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Faba beans (*Vicia faba* var. minor) in broiler chickens feeding

Bobik (*Vicia faba* var. minor) w żywieniu kurcząt rzeźnych

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ABSTRACT

The underlying components of broiler chicken diets are cereal grain, mainly maize and wheat, supplemented with protein feed, predominantly soybean meal (SBM). In the European Union, SBM is an imported raw material, nearly all of which is derived from genetically modified (GMO) soybeans. This situation has prompted attempts to eliminate or at least reduce SBM in bird diets by replacing it with other protein feeds, including legume seeds, such as peas, faba beans, and lupine. Raw faba beans or other legume seeds cannot entirely replace SBM in broiler chicken diets. Nevertheless, producers continually explore opportunities to develop new cultivars with lower levels of antinutrients, mainly tannins, and refine their seeds to increase their nutritional value. Given that a change in the feed ration may affect growth performance and modify the bird carcass composition, including meat quality, this study examined the nutritional value of faba beans and their effect on growth performance and carcass composition, as well as the physicochemical and sensory traits of muscles in broiler chickens fed diets containing various percentages of faba beans in different forms.

Keywords: nutrition, faba beans, broiler chickens, rearing results, carcass yield, meat quality

STRESZCZENIE

Podstawowymi surowcami paszowymi wchodzącymi w skład diety kurcząt brojlerów są zboża (głównie kukurydza i pszenica) uzupełnione paszami białkowymi, wśród których dominującą jest śruta poekstrakcyjna sojowa (SBM). W Unii Europejskiej należy ona do surowców importowanych i niemal w całości pochodzi z nasion soi GMO. Z wyżej wymienionych powodów próbuje się wyeliminować lub przynajmniej ograniczyć SBM w dietach ptaków poprzez zastosowanie innych pasz białkowych, m.in.: nasion bobowatych (grochu, bobiku, łubinów). Surowymi nasionami bobiku, czy innych bobowatych nie można całkowicie zastąpić SBM w żywieniu kurcząt brojlerów, ale nieustannie poszukuje się możliwości substytucji poprzez tworzenie nowych odmian o obniżonej zawartości substancji antyżywieniowych (głównie tanin) i/lub poddawanie nasion zabiegom uszlachetniającym (zwiększającym wartość pokarmową). Z uwagi na fakt, że zmiana składu dawki pokarmowej może wpływać na wyniki odchowu, a także modyfikować wartość rzeźną ptaków, w tym jakość mięsa w niniejszej pracy przedstawiono wartość pokarmową bobiku oraz jego oddziaływanie na parametry odchowu i wartości rzeźnej, jak również cechy fizyko-chemiczne i organoleptyczne mięśni kurcząt brojlerów otrzymujących w dietach bobik w różnym udziale i formie.

Słowa kluczowe: żywienie, bobik, kurczęta brojlery, wyniki odchowu, wartość rzeźna, jakość mięsa

