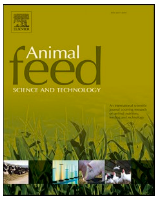
Animal Feed Science and Technology 332 (2026) 116604

Contents lists available at ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci



Nutritive value of fodder beet for broilers chickens

K. Ganraj, L.S. David, P.C.H. Morel [*]

School of Agriculture and Environment, Massey University, Palmerston North 4442, New Zealand

ARTICLE INFO

Keywords:
Amino acids
Apparent metabolisable energy
Crude protein
Digestibility
Fodder beet

ABSTRACT

An experiment was conducted to determine the apparent metabolisable energy (AME), nitrogen-corrected AME (AMEn) and the standardised ileal digestible content of amino acids in fodder beet (FB). Three maize-soybean-based diets were formulated, a basal diet (FB0), the basal diet supplemented with 12.5 % of FB (FB12.5), and the basal diet supplemented with 25 % of FB (FB25). Each diet was randomly allocated to six replicate cages with six birds per cage and fed from days 14–21. Titanium dioxide (4 g/kg) was included in all diets as an indigestible marker for the measurement of marker-based AME and ileal nutrient digestibility. The total collection (TC) method was also used for the measurement of AME. A regression method was used to determine the nutritive value of FB. The AME and AMEn of FB were determined to be 9.63 MJ/kg and 9.36 MJ/kg, respectively, using the TC method, and 7.97 MJ/kg, 7.79 MJ/kg, respectively, using the marker method. The apparent ileal crude protein (CP) and gross energy (GE) content of FB were 56.4 g/kg and 11.2 MJ/kg, respectively. Standardised ileal digestible amino acid content was higher for glutamic acid (21.1 g/kg) while it was lower for sulfur containing amino acids (-0.1 to −0.4 g/kg). In conclusion, nutritive value of FB was determined for 14–21 day old broilers using regression method. Further studies are needed to validate the current findings, and to determine the optimal inclusion level of FB in poultry diets.

1. Introduction

The Poultry industry has undergone tremendous changes in the last five decades as genetic selection and advance in nutritional management have resulted in large improvements in broiler growth performances (Havenstein et al., 2003; Korver, 2023). In broiler production feed cost represents about 60–70 % of the total cost of production. Poultry nutrition has evolved from using a variety of naturally occurring feedstuffs to modern diets primarily based on cereal grains (maize, wheat) as a source of energy and soybean as a main source of protein. Efforts are being made worldwide to use alternative sources of protein and energy to replace soybean meal, maize and wheat in poultry and pig diets (Ravindran, 2012; 2013a). These alternatives ingredients must be nutritious, palatable, cost-effective, readily available throughout the year, and non-competitive with human food supplies.

The main role of feed ingredients is to supply the birds with nutrients that are digested and utilised effectively for growth. However, each feed ingredient has unique nutritional, structural and antinutritional properties (Ravindran, 2013b; Babatunde et al., 2021) that

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Abbreviations: AME, Apparent metabolisable energy; AMEn, Nitrogen-corrected apparent metabolisable energy; AIDC, Apparent ileal digestibility coefficient; ATTDC, Apparent total tract digestibility coefficient; CP, Crude protein; DM, Dry matter; FB, Fodder beet; GE, Gross energy; SIDC, Standardised ileal digestibility coefficient; TC, Total excreta collection; FB0, Basal diet; FB12.5, Basal diet supplemented with 12.5 % of fodder beet; FB25, Basal diet supplemented with 25 % of fodder beet.

[*] Corresponding author.

