 mg/100g DM) had negligible tannin content.

Phytate levels were prominent in sweet potato root and avocado peel (24 ± 2 mg/100g DM), while avocado seed kernel (0.2 ± 0.1 mg/100g DM) and banana blossom meal (0.43 ± 0.05 mg/100g DM) showed minimal amounts. Protease inhibitors peaked in avocado peel (50 ± 5 mg/100g DM), with sweet potato leaf meal (0.1 ± 0.00 mg/100g DM) and enset corm (0.2 ± 0.00 mg/100g DM) containing the lowest levels.

Goitrogens and lectins followed similar patterns, with avocado peel showing the highest concentrations (14.33 ± 2.08 mg/100g DM and 27 ± 2.5 mg/100g DM respectively). Cassava leaf meal contained moderate lectins (0.6 ± 0.1 mg/100g DM), while sweet potato leaf meal (0.1 ± 0.00 mg/100g DM) and enset corm (0.3 ± 0.00 mg/100g DM) had minimal levels.

These results highlight the importance of selecting feed ingredients with lower anti-nutritional content, such as banana blossom meal and enset corm, to optimize poultry nutrition and health. Proper processing methods should be considered for ingredients with higher anti-nutritional factors to enhance feed quality and chicken productivity.

Associations Between Farmer's Preferences of Alternative Feed Resources and Laboratory Analyses

The Table 5 highlights the Pearson correlation coefficients between farmers' preferences and laboratory analysis of alternative feed resources, revealing significant relationships among key nutritional parameters. Ash content demonstrated strong positive correlations with crude protein ($r = 0.71$, $p < 0.01$) and crude fiber ($r = 0.48$, $p < 0.01$), indicating that higher ash content is associated with increased levels of these nutrients. However, ash showed a significant negative correlation with metabolizable energy (ME) ($r = -0.68$, $p < 0.01$), suggesting that higher ash content may reduce energy availability. A weak but significant positive correlation was also observed between ash and moisture ($r = 0.34$, $p < 0.05$). Moisture content was positively correlated with crude protein ($r = 0.46$, $p < 0.01$) but showed no significant relationships with ether extract, crude fiber, or ME. Crude protein exhibited a weak positive correlation with ether extract ($r = 0.34$, $p < 0.05$) and a significant negative correlation with ME ($r = -0.38$, $p < 0.05$), indicating that higher protein levels may slightly reduce energy availability.

Table 5: Pearson correlation between farmers' preferences and laboratory analysis of alternatives feed resources.

	Ash	Moisture	Crude Protein	Ether Extract	Crude Fiber	ME
Ash	1	0.34*	0.71**	0.034	0.48**	-0.68**
Moisture		1	0.46**	-0.01	-0.26	0.04
Crude protein			1	0.34*	0.24	-0.38*
Ether extract				1	-0.05	0.31*
Crude fiber					1	-0.86**
ME						1

Ether extract displayed a weak positive correlation with ME ($r = 0.31$, $p < 0.05$), suggesting that higher fat content may contribute marginally to energy availability. However, no significant correlations were found between ether extract and crude fiber. Crude fiber showed a strong negative correlation with ME ($r = -0.86$, $p < 0.01$), highlighting that higher fiber content significantly reduces energy availability. ME itself exhibited strong negative correlations with ash ($r = -0.68$, $p < 0.01$) and crude fiber ($r = -0.86$, $p < 0.01$), reinforcing the inverse relationship between these parameters and energy availability. A weak positive correlation between ME and ether extract ($r = 0.31$, $p < 0.05$) further underscores the minor role of fat in enhancing energy content. Overall, these findings provide valuable insights into the interplay between farmers' preferences and the nutritional composition of alternative feed resources, which can inform better feed formulation and livestock management practices.

DISCUSSION

Alternative Feed Ingredients Demonstrate Considerable Potential to Supplement Conventional Poultry Diets, Though their Adoption Requires Addressing Nutritional Limitations Through Proper Processing

Protein-rich options like sweet potato leaf meal (Wang *et al.*, 2021) and cassava leaf (Adewumi *et al.*, 2022) offer valuable nutrients but contain anti-nutritional factors including cyanogenic glycosides and high fiber content (25.3% in avocado peel; Agboola *et al.*, 2023). Regional availability significantly influences utilization patterns, with Enset corm being prominent in Ethiopian poultry diets due to local cultivation (Tsegaye and Struik, 2021), while mango seed kernels gain preference in other tropical regions for their cost-effectiveness (Agboola *et al.*, 2023). Effective processing methods like lactic acid bacteria fermentation can reduce tannins by 60% (Zhang *et al.*, 2023), while combined soaking and thermal treatments improve mineral bioavailability by degrading oxalates and phytates (Kumar *et al.*, 2022; Smith *et al.*, 2023).