INTRODUCTION

The underlying components of the broiler chicken diet are cereal grains, mainly maize and wheat, supplemented with high-protein feed (Dal Bosco et al., 2013; Usayran et al., 2014; Escobedo del Bosque et al., 2020; Proskina et al., 2021). The most popular protein feed is genetically modified soybean meal (SBM) imported from South America and the USA, which accounts for approximately 70% of the broiler chicken dietary protein requirement. Numerous researchers (Nalle et al., 2010, Laudadio et al., 2011; Osek et al., 2013; Koivunen et al. 2016, Milczarek and Osek, 2019; Konieczka et al., 2020; Biesek et al., 2020) have explored the possibility of replacing SBM with protein-rich feeds, including dried cereal extract, rapeseed products, and legume seeds (*Fabaceae*). According to FAO (2021), *Vicia faba* L. (faba beans) is the fourth most widely grown cool season legume after pea (*Pisum sativum*), chickpea (*Cicer arietinum*) and lentil (*Lens culinaris*). The largest producers of faba beans are China, Ethiopia, the United Kingdom, Australia, and France. In 2020, China and the world produced 1.69×10^6 and 5.68×10^7 metric tons of faba beans, respectively, with total harvested areas of 8.11×10^5 and 2.66×10^6 ha, respectively (dry beans), followed by Ethiopia, Australia, and the UK (FAOSTAT, 2022). The data resulting from applications for direct payments submitted to the Agency for Restructuring and Modernization of Agriculture show that last year in Poland, field beans were cultivated in an area of nearly 38,000 ha. The average yield of faba beans per 1 ha is nearly 2.5 tons (Księżak et al., 2020). The area of production of faba beans is not increasing relative to other crops, mainly because of high yield instability. Faba bean is an important legume crop because of its high-yield potential and nutrition-dense grains. There have been significant achievements in faba beans improvement in the last four decades, which led to the doubling of the global yield average (Bangar and Kajla, 2022). Its protein content is higher than other common food legumes (Moschini et al., 2005; Nalle et al., 2010; Osek et al., 2013). However, faba beans (*Vicia faba*), peas (*Pisum sativum*), and lupin (*Lupinus*) exhibit variations in protein and crude fibre content as well as in the levels of antinutrients (Osek et al., 2003; Moschini et al., 2005; Vilariño et al., 2009; Laudadio et al., 2011; Hejdysz et al., 2020). Factors such as phytates, tannins, proteolytic enzyme inhibitors, and alkaloids in lupin (Diaz et al., 2006; Crépon 2010; Osek et al., 2013; Zduńczyk et al., 2018) contribute to the diverse dietary suitability of legume seeds. Several studies (Milczarek and Osek 2017, 2017a; Zduńczyk et al. 2018; Cho et al., 2019; Konieczka et al., 2020) have sought to enhance the nutritional value of legumes, including faba beans, by refining treatments and cultivating cultivars with reduced tannin levels. This approach aims to expand the potential applications of faba beans in broiler chicken feed rations (Jamroz and Kubizna, 2008; Jezierny et al., 2010; Hanczakowska and Księżak, 2012; Kopmels et al., 2020). Nevertheless, Kasprowicz et al. (2022) emphasised that leguminous plant seeds included in the diet should originate from the most efficient cultivars.

The purpose of this article was to present current knowledge about the nutritional value of faba beans and its effects on the growth performance, carcass yield, and meat quality of broiler chickens.

THE NUTRITIONAL VALUE OF FABA BEANS

Many researchers (Moschini et al., 2005; Osek et al., 2013; Milczarek and Osek 2017; Konieczka et al., 2019; Komples et al., 2020; Biesek et al., 2020; Smit et al., 2021) have evaluated the nutritional value of faba beans (Table 1, Table 2).

The above mentioned researchers observed high variability in the content of essential nutrients, including crude protein (22.9–32.6%), crude fat (0.89-2.37%), and crude fibre (2.64-9.16%). The results exhibited such significant variation that it becomes challenging to pinpoint the factors (such as cultivar or refining treatment) that contribute to the variability in the content of these nutrients. Diaz et al. (2006) and Hejdysz et al. (2020) found a similar protein content in raw faba beans compared to extruded seeds, while Konieczka et al. (2020) observed a higher amount (by 3%) protein in extruded seeds.

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Table 1. Chemical composition of faba bean seeds