E-mail address: P.C.Morel@massey.ac.nz (P.C.H. Morel).

https://doi.org/10.1016/j.anifeedsci.2025.116604
Received 15 January 2025; Received in revised form 3 November 2025; Accepted 8 December 2025

can affect an animal's growth performance. Therefore, when formulating diets for poultry, the chemical composition and digestible nutritive value of the ingredients should be taken into account (Pesti and Choct, 2023). The poultry sector relies on a few major ingredients for feed formulation. Cereal grains are the main sources of energy in poultry diets. The industry has always been inclined to use low-cost ingredients to maximise profit. However, such low-cost ingredients many not support optimum productivity, and are therefore incorporated only in small amount or additives are used to enhance their nutritive value (Ravindran, 2013b; Perera and Ravindran, 2025).

The FB (*Beta vulgaris L.*) is a herbaceous dicotyledonous plant which belongs to the family *Amaranthaceae* (Henry, 2010). Fodder Beet can be considered as alternative feed ingredient that might be useful for the poultry industry, as it is easily cultivated, palatable and has good nutritive properties in terms of energy (Matthew et al., 2011; Woods et al., 2023). The gross energy (GE) content of FB has been reported to be 16 MJ/kg dry matter (DM; Clark, 1987). On the other hand, FB, being low in protein (Woods et al., 2023), does not form a whole diet, and should be complemented with a protein source. The crude protein (CP) content of FB ranged from 90 to 140 g/kg for whole FB crop and 30–180 g/kg (average of 82 g/kg) for bulb (Woods et al., 2023). According to Al-Jbawi (2020), the protein content of FB was 170 g/kg for shoots and 113 g/kg for roots. A higher amount of fiber and sugar (654 g/kg; Woods et al., 2023) in the FB may cause digestive problems in poultry. The crude fibre content of FB is approximately 60 g/kg, while the neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin contents are 127–160, 68–95 and 9 g/kg, respectively (Clark, 1987; INRA, 2024). The nutritive content of FB is also known to vary depending on the cultivar and harvest period (Enchev and Bozhanska, 2022).

Table 1
Ingredient (g/kg, as-fed basis) and chemically analysied nutrient (g/kg, dry matter basis) compositions of the experimental diets.

Ingredient / Nutrient	Fodder beet	FB0	FB12.5	FB25
Maize		604.4	528.9	453.3
Soybean meal		338.1	295.8	253.6
Fodder beet		0.0	125.0	250.0
Soybean oil		14.2	12.4	10.7
Dicalcium phosphate		15.8	13.8	11.9
Limestone		10.4	9.1	7.8
Sodium chloride		1.0	0.9	0.8
Sodium bicarbonate		3.9	3.4	2.9
DL Methionine		3.1	2.7	2.3
Lysine HCl		3.7	3.2	2.8
L Threonine		2.0	1.8	1.5
L Valine		0.7	0.6	0.5
Vitamin premix		1.0	0.9	0.8
Mineral premix		1.0	0.9	0.8
Choline chloride 60 %		0.7	0.6	0.5
Titanium dioxide		4.0	4.0	4.0
Analysed nutrients				
Dry matter (DM)	896	918	920	914
Ash	91	57	61	62
Crude protein	93	227	209	195
Fat	< 0.1	49	39	29
Starch	2	431	384	322
Neutral detergent fibre	183	57	53	75
Acid detergent fibre	107	19	14	32
Lignin	21	3	7	5
TiO_2	-	5	5	5
Gross energy (MJ/kg DM)	16.0	18.3	18.1	17.8
Sugar	424	53	110	168
Total Amino Acids				
Aspartic Acid		23.7	21.7	20.5
Threonine		9.8	10.0	8.7
Serine		9.8	10.5	9.4
Glutamic Acid		42.1	39.9	38.8
Proline		12.5	12.5	11.6
Glycine		8.0	8.6	7.8
Alanine		10.5	10.3	9.8
Valine		11.0	11.1	10.2
Isoleucine		8.6	8.7	8.0
Leucine		17.5	17.3	15.8
Tyrosine		8.3	8.5	7.8
Phenylalanine		11.4	11.5	10.6
Histidine		4.5	4.9	4.1
Lysine		14.9	14.2	12.7
Arginine		13.6	13.6	11.8
Cysteine		3.9	3.3	3.0
Methionine		7.7	6.8	5.8
Tryptophan		2.3	2.1	1.9

Dietary treatments: FB0 - basal diet (no fodder beet [FB] inclusion); FB12.5–12.5 % FB inclusion; FB25 - 25 % FB inclusion.

The high sugar content of FB makes it highly palatable to livestock, including poultry (Al-Jbawi, 2020). However, it may also exert adverse effects on livestock. Root vegetable crops tend to possess purgative properties, which can cause scouring when fed in excessive amounts (Smith, 1905; Bull, 1916; Gullickson, 1943). In sheep, higher levels of FB intake have been associated with the formation of renal and urinary calculi. Conversely, when included at appropriate levels in the diet, FB has been shown to improve the fat and protein content of milk without affecting milk yield in dairy cows (Roberts, 1987). However, limited data are available on the use of FB in poultry. According to Koschayev et al. (2019), replacing the basal diet with 4 % dry beet pulp can reduce the feed cost by 4.7 %.

The potential limitations of incorporating FB into poultry diets could be related to its nutrient imbalance or the presence of certain antinutritional factors. Proper feed formulation and balancing diets with protein-rich ingredients can help mitigate nutrient imbalances. According to Baker and Eden (1954), the maximum concentration of total oxalates in FB reached 9 % during the summer months, which subsequently declined to 3 %. Elevated oxalate levels can interfere with the absorption of calcium and other minerals in animals (Rahman et al., 2013). However, the adverse effects of oxalates can be alleviated through dietary supplementation with additional minerals or with compounds such as pyruvate (Choi et al., 2025) that reduce mineral binding by modulating metabolic pathways. Very few studies have investigated the nutritive value of FB in poultry. Clark et al. (1987) reported that the mean digestible and metabolisable energy contents of FB roots were 14 and 11.8 MJ kg per DM respectively. Hence, further research is needed.

The current study aims to evaluate the nutritive value of FB as a potential alternative feed ingredient for poultry nutrition and to highlight the benefits it offers in at least partially replacing conventional feed resources, such as maize or wheat, which are consumed by both animals and humans, thereby helping to minimise competition for feed ingredients. The objective of this study is to determine the apparent metabolisable energy (AME) and the ileal digestibility of GE, CP and amino acids of FB for poultry.

2. Material and methods

The experiment was carried out Massey University Poultry Unit in Palmerston North. All experimental procedures were approved by the Massey University Animal Ethics Committee (MUAEC 21/04).

2.1. *Birds, housing and experimental design*

A total of 108, day-old broilers (Ross 308) were obtained from a commercial hatchery and raised in floor pens on a litter of wood shaving in an environmentally controlled room. The temperature was maintained at 32°C during the first week and then it was gradually reduced to 23°C by the end of the third week. Ventilation was controlled by a central ceiling extraction fan and wall inlet ducts. The birds were offered a commercial broiler starter diet until the introduction of the experimental diets on day 14. On day 14, 108 birds were weighed and randomly assigned to 18 grower cages.

2.2. *Experimental diets*

Fodder beets were harvested in October, chopped in smaller pieces and dried at 70 ± 1°C to a constant weight for 48 h. They were ground through a 3 mm screen and then with a 2 mm screen with a hammer mill, before being incorporated into the diets. Three experimental diets, namely, basal diet (FB0), combination of basal diet (87.5 %) and 12.5 % FB (FB12.5) and combination of basal diet (75 %) and 25 % FB (FB25) were developed in mash form. The basal diet was formulated to meet the nutritional requirement of the growing birds (Aviagen, 2022). Titanium dioxide (TiO_2) was added (4 g/kg) to all diets as an indigestible marker to calculate the digestibility of amino acids and energy. The ingredient composition of the assay diets (FB0, FB12.5 and FB25) and the analysed nutrient composition of the FB and the experimental diets are presented in Table 1. The analysed GE and CP content of FB were 16 MJ/kg DM and 93 g/kg DM, respectively. Each diet was allocated to six replicate cages with six birds per cage. The birds were fed *ad-libitum* from day 14–21 post-hatch. Mortality was recorded daily. Water was always freely accessible to the birds during the experiment.

2.3. *Sample collection and preparation*

The AME, AMEn and apparent total tract CP digestibility were determined using the classical total excreta collection method. The fresh excreta samples were collected during four days from day 17 to day 21. Feed intake of birds was also measured during this period. The daily excreta from each cage were stored in plastic bags and kept frozen at −20°C until further processing. They were then thawed at room temperature, pooled by cage, mixed, sub-sampled and freeze-dried before being submitted for chemical analysis. Feed intake and excreta output were recorded during these 4 days to measure the total tract nutrient digestibility.

On day 21, all the birds were euthanised by an intravenous injection (0.5 mL per kg body weight) of sodium pentobarbitone (Provet NZ Pty. Ltd., Auckland, New Zealand), and contents of the lower half of the ileum was collected by flushing the contents gently with distilled water into plastic containers and stored at −20°C before being freeze dried. The ileal digesta was processed as described by (Ravindran et al., 2005). The ileum was defined as that portion of the small intestine that extends from the Meckel's diverticulum to a point that is approximately 40 mm proximal to the ileo-cecal junction. The freeze-dried samples of the diet, excreta and digesta were ground to pass through a 0.5 mm sieve and stored in the airtight containers before being chemically analysed.

2.4. Chemical analysis

The chemical composition of the diets, digesta and excreta were determined at Nutrition Laboratory of the Massey University, Palmerston North, New Zealand. Dry matter was determined after oven-drying the samples at 105 °C according to the method 925.10 of AOAC International (2016). Ash was determined by complete combustion at 550 °C in an electric furnace for 16 h (method 942.05; AOAC International, 2016). Nitrogen was determined (method 968.06, AOAC International, 2016) by combustion using a carbon nanosphere-200 carbon, N, and Sulphur auto analyser (rapid MAX N exceed, Elementar, Donaustraze, Hanau, Germany). The CP content was calculated as N × 6.25. The crude fat was determined by Soxtec extraction procedure (Method 2003.06; AOAC International, 2016) using (Soxtec System HT 1043 Extraction Unit, Höganäs, Sweden). The diet samples were analysed for neutral detergent fibre (NDF), acid detergent fibre (ADF), and crude fibre using Tecator Fibertec™ (FOSS Analytical AB, Höganäs, Sweden) (method 2002.04, 973.18, AOAC International, 2016). The GE in all diets was determined using a bomb calorimeter (Gallenkamp Autobomb, Weiss Gallenkamp Ltd, Loughborough, UK) standardised with benzoic acid.). Total starch content was analysed using the Megazyme α-amylase total starch assay kit (AOAC 996.11, AOAC International, 2016). Sugar was analysed after phenol sulfuric extraction.

The amino acid concentration was determined by high-performance liquid chromatography. In brief, stable amino acids were determined after acid hydrolysis followed by RP HPLC separation using AccQ Tag derivation (994.12 of AOAC International, 2016). Methionine and cysteine were measured after performic acid oxidation (AOAC 994.12). Tryptophan was measured after alkaline hydrolysis following method 988.15 of AOAC International (2016). Titanium oxide was measured using colorimetric method as described by Short et al. (1996) and Jagger et al. (1992).

2.5. Calculations

The AME (total collection method) of the experimental diets was calculated using the following formula.

$$AMEdiet(MJ\Big/kg) = \frac{(FI \times GE_{diet}) - (EO \times GE_{excreta})}{FI}$$

Where, FI = feed intake (kg, DM basis), GE_{diet} = GE in the diet, $GE_{excreta}$ = GE in the excreta and EO = excreta output (kg, DM basis).

The AME of the experimental diets was also calculated using titanium (Ti) marker ratios in the diet and excreta as follows:

$$AMEdiet(MJ\Big/kg) = GE_{diet} \times \frac{[(GE/Ti)diet - (GE/Ti)excreta]}{(GE/Ti)diet}$$

Nitrogen (N)-corrected AME (AMEn) was determined using a factor of 36.54 kJ per gram N retained in the body as follows (Hill and Anderson, 1958).

$$\mathrm{AMEn_{diet}\ (MJ/kg) = AME_{diet} - (36.54 \times N\ retention)\ /1000}$$

The apparent total tract CP digestibility coefficient ($ATTDC_{CP}$) of experimental diets was calculated using the following formula.

$$\mathrm{ATTDC\ of CP}\left(\frac{MJ}{kg}\right) = \frac{(FI \times CP\_diet) - (EO \times CP\_excreta)}{FI \times CP\_diet} \times 100$$

The coefficient of apparent ileal nutrient (amino acids, GE and CP) digestibility (AIDC) of the experimental diets was calculated, using titanium marker ratios in the diet and ileal digesta as shown below:

$$\mathrm{AIDC\_diet} = \frac{\left(\frac{\mathrm{Nu}}{\mathrm{Ti}}\right)\mathrm{d} - \left(\frac{\mathrm{Nu}}{\mathrm{Ti}}\right)\mathrm{i}}{\left(\frac{\mathrm{Nu}}{\mathrm{Ti}}\right)\mathrm{d}}$$

Where, $(\mathrm{Nu/Ti})_{\mathrm{d}}$ = ratio of nutrient (GE or CP or amino acid) and titanium in the diet, and $(\mathrm{Nu/Ti})_{\mathrm{i}}$ = ratio of nutrient (GE or CP or amino acid) and titanium in ileal digesta.

The AIDC were then converted to standardised ileal digestibility (SIDC) using the basal ileal endogenous flow (Basal EAA) per kg DM intake values reported by Ravindran (2021) with the formula below:

$$\mathrm{(SIDC) = AIDC} + \frac{\mathrm{Basal\ EAA}(\frac{\mathrm{g}}{\mathrm{kg}}\mathrm{DM\ intake})}{\mathrm{Diet\ AA(g/kg\ DM)}}$$

The value of the basal EAA used (g/kg DM intake) were: Arginine, 0.29; Histidine, 0.15; Isoleucine, 0.30; Leucine, 0.43; Lysine, 0.29; Methionine, 0.09; Phenylalanine, 0.31; Threonine, 0.50; Valine, 0.37; Alanine, 0.30; Aspartic, 0.58; Cysteine, 0.18; Proline, 0.43; Glycine, 0.36; Glutamic, 0.77; Serine, 0.45; and Tyrosine, 0.23

The titanium recovery was calculated as follow:

$$Recovery(\%) = \frac{(EO \times Tidiet)}{FIxTidiet}\text{x}100$$

Where, Ti = titanium oxide per kg DM, FI = Feed Intake (kg DM), EO = Excreta Output (kg DM)

The AME and strandardised ileal digestible amino acids contents (on as is basis) of the FB were calculated by a regression method using the individual values from each cage (n = 18). The following regression was fitted (Proc REG, SAS 9.4):

$Y = B_0 + B_1 \text{ x } X$

Y: Digestible nutrient content in the diets (FB0, FB12.5, FB25)
X: is amount the of basal in the diet (kg/kg: 1, 0.875, and 0.75)
B_0: is the intercept and represent the nutrient content of the FB
B_1: is the slope and represent the change in nutrient content per unit of basal

2.6. Statistical analysis

A linear model with diet as a fixed effect was fitted to the digestibility data (Prog GLM, SAS 9.4, SAS, 2019). Where appropriate, differences between LSmeans were determined by the Least Significant Difference (LSD) post-hoc test where $P < 0.05$ was deemed significant.

3. Results

3.1. Total tract nutrient digestibility in diets

Table 2 summarises the apparent total tract nutrient digestibility in experimental diets, measured with total collection and TiO_2 marker methods. With both methods, the FB0 diet had greater apparent total tract CP digestibility coefficient, GE metabolisability coefficient and AME ($P \leq 0.001$) when compared to other diets. The values obtained by the total collection methods were always numerically higher than the values obtained by the indicator method.

3.2. Marker recovery

There was no significant difference in the % recovery of TiO_2 between the diets ($P = 0.5365$). The % recovery of TiO_2 varies numerically between 83 % and 88 %.

3.3. Apparent ileal nutrient digestibility in diets

There was no difference ($P > 0.05$) in the apparent ileal digestibility coefficient for CP and GE as described in Table 3. There was no difference ($P > 0.05$) between diets in the SIDC for all the amino acids, except for threonine, serine, isoleucine, phenylalanine and arginine (Table 3). The SIDC for those AA were similar between the FB0 and FB12.5 diets, but were higher in the FB25 than in the FB0.

3.4. AME, AMEn and ileal digestible nutrient content of fodder beet

The AME, AMEn and the ileal digestible content of protein and amino acids (SID) in the FB estimated by the regression method are presented in Table 4. The AME and AMEn of the FB were determined to be 9.63 and 9.36 MJ/kg, respectively, using the total collection method. Corresponding values for marker method were 7.97 and 7.79 MJ/kg, respectively, which were lower than the values obtained with the total collection method. The apparent ileal digestible content of protein and GE of FB were 56.4 and 11.2 g/kg, respectively.

Table 2
Apparent total tract metabolisability coefficient of gross energy (MEc) and crude protein digestibility coefficient ($ATTDC_{CP}$) as well as the AME and AMEn content in the experimental diets, measured either by total collection or indicator method (TiO_2).

Dry matter basis	FB0	FB12.5	FB25	SEM	*P* value
MEc (Total collection)	0.824^a	0.803^b	0.786^c	0.0035	< 0.001
MEc (TiO_2)	0.765^a	0.746^a	0.714^b	0.0078	0.001
$ATTDC_{CP}$ (Total collection)	0.877^a	0.848^b	0.832^c	0.0048	< 0.001
$ATTDC_{CP}$ (TiO_2)	0.833^a	0.807^b	0.777^c	0.0071	< 0.001
AME (Total collection; MJ/kg)	15.1^a	14.5^b	14.0^c	0.06	< 0.001
AME (TiO_2; MJ/kg)	14.0^a	13.5^b	12.7^c	0.14	< 0.001
AMEn (Total collection; MJ/kg)	13.9^a	13.5^b	13.0^c	0.06	< 0.001
AMEn (TiO_2; MJ/kg)	12.9^a	12.5^b	11.8^c	0.13	< 0.001
Marker recovery (%)	83.5	87.7	85.2	2.60	0.537

Dietary treatments: FB0 - basal diet (no fodder beet [FB] inclusion); FB12.5–12.5 % FB inclusion; FB25 - 25 % FB inclusion.
a-c Values within a row with different superscripts are significantly different (LSD, $P < 0.05$).

Table 3
Apparent ileal digestibility coefficients of protein and energy and standardised ileal digestibility coefficient of amino acids in the experimental diets.

	FB0^{2}	FB12.5	FB25	SE	*P* value
Crude Protein	0.722	0.715	0.711	0.0136	0.845
Gross Energy	0.765	0.760	0.760	0.0092	0.911
Amino acids	0.832	0.834	0.851	0.0072	0.156
Aspartic					
Threonine	0.863^{a}	0.873^{ab}	0.893^{b}	0.0080	0.047
Serine	0.862^{a}	0.867^{a}	0.891^{b}	0.0081	0.044
Glutamic	0.911	0.896	0.901	0.0049	0.129
Proline	0.859	0.870	0.878	0.0086	0.312
Glycine	0.830	0.848	0.864	0.0098	0.078
Alanine	0.878	0.878	0.888	0.0074	0.540
Valine	0.865	0.872	0.884	0.0081	0.287
Isoleucine	0.877^{a}	0.884^{ab}	0.906^{b}	0.0071	0.033
Leucine	0.888^{a}	0.893^{ab}	0.912^{b}	0.0064	0.040
Tyrosine	0.866	0.870	0.880	0.0081	0.449
Phenylalanine	0.878^{a}	0.890$_{a}$	0.913^{b}	0.0074	0.014
Histidine	0.880	0.898	0.903	0.0081	0.137
Lysine	0.898	0.903	0.914	0.0066	0.267
Arginine	0.919^{a}	0.923^{a}	0.941^{b}	0.0046	0.007
Cysteine	0.817	0.776	0.789	0.0122	0.084
Methionine	0.944	0.939	0.947	0.0047	0.442

2Dietary treatments: FB0 - basal diet (no fodder beet [FB] inclusion); FB12.5–12.5 % FB inclusion; FB25 - 25 % FB inclusion.
a-b Values within a row with different superscripts are significantly different (LSD, $P < 0.05$).

Table 4
Regression equation to determine the digestible nutrient content of fodder beet (intercept) on a as fed basis (90 % DM).

	Intercept	*P* value	slope	*P* value	R2
Total Tract (MJ /kg)					
AMEtot	9.63	< 0.001	4.22	< .001	0.92
AMETio2	7.97	< 0.001	4.92	< .001	0.74
AMEntot	9.36	< 0.001	3.42	< .001	0.90
AMEnTio2	7.79	< 0.001	4.10	< .001	0.68
Ileal digestible content (g / kg)					
Apparent crude protein	56.4	0.004	93.6	< .001	0.73
Apparent energy (MJ/kg)	11.2	< 0.001	1.7	0.063	0.20
Standardised Amino acid (g/kg)					
Aspartic	9.1	< 0.001	8.4	< .001	0.86
Threonine	5.2	< 0.001	2.8	0.020	0.56
Serine	7.3	< 0.001	0.6	0.579	0.05
Glutamic	21.1	< 0.001	13.9	< .001	0.86
Proline	7.9	< 0.001	2.1	0.023	0.55
Glycine	6.2	< 0.001	0.1	0.931	0.01
Alanine	6.3	< 0.001	2.2	0.003	0.74
Valine	6.9	< 0.001	2.0	0.022	0.55
Isoleucine	5.4	< 0.001	1.6	0.010	0.63
Leucine	9.8	< 0.001	4.7	< .001	0.82
Tyrosine	5.4	< 0.001	1.3	0.096	0.35
Phenylalanine	7.8	< 0.001	1.5	0.081	0.37
Histidine	3.0	0.005	0.8	0.383	0.11
Lysine	6.0	< 0.001	6.4	< .001	0.95
Arginine	6.4	< 0.001	5.3	0.002	0.76
Cysteine	-0.4	0.395	3.2	< 0.001	0.87
Methionine	-0.1	0.734	6.8	< 0.001	0.99

The standardised ileal digestible amino acids content ranged from −0.3–21.9 g/kg with the lowest and highest values being for cysteine and glutamic acid, respectively.

4. Discussion

The nutritive value of FB has been widely studied for different type of livestock (Ferris et al., 2003; Wang et al., 2016; Waghorn et al., 2018). However, there is limited information on the suitability of FB in poultry production. According to INRA table (2024), the average concentration of DM, CP, crude fibre, neutral detergent fibre, acid detergent fibre and total sugars of FB was 161, 79, 60, 160, 95 and 658 g/kg DM basis, respectively. However, the FB used in the current study was relatively higher in protein (93 g/kg DM), NDF

(183 g/kg DM) and ADF (107 g/kg DM). Also, the current FB was a good source of energy, as indicated by its high analysed GE (16 MJ/kg DM) and sugar (424 g/kg DM) content. The FB samples used in the current study were harvested in October and processed later before being used in the trial. The results of the trial could have been different if another sample of FB was used, as there are several factors such as climate, harvesting, storage and feeding practices, diseases and others could affect the chemical composition of FB.