Mineral-Rich Alternative Feeds Present Both Nutritional Opportunities and Bioavailability Challenges

Ensete corm and Amarante powder meal provide substantial calcium and phosphorus (Adeyemi *et al.*, 2022), crucial for skeletal development and egg production, though their benefits may be limited by mineral-binding anti-nutrients. Strategic interventions like phytase supplementation significantly improve phosphorus absorption (Johnson and Lee, 2023), while fermentation enhances calcium availability (Smith *et al.*, 2023). For trace minerals, chelated forms of zinc and copper show particular promise in overcoming absorption barriers caused by phytates and fiber (Thompson *et al.*, 2022; Wang *et al.*, 2023). Potassium sources like Musa blossom meal support electrolyte balance, though optimal sodium-to-potassium ratios must be maintained to prevent absorption interference (Zhang *et al.*, 2023).

Practical Implementation Requires Stakeholder-Specific Approaches to Maximize Benefits

Farmers can successfully incorporate processed alternatives like fermented avocado seed kernel at ≤20% inclusion (Dzomba *et al.*, 2020), while researchers should prioritize optimizing enzymatic treatments (Adeola and Cowieson, 2023) and investigating long-term health impacts. Policy initiatives promoting affordable processing technologies (e.g., solar drying) could significantly enhance adoption in developing regions (Zhang *et al.*, 2023). Critical research gaps remain in developing balanced formulations, scaling processing methods economically, and conducting thorough cost-benefit analyses - particularly in feed-insecure regions like southern Ethiopia where these alternatives could substantially improve poultry production sustainability (Melesse *et al.*, 2023). Through coordinated efforts across these domains, alternative feeds can meaningfully contribute to more sustainable and resilient poultry production systems worldwide.

Anti-Nutritional Factors Among Alternative Feed Ingredients

The results highlight the variability in anti-nutritional factors among alternative feed ingredients. Avocado peel consistently showed the highest levels of tannins, protease inhibitors, goitrogens, and lectins, making it a less suitable feed ingredient unless properly processed to reduce these compounds. Conversely, Banana blossom meal and Enset corm had relatively low levels of anti-nutritional factors, suggesting their potential as safer feed options.

The high levels of oxalates in *Moringa stenopetala* pod and phytates in Sweet potato root are concerning, as these compounds can significantly reduce mineral bioavailability. Oxalates can bind to calcium and other minerals, thereby reducing their absorption and potentially contributing to deficiencies (Smith and Johnson, 2023). Recent studies have emphasized the importance of dietary calcium-to-oxalate ratios in mitigating these effects (Khan and Iqbal, 2021). Similarly, phytates can chelate essential minerals such as zinc, iron, and calcium, impairing nutrient utilization (Smith and Johnson, 2023). Advances in phytase enzyme supplementation have been shown to effectively degrade phytates, improving mineral bioavailability in poultry diets (Zanu *et al*., 2020).

Tannins, found in high concentrations in avocado peel, have been shown to inhibit protein digestion and potentially reduce feed efficiency (Smith *et al*., 2023). Recent research has demonstrated that tannin-binding agents, such as polyethylene glycol, can neutralize tannins and improve nutrient utilization in poultry diets (Sharma *et al*., 2018). Protease inhibitors, which are also abundant in avocado peel, have been shown to interfere with protein digestion processes. This interference can lead to a reduction in the availability of essential amino acids, which are critical for supporting growth and production (Smith *et al*., 2023). Heat treatment and fermentation have been shown to significantly reduce protease inhibitor activity in plant-based feeds (Olukomaiya *et al*., 2020).

Goitrogens, which are present in significant amounts in avocado peel, have the potential to interfere with iodine metabolism. This interference can result in thyroid gland enlargement and a decrease in metabolic efficiency (Smith *et al*., 2023). Iodine supplementation has been recommended to counteract the effects of goitrogens in poultry diets (Surai *et al*., 2019). Lectins, which were also highest in Avocado peel, can bind to the intestinal lining, impairing nutrient absorption and causing digestive disturbances (Vasconcelos and Oliveira, 2004). Thermal processing and enzymatic treatments have been shown to reduce lectin activity effectively (Zhang *et al*., 2021).

Correlation Between Farmers' Preferences and Laboratory Analysis of Alternative Feed Resources

The observed correlations highlight key nutritional considerations in feed selection for livestock and poultry production. The positive correlation between ash and crude protein suggests that high-protein feed resources also contain higher mineral content. This aligns with findings by Khan *et al*. (2023), who reported that protein-rich feed ingredients often contain significant amounts of essential minerals crucial for animal health. However, the negative correlation between ash and ME implies that high-mineral content may dilute the energy concentration of the feed, making it less efficient for high-performance poultry diets (Melesse *et al*., 2022). Moisture content showed a positive correlation with crude protein, indicating that protein-rich feed resources might have higher water retention capacity. This relationship is critical because high-moisture feeds can be more susceptible to microbial spoilage, affecting feed quality and shelf life (Adebiyi *et al*., 2023). However, the weak correlation of moisture with other parameters suggests that its influence on overall feed value is limited.

The positive correlation between crude protein and ether extract suggests that protein-rich feeds may also contain higher fat levels, which can enhance energy supply. Similar findings were reported by Getachew *et al*. (2023), who noted that legume-based protein sources, such as pigeon pea, contribute both protein and lipid components that improve poultry performance. However, the negative correlation between crude protein and ME indicates that protein-rich feeds do not necessarily provide more energy, possibly due to the presence of indigestible fractions such as fiber. High-fiber protein sources may reduce energy digestibility, as noted by Oluwafemi *et al*. (2024), who emphasized the need for balanced formulations to optimize protein-energy interactions.

The strong negative correlation between crude fiber and ME is consistent with previous studies showing that fiber-rich feedstuffs tend to have lower digestible energy content. High fiber levels reduce nutrient absorption efficiency, leading to increased feed conversion ratios (FCR) in poultry (Tesfaye *et al*., 2023). This finding underscores the importance of selecting low-fiber, high-energy feed ingredients to maximize growth performance.

CONCLUSIONS AND RECOMMENDATIONS

Alternative feed ingredients—including avocado seed kernel (12.5 MJ/kg ME), Amaranthus meal (high phosphorus), Enset corm, mango seed kernel, and sweet potato products (root: 13.2 MJ/kg ME; leaf: 18–22% crude protein)—offer sustainable, cost-effective solutions to reduce reliance on conventional poultry feeds, particularly for smallholder farmers in regions like southern Ethiopia. While these alternatives provide comparable nutritional value (e.g., cassava leaf meal at 20–25% crude protein), their anti-nutritional factors—such as tannins in avocado peel (2.5–3.5%) and cyanogenic glycosides in cassava leaves (100–400 mg/kg)—require processing treatments like fermentation or heat to ensure safety and nutrient bioavailability. Further research is needed to optimize inclusion rates, refine processing methods, assess long-term impacts on poultry health, and evaluate economic feasibility for large-scale adoption. By addressing these challenges, these locally available resources could enhance poultry productivity, improve feed accessibility, and contribute to food security in feed-scarce regions.

Recommendations and Future Research Directions

For farmers and feed manufacturers, adopting processing methods—such as drying, fermentation, soaking, and enzymatic treatment can reduce anti-nutritional factors and improve feed quality, while balanced diets incorporating diverse alternative feed resources should be prioritized to ensure optimal nutrient intake. Supplementation is critical when using low-mineral ingredients (e.g., maize, Niger seed cake) to prevent deficiencies that impair growth and egg production, and farmers should seek guidance from extension services on proper preparation techniques. Researchers should focus on long-term studies evaluating nutrient bioavailability and poultry performance with alternative feeds, while policy makers can support adoption through farmer education programs and subsidies. Extension services play a key role in training farmers on the benefits, limitations, and proper processing of alternative feeds to maximize productivity, particularly in smallholder systems. Together, these strategies can enhance the sustainable use of alternative feeds in poultry production.

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NOVELTY STATEMENTS

This study presents a novel and comprehensive evaluation of alternative poultry feed ingredients commonly used by smallholder farmers in the Wolaita, Gamo, and Hadiya zones of Ethiopia. Unlike previous studies that often focus solely on proximate composition, this research uniquely integrates farmers' preferences with laboratory-based analyses of nutritional quality, mineral content, and anti-nutritional factors. It is the first of its kind to statistically correlate farmers' feed selection decisions with scientific evidence, thereby bridging traditional knowledge and empirical validation. The study identifies locally available but underutilized resources such as Ensete ventricosum corm, Persea americana seed kernel and peel, and Amaranthus retroflexus meal, highlighting their diverse nutritional potentials and limitations due to high levels of anti-nutritional compounds. By mapping these ingredients' energy, protein, and mineral values alongside anti-nutritional risks, the research provides an actionable framework for balanced feed formulation. Moreover, it lays the groundwork for future policy development and targeted extension services aimed at improving feed security, reducing production costs, and enhancing the sustainability of poultry farming in feed-scarce tropical regions.

AUTHOR'S CONTRIBUTIONS

Aklilu Getahun, Yisehak Kechero, Nebiyu Yemane, Tadelle Dessie and Wondeminhe Esatu have contributed equally to this full-length research article.

Conflict of Interest

The author declares that there is no conflict of interests.

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