Item	Crude protein (%)	Crude fat (%)	Crude fibre (%)	Tannins (g/kg)	Phytates (g/kg)	References*
Faba beans cv. Akord	27.62	1.50	6.01	10.20	9.20	Osek et al. (2003)
Faba beans	25.90	1.61	7.77	0.47	nd	Moschini et al. (2005)
Raw faba beans	25.90	1.61	7.77	0.47	nd	Diaz et al. (2006)
Extruded faba beans	25.46	1.75	8.28	0.42		
Low tannin faba beans cv.: PGGTic, Spec Tic, South Tic, Board	22.9-30.6	1.95-2.37	nd	nd	nd	Nalle et al. (2010)
High-tannin faba beans	24.51	1.11	7.18	10.20	10.83	Osek et al. (2013)
Tannin-free fava beans	26.7-29.2	0.9-2.12	6.62-8.01	traces-0.003	nd	Usayran et al. (2014)
Low-tannin faba beans	25.41	0.93	8.23	3.65	nd	Milczarek and Osek (2017)
High-tannin faba beans	24.71	1.21	6.82	9.01		
Raw and soaked faba beans	27.44-30.68	0.59-1.24	7.59-8.78	10.60-11.47	11.86-12.26	Osek et al. (2017)
Low-tannin faba beans	26.08	1.04	nd	nd	0.68	Zduńczyk et al. (2018)
High-tannin faba beans	25.25	1.26	nd	nd	7.07	
Raw faba beans	32.6	nd	nd	nd	3.52	Hejdysz et al. (2019)
Extruded faba beans	32.1	nd	nd	nd	2.61	
Non-dehulled faba beans	25.85-28.69	1.08-1.32	2.85-5.52	nd	nd	Cho et al. (2019)
Dehulled faba beans	26.27-29.66	1.12-1.43	2.64-4.44	nd	nd	
Faba beans	25.61	0.89	nd	nd	nd	Hejdysz et al. (2020)
Raw faba beans	26.12	nd	nd	0.046	nd	Konieczka et al. (2020)
Extruded faba beans	26.87	nd	nd	0.046	nd	
Faba beans	24.31-27.09	0.96-1.18	5.29-8.70	nd	nd	Kopmels et al. (2020)
Faba beans (Olga)	29.2	nd	nd	0.06	nd	Biesek et al. (2020)
Faba beans	23.71-26.18	1.20-160	7.29-9.16	nd	nd	Smit et al. (2021)

* - from the oldest to the newest, nd – not was given

Moreover, it is not straightforward to definitively state which cultivar, low- or high-tannin, contains more protein. Nalle et al. (2010) reported protein content ranging from 22.9% to 30.6% for low-tannin cultivars, a range that also encompasses values reported for cultivars rich in tannins. The substantial variability in the essential nutrient content of faba beans arises from a combination of cultivar differences, environmental conditions, agrotechnical factors, and the refining treatments of seeds (Osek et al., 2003; Vilariño et al., 2009; Szpunar-Krok et al., 2009; Hanczakowska and Księżak, 2012; Fordoński et al., 2015). It was proved also in amino acid content of faba beans (Table 2). Faba beans seeds contain less essential amino acids in comparison to soybean meal. The crude protein of faba beans is poorer in sulphur amino acids: methionine and cystine (Moschini et al., 2005; Diaz et al., 2006; Usayran et al., 2014; Hejdysz et al., 2020; Biesek et al., 2020; Proskina et al., 2021).

In the analysis of the crude fibre content of faba beans, the relevant fractions included acid detergent fibre (ADF), neutral detergent fibre (NDF), and acid detergent lignin (ADL). Studies conducted by Osek et al. (2003), Osek et al. (2013), Osek et al. (2017), and Milczarek and Osek (2017) demonstrated that tannin-rich faba beans contained ADF ranging from 12.47% to 16.72%, NDF from 11.15% to 36.74%, and ADL from 3.80% to 5.22%. In contrast, the low-tannin cultivars exhibited ADF values between 9.87% and 11.94%, NDF values between 18.80% and 19.80%, and ADL values between 1.56% and 2.43%. Zijlstra et al. (2008) and Woyengo and Nyachoti (2012) reported similar ADF and NDF levels, while Beltranena et al. (2009), Kiarie et al. (2013), and Hanczakowska and Świątkiewicz (2014) observed lower content of these fractions.

The tannin content of faba beans is influenced by the cultivar, with tannin-rich cultivars containing between 9.01 g/kg and 11.47 g/kg of tannin, while low-tannin cultivars have up to 3.65 g/kg. According to Zduńczyk et al. (2018), low-tannin faba beans contain ten times less phytate than tannin-rich cultivars. In contrast, Hejdysz et al. (2020) found that the extrusion process reduces the phytate level by 0.91 g/kg (Table 1).

Numerous researchers (Beltranena et al., 2009; Vilariