Refining the metabolisable energy value of field beans for turkeys

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Abstract

1. The study examined the feeding value of ten UK grown field bean (Vicia faba L. var. minor) cultivar samples from the same harvest year on nitrogen corrected apparent metabolisable energy (AMEn) and nutrient retention coefficients when fed to young female turkeys.
2. A balancer feed (BF) was formulated to contain 12.39 MJ/kg ME and 269 g/kg crude protein. Ten nutritionally complete, mash diets were then prepared by mixing 200 g/kg of each ground field bean cultivar with 800 g/kg of the BF, totalling eleven diets. Diets were fed to female BUT Premium turkeys from 40 to 50 days of age. Each diet was fed to eight raised floor pens, housing two birds, following randomisation. The AMEn was determined by the total collection technique over the last four days of the study. Relationships were

examined between AMEn, chemical composition and quality variables of the field bean samples.

3. The overall determined AMEn value of the beans ranged from 7.72 MJ/kg DM to 9.87 MJ/kg DM, giving an average AMEn of 8.80 MJ/kg DM ($P < 0.05$). The soluble non-starch polysaccharide (NSP) content of the beans negatively correlated with their determined AMEn ($r = -0.730$; $P < 0.05$). Bean flour lightness-darkness degree (L*) correlated positively with the AMEn ($r = -0.643$; $P < 0.05$). A positive correlation was observed between the degree of yellowness-blueness of bean flour and the condensed tannins content of the beans ($r = 0.696$; $P < 0.05$). Step-wise regression indicated that soluble NSP + L* of field beans are explanatory variables suitable for estimating the AMEn value for turkeys ($r^2 = 0.737$; $P < 0.05$).
4. This information may be used by nutritionists to refine dietary formulations and plant breeders who may be able to incorporate it in the development of new field bean cultivars.

Keywords: field beans; alternative protein source; turkeys; metabolisable energy; nutrient digestibility

Introduction

Imported soya bean meal (SBM) is the main protein source used in turkey feeding in Europe (Palander et al. 2006). In 2019, the European Union (EU) imported 12.1 million tonnes of soybeans and 18.8 million tonnes of SBM (IDH, 2021). However, due to the growing global demand for SBM, the price is continuously increasing, particularly after the EU prohibited the use of animal protein in poultry diets (O'Neill et al. 2012). In addition, the world's soybean production declined to 334 million tonnes in 2019 compared to the 359 million tonnes in 2018 (IDH, 2021). This emphasises the requirement for more sustainable feed ingredients, thus strengthening the need to develop alternative protein sources for modern turkey production (Whiting et al. 2019; Karkelanov et al. 2020; Watts et al. 2021). Studying the feeding value of locally grown protein sources, such as field beans (Vicia faba L. var. minor), is essential and may decrease the dependency of the European poultry industry on imported SBM (Abdulla et al. 2017).

Investigations with broiler chickens revealed that concentrations of nitrogen corrected apparent metabolisable energy (AMEn) within cultivars of field beans are variable. For example, AMEn concentrations ranged from 10.17 to 11.72 MJ/kg DM in six field bean samples (Carpenter and Johnson, 1968; Lacassagne et al. 1988), from 11.94 to 12.74 MJ/kg DM in seven field bean samples (Metayer et al. 2003; Vilariño et al. 2009), from 7.78 to 9.96 MJ/kg DM in ten field bean samples (Abdulla et al. 2020). For laying hens, a range of from 9.31 MJ/kg DM to 12.26 MJ/kg DM of nine field bean cultivar samples was recently reported (Pirgozliev et al. 2023). Comprehensive information on variations in ME concentrations in field beans in turkeys is lacking. In addition, studies describing ME concentrations compared birds taking into consideration other factors such as, different age, hybridity and rearing conditions. Metabolisable energy may vary due to age (Yang et al., 2020), dietary form and processing (Pirgozliev et al. 2016; Karkelanov et al. 2021), dietary ingredient composition (Lim et al., 2021), rearing conditions (Pirgozliev et al. 2014) as well as other factors.

The objective of this experiment was to study the variation in AMEn concentrations of field beans in turkeys. It has been hypothesised that AMEn concentrations between field bean cultivars differ to an extent of relevance for practical feed formulation. We further hypothesised that the AMEn concentrations of beans could be predicted from their chemical and physical characteristics.

Material and methods

This manuscript complies with the ARRIVE 2.0 guidelines (Percie du Sert et al., 2020).

Field bean cultivar samples

Ten different flower colour, UK-grown field beans, including three spring (Fury, Fuego and Maris Beads) and seven winter grown cultivars (Arthur, Buzz, Clipper, Divine, Honey, Sultan and Wizard) from the same harvest year were obtained from Askew & Barrett (Pulses) Ltd, Wisbech, UK. Proximate analysis, gross energy, carbohydrates, amino acid and mineral contents, phenolic compounds and bean quality (including L*, a*, b*) of the freshly milled bean samples are presented in previous reports (Abdulla et al. 2020; 2021).

Diet formulation

A wheat-soybean meal balancer diet (BD) was prepared, containing wheat (443 g/kg), soya bean meal (360 g/kg) and prairie meal (50 g/kg) as main ingredients (Table 1).

Ten additional diets were then produced including 200 g/kg of one of the ten different field bean cultivars and 800 g/kg of the BD. A total of eleven experimental diets were compared including the basal diet and the diets containing the field beans. Freshly milled field beans were used in the formulation of the diets and were fed as mash. All diets approximately met or exceeded the dietary specifications for BUT Premium turkeys (Aviagen, Turkeys Ltd, UK). Diets did not contain any coccidiostat, antimicrobial growth promoters, prophylactic or other similar additives.

Husbandry and sample collection

The study was approved by the Research Ethics Committee of Harper Adams University and birds cared for in compliance with the UK Code of Practice for the welfare of meat chickens and meat breeding chickens (DEFRA, 2018). Approximately 200 one-day old, female BUT Premium turkeys were obtained from a commercial supplier (Faccenda Turkeys, Dalton, Thirsk YO7 3JD, UK). On arrival, the birds were fed in a communal floor pen bedded with wooden shavings and received wheat soya bean based proprietary crumbed turkey feed containing 285 g/kg crude protein and 12.21 MJ/kg metabolisable energy. Standard temperature and lighting programmes for turkeys were used (Aviagen, Turkeys ltd, UK). At 40 d age, 176 birds, excluding small and malformed, were randomly allocated to 88 metal cages, two bird in a cage, with eight replications per treatment. Bird housing was equipped with nipple drinkers inside and a separate feeder at the front. Housing dimensions were 0.61 m x 0.61 m x 0.95 m and consisted of a wire mesh flooring (area of 0.372 m^2) which contained no bedding material.

To ensure all birds were healthy and environmental conditions were adequate, birds were observed at least twice a day. The birds received the experimental diets for 10 days, from 40 to 50 d age. During the final 4 days of the experiment, excreta were quantitatively collected daily and dried immediately at 60 °C, until a constant weight. Feed intake was also determined for the same period. The dried excreta, as well as representative balancer diet sample were ground to pass through 0.8 mm screen. The nutrient composition and gross energy of the dried excreta, beans and balancer diet samples were determined in duplicate as previously described (Abdulla et al. 2016b). The AMEn of diets and beans and nutrient retention coefficients of dietary dry matter (DMR), nitrogen (NR) and fat (FR) were determined using total collection technique, although the AMEn in beans was determined via recalculation techniques (Pirgozliev et al. 2022). The following equations were employed:

$$\text{AMEn}_{\text{whole diet}}\ (\text{MJ/kg DM}) = \frac{\left(\text{GE}_{\text{intake}}(\text{MJ}) - \text{GE}_{\text{output}}\ (\text{MJ}) - \text{N}_{\text{retained}} * 34.39\right)}{\text{Feed intake (kg DM)}}$$

$$\text{AMEn}_{\text{field bean}}\ (\text{MJ/kg DM}) = \frac{\text{AMEn}_{\text{whole field bean diet}} - (\text{AMEn}_{\text{balancer diet}} \times 0.8)}{0.2}$$

$$\text{Nutrient Retention}_{\text{whole diet}} = \frac{\text{Nutrient}_{\text{intake}} - \text{Nutrient}_{\text{output}}}{\text{Nutrient}_{\text{intake}}}$$

where *GE intake* was the dietary intake for the collecting period multiplied by the gross energy of the diet, *GE output* was the dry excreta collected multiplied b the gross energy of the excreta, *N retained* was the nitrogen retained by the birds during the collection period, 34.39 was MJ/kg DM of uric acid,

Nutrient intake was the respective dietary nutrient intake, i.e. dry matter, nitrogen or fat, for the collecting period and *Nutrient output* was the respective nutrient of the excreta collected.

Statistical procedure

The observational unit was the cage with two turkeys. Statistical analyses were performed using Genstat 21st edition statistical software package (Genstat for Windows; IACR, Rothamstead, Hertfordshire, UK). The AMEn and the retention coefficient of the experimental diets and field bean samples were statistically compared using a randomised block one-way analysis of variance. The position of pens within the room was used as the blocking factor. Duncan's multiple range test was used to determine significant differences between field bean treatment groups. Additionally, multiple step-wise linear regression was used to assess the relationship between the determined AMEn (dependent variable) and independent terms relating to the chemical composition and quality characteristics of the field bean samples. The coefficients of Pearson's correlation between all studied variables were also obtained. In all instances, differences were reported significant at $P < 0.05$.

Results

The determined dietary chemical composition is presented in Table 1 and was within the expected range for turkeys. However, there was some difference between the calculated and determined CP and fat values. Data on chemical composition and physical characteristics of the experimental field bean cultivar samples were previously published (Abdulla et al. 2020; 2021). Table 2 contains some selected laboratory analyses of the experimental field bean cultivars. In brief, the average lightness score was 93, with lowest being 88 (cv. Sultan) and highest being 95 (cultivars Divine, Fury, Honey) (CV = 2.4 %). The mean starch content was 456 g/kg (CV = 7.5 %), as cv. Clipper had the lowest (397 g/kg) and cv. Honey had the highest (517 g/kg) starch content. There was a range of crude protein contents. The lowest being 245 g/kg (cv. Sultan) and the highest being 305 g/kg (cv. Maris Bead) (CV = 6.5 %). The soluble non-starch polysaccharides (NSP s) contents varied from 30 g/kg (cv. Maris Beads) to 72.8 g/kg (cv. Clipper) (CV = 22.9 %). There was a range of condensed tannin (CT) concentration with 2.8 g/kg the lowest (cv. Arthur) and 7.3 g/kg the highest (cv. Sultan) (CV = 30.9 %).

The results on feed intake, AMEn of field beans and diets and dietary nutrient retention coefficients are shown in Table 3. There were no differences ($P > 0.05$) in FI and BW of the turkeys fed different diets. The AMEn of the balancer diet was 13.08 MJ/kg DM (Table 3) and was later used to determine the AMEn in the studied field bean cultivar samples. The AMEn value of the bean containing diets varied from 11.99 MJ/kg DM (cv. Sultan) to 12.44 MJ/kg DM (cv. Fury) ($P < 0.001$). The overall dietary DMR, including basal feed, was 0.649, as DMR of basal feed was higher ($P < 0.05$) compared to diets based on cultivars Buzz, Clipper, Divine, Fuego, Honey and Sultan, and did not differ from the rest ($P > 0.05$). There were no differences in NR between the diets ($P > 0.05$). Dietary FR coefficient was lower in Fury and higher in Buzz containing diets ($P < 0.05$), although the FR coefficient of basal diet did not differ from any of the diets used ($P > 0.05$). The overall determined AMEn value of the beans was 8.80 MJ/kg DM and varied between 7.72 (cv. Sultan) and 9.87 (cv. Fury) MJ/kg DM ($P < 0.05$).

Table 4 shows selected correlation coefficients between determined AMEn and compositional profile of the experimental field bean cultivar samples when fed to turkeys. There was a negative correlation ($r = -0.730$; $P < 0.05$) between AME and soluble NSP content of the beans. There was also a positive correlation between AMEn and L* score of the beans ($r = 0.643$; $P < 0.05$). There was a positive correlation ($r = 0.672$; $P < 0.05$) between CP and bean lightness (L*), although there was a negative correlation ($r = -0.775$; $P < 0.01$) between CP and redness-greenness degree of bean (a*). A positive correlation ($r = 0.696$; $P < 0.05$) was observed between b* (yellowness index) score and CT content of the beans.