In the current study, AME and AMEn of experimental diets were measured by both total collection and marker methods, where the values obtained by the total collection method were relatively higher. This can be expected as the TiO_2 recoveries were only around 85 %. Scott et al. (1998) and Smeets et al. (2015) and Masood et al. (2011) also observed higher values for total collection method than the marker method. However, Khalil et al. (2020) reported similar values between the total collection and marker methods for energy digestibility of sorghum, with numerically higher values for the total collection method, but the opposite was observed for other ingredients, namely, maize, wheat and barley. Similarly, Cheng and Coon (1990) reported higher digestibility values for calcium using the total collection method than the marker method in laying hens. However, Bertechini et al. (2020) reported 3.7 % lower values for amino acid digestibility using total collection method than marker method. Moreover, the values of AME and AMEn of the FB as determined by regression method in the current study were 9.63 and 9.36 MJ/kg for total collect method and 7.97 and 7.79 MJ/kg for marker method, respectively. According to Heuzé et al. (2013), the AMEn of FB is 10.1 MJ/kg for broilers and cockerels, which is close to the values obtained with the total collection method in the current study. Hence, the total collection method is recommended over the marker method for determining AME in diets containing FB.

The AME and AMEn of the diets decreased as the concentration of FB in the diet increased. This finding may be explained by the observed decrease in analysed starch content and the corresponding increase in sugar content with increasing FB inclusion (Table 1). A strong positive correlation between AME and starch content was reported by Stefanello et al. (2015). In pigs, the total tract digestibility coefficient for energy was reduced by 4 %age points, when 25 % FB were added to a basal wheat and soybean diet (Tsikira et al., 2021). Similarly, in our study, the metabolisable coefficient for energy was reduced by 5 %age points when 25 % FB were added to the basal diet.

Increasing the FB in the diet decreased their ATTDC for both energy and protein, this could be due to the reduced analysed-CP in the diets containing FB. Therefore, further studies may be warranted with a balanced dietary CP across the dietary treatments to study the effect of different FB inclusions. However, the apparent ileal digestibility coefficient of GE and CP were not affected by the level of FB in the diet. Similarly, there was no difference in the standardised ileal digestibility coefficients for most of the amino acids, demonstrating the potential of using FB in poultry nutrition. Hence, further research is warranted regarding long-term feeding with isocaloric and isonitrogenous diets to determine the optimal inclusion level. Another point to consider, is that the high sugar content of FB will limit its inclusion level when the diets are pelleted. The combination of sugar, steam and temperature will result in a sticky mixture difficult to pellet when the inclusion level is too high.

In our study we have used a regression method to estimate the nutritive value of the Fodder Beet. This approach allows us to use the digestible content values of all replicates, across all three diets ($n = 18$), thus taking into account the variation between and within diets.

5. Conclusion

The AME and AME_n of FB was determined using both the total collection and the marker methods. The values obtained using the total collection method (9.63 and 9.36, respectively) were higher than those obtained using the marker method (7.97 and 7.79, respectively). Furthermore, there were no differences in the apparent ileal digestibility coefficient of CP (0.71 vs 0.72) and SID amino acids coefficient between the basal diet and the diet with 12.5 % FB. Given these findings and the year-round availability of FB in New Zealand and many other parts of the world, there is a potential for using FB as an alternative feed ingredient in poultry diets. Further research is warranted to evaluate the potential of FB as a component in poultry feed formulations.

CRediT authorship contribution statement

K.Ganraj: Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **L. David:** Methodology, Formal analysis, Writing – review & editing. **P. C. H. Morel:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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