The step-wise regression technique identified the chemical components of the field bean samples, and the laboratory measures of quality, that minimised the residual mean squares for AMEn (Table 5). The statistically significant explanatory variables were bean lightness (L*) and soluble NSP content ($P < 0.05$). The addition of other explanatory variables did not significantly ($P > 0.05$) reduce the residual mean squares in the AMEn of the studied bean samples.

Discussion

The overall daily FI and bird weights were within the expected range for female turkeys over this age range (Aviagen Turkeys, 2021), indicating results are commercially valid. The observed differences between the calculated and determined values of CP and fat in the basal diet are likely due to differences in laboratory analysis technique and values used in software for dietary formulation, versus the actual chemical composition of dietary feed ingredients. Classen (2017) studied extensively the relationship between FI and dietary AMEn, finding that dietary energy does not accurately correlate with FI. This may explain why there was no correlation between FI and dietary AMEn observed.

The overall determined AMEn value of all cultivars was 8.80 MJ/kg DM, which is within the reported range for laying hens (Perez-Maldonado et al. 1999) and broilers (Abdulla et al., 2020). The AMEn for cv. Sultan was numerically the lowest, and was significantly lower compared to cv. Arthur, Maris Bead and Wizard.

Turkeys do not directly produce NSP degrading enzymes (although gut microflora do), thus the observed reduction in AMEn when feeding beans high in soluble NSP is expected. Research suggests that the mode of action of dietary NSP combines encapsulation of dietary nutrients and/or increases the viscosity of the intestinal digesta (Bedford, 2000; Pirgozliev et al. 2019), which can reduce dietary AMEn. The negative correlation and high variance accounted for ($r^2 = 0.74$) in the regression model between AMEn and soluble NSP + L* supports the observed range of AMEn in diets, requiring refinements when formulating diets. These wide variances of AMEn content in field beans are of commercial importance, potentially necessitating reformulation with cultivar specific information (soluble NSP + L*).

The higher lightness degree of beans (L*) is associated with less condensed tannins (Oomah et al. 2011), thus suggesting an explanation of the observed tendency of positive correlation between AMEn and increased L* values, although there was no correlation with the condensed tannins themselves. Igbasan et al. (1997) also found higher ME for light coloured pea cultivars than in dark types, when fed to mature cockerels. It has been reported that pale legume seeds have higher nutritive value than dark seeds, as seed-coat colour has some connection with the levels of one or more anti-nutrients in field beans including tannins (Helsper et al. 1993; Oomah et al. 2011), phytate (Rubio et al. 1992) and fibre (Abdulla et al. 2021). The AMEn of cv. Sultan was 1.2 MJ/kg DM lower than the mean of the other nine samples and may be connected to the highest tannin content, based on other reports (Brufau et al. 1998; Vilariño et al. 2009). The existence of tannins affects coloration of the beans (Oomah et al. 2011), thus explaining the observed positive correlation between yellowness-blueness degree (b*) and condensed tannins content. Due to the variability of tannin content measured across bean cultivars in the present study (CV = 30.9%), the use of tannase enzymes (Abdulla et al. 2016a; 2016b) may be a useful strategy to improve the feeding value of field beans for poultry.

In conclusion, the range of AMEn values of ten different field bean cultivar samples, determined using female turkeys, was high (> 2 MJ/kg DM) and should therefore be considered when formulating practical diets for turkeys. Modern hybrid turkeys require diets to have high energy densities. Nutritionists will only be able to incorporate significant amounts of field beans in turkey diets if the beans have a high AMEn value. It is thus crucial that nutritionists are able to identify and only use samples with high AMEn. Data from the present study confirms that the AMEn of field beans can be predicted by their soluble NSP content and lightness. These characteristics could be estimated by near infra-red techniques and so they could be used as a rapid test of the nutritive quality. This information may further be used by plant breeders who may be able to incorporate it in the development of new field bean cultivars.

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Disclosure statement

The authors declare no conflict of interests.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request, subject to restrictions and conditions.

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Table 1. Ingredient composition (g/kg, as-fed) of the experimental turkey balancer formulation

Dietary ingredients	g/kg
Wheat	443.0
Soybean meal (48)	360.0
Prairie meal	50.0
Wheat feed	50.0
Soya oil	40.0
Dicalcium phosphate	30.0
Limestone	10.0
NaCl	3.0
L Lysine	5.0
DL Methionine	3.5
L Threonine	1.5
Vitamin mineral premix[1]	4.0
Calculated analysis (% as fed)	
Crude Protein	269
ME MJ/kg	12.39
Crude fat	56
Ca	13.5
Total P	9.7
Available P	7.0
Available Lysine	16.3
Methionine + Cysteine	11.7
Determined composition	
Dry matter (g/kg)	876
Crude protein (g/kg)	247
Crude fat (g/kg)	47

This balancer was fed as a part of complete diet comprised 200 g/kg of each experimental field bean sample and 800 g/kg of the balancer. Each experimental diet met the diet specification for this strain of turkeys (BUT Premium, Aviagen, UK).

*Vitamin and mineral premix provided (units per kg/feed): retinol,2160µg; cholecalciferol, 75µg;α-tocopherol, 25 mg; menadione, 1.5 mg; riboflavin, 5 mg; pantothenic acid, 8 mg; cyanocobalamin, 0.01 mg; pyridoxine, 1.5 mg; thiamine, 1.5 mg; folic acid, 0.5 mg; niacin, 30 mg; biotin,0.06 mg; iodine, 0.8 mg; copper, 10 mg; iron, 80 mg; selenium, 0.3 mg; manganese, 80 mg; and zinc, 80 mg.

Table 2. Selected chemical and quality characteristics of field bean cultivars used in this study[1]

Diet	L*	a*	b*	Starch	CP	NSP tot	NSP ins	NSP sol	CT
Arthur	94	1.07	17.72	488	271	148.6	98.3	50.3	2.8
Buzz	91	1.27	14.69	452	276	189.7	139.2	50.6	2.9
Clipper	92	1.17	18.94	397	285	250.4	177.6	72.8	5.3
Divine	95	0.99	17.59	434	300	180.4	134.0	46.4	6.2
Fuego	94	1.14	17.96	473	270	171.0	116.9	54.1	6.8
Fury	95	1.21	18.22	464	281	180.5	136.4	44.1	4.7
Honey	95	1.06	17.04	517	294	158.8	95.9	62.9	3.9
Maris Bead	93	1.01	19.05	443	305	155.5	125.5	30.0	4.5
Sultan	88	1.44	22.29	467	245	190.2	135.4	54.8	7.3
Wizard	94	1.18	19.34	424	300	193.2	150.4	42.8	6.0
Mean	93	1.15	18.28	456	283	181.8	131.0	50.9	5.04
CV%	2.4	11.7	10.6	7.5	6.5	15.8	18.4	22.9	30.9

L*, lightness-darkness degree of bean flour 0–100 representing dark to light; a*, redness-greenness degree of bean flour with a higher positive a* value indicating more red; b*, yellowness-blueness degree of bean flour with a higher positive b* value indicating more yellow; Starch, (g/kg DM); CP, crude protein in beans (g/kg DM); NSP tot, NSP ins and NSP sol, is respectively total, non-soluble and soluble non-starch polysaccharide contents in beans (g/kg DM); CT, condensed tannins, as tannic acid equivalents, content in beans (mg/g DM); CV%, coefficient of variation.

[1]Data adapted from Abdulla et al. (2021a).

Table 3. Feed intake (FI) of turkeys fed on basal diet and diets containing 200 g/kg of one of the nine different UK grown field bean cultivar samples. Nitrogen corrected apparent metabolisable energy (AMEn) (obtained with substitution method) of nine UK grown field bean cultivar samples and AMEn and total tract dry matter (DMR), nitrogen (NR) and fat (FR) retention coefficients of the whole diets fed to turkeys.

Diet	FI (kg DM/d/b)	BW (kg)	AMEn diet (MJ/kg DM)	DMR diet	NR diet	FR diet	AMEn beans (MJ/kg DM)
Control	0.181	2.436	13.08^{d}	0.677^{c}	0.593	0.915^{abc}	*
Arthur	0.184	2.387	12.35^{bc}	0.657^{bc}	0.574	0.923^{bc}	9.41^{bc}
Buzz	0.188	2.403	12.12^{abc}	0.648^{ab}	0.572	0.936^{c}	8.28^{ab}
Clipper	0.180	2.225	12.02^{ab}	0.639^{ab}	0.582	0.916^{abc}	7.74^{a}
Divine	0.190	2.387	12.22^{abc}	0.629^{a}	0.564	0.909^{ab}	8.76^{abc}
Fuego	0.190	2.415	12.16^{abc}	0.641^{ab}	0.576	0.915^{abc}	8.47^{abc}
Fury	0.191	2.302	12.44^{c}	0.658^{bc}	0.577	0.899^{a}	9.87^{c}
Honey	0.173	2.265	12.17^{abc}	0.645^{ab}	0.560	0.914^{abc}	8.52^{abc}
Maris Bead	0.180	2.315	12.35^{bc}	0.655^{bc}	0.564	0.928^{bc}	9.45^{bc}
Sultan	0.194	2.377	11.99^{a}	0.635^{ab}	0.555	0.931^{bc}	7.72^{a}
Wizard	0.179	2.252	12.43^{c}	0.656^{bc}	0.575	0.929^{bc}	9.81^{bc}
Mean	0.185	2.343	12.30	0.649	0.572	0.920	8.80
CV%	10.5	7.9	2.5	3.5	7.7	2.1	15.5
SEM	0.0068	0.0658	0.108	0.0080	0.0156	0.0067	0.483
P value	0.517	0.304	<0.001	0.005	0.894	0.008	0.010

Each value represents mean of eight replicate pens of two laying hen pullets each; FI, AMEn and DMR coefficients were determined during the 4 last days of the study; ^{a,b,c} Values within a column with different superscripts differ significantly at $P \leq 0.05$.

Table 4. Selected correlation coefficients between determined AMEn and compositional profile of field bean cultivars when fed to laying hen pullets

	AMEn	L*	a*	b*	Starch	CP	NSP tot	NSP ins	NSP sol
L	0.643								
a	-0.403	-0.796							
b	-0.115	-0.447	0.400						
Starch	0.135	0.180	-0.044	-0.184					
CP	0.467	0.672	-0.775	-0.332	-0.298				
NSP tot	-0.561	-0.365	0.396	0.189	-0.756	-0.076			
NSP in	-0.302	-0.343	0.354	0.238	-0.916	0.078	0.918		
NSP s	-0.730	-0.192	0.246	-0.028	0.027	-0.348	0.571	0.197	
CT	-0.262	-0.238	0.300	0.696	-0.305	-0.211	0.312	0.345	0.055

P<0.1 (r ≥ 0.542; 0.631 ≤ r); P<0.05 (r ≥ 0.632; 0.764 ≤ r); P<0.01 (r ≥ 0.765)

AMEn, nitrogen corrected apparent metabolisable energy (MJ/kg DM); L*, lightness-darkness degree of bean flour; a*, redness-greenness degree of bean flour; b*, yellowness-blueness degree of bean flour; Starch, (g/kg DM); CP, crude protein in beans (g/kg DM); NSP tot, NSP ins and NSP sol, is respectively total, non-soluble and soluble non-starch polysaccharide contents in beans (g/kg DM); CT, condensed tannins, as tannic acid equivalents, content in beans (mg/g DM)

Table 5. The relationship between the AME of different field bean samples and their determined chemical composition and quality characteristics.

Dependent variate	Explanatory variates Constant	Sol NSP	L*	r^2	Residual standard deviation
AMEn	11.35 (± 0.861)	-0.05 (± 0.050)		0.48	0.577*
AMEn	-12.53 (± 9.000)		0.23 (±0.097)	0.34	0.647*
AMEn	-6.32 (± 5.930)	-0.04 (± 0.012)	0.19 (± 0.062)	0.74	0.408*

Values in brackets are standard errors
Statistical significance of regression equation: * $P < 0.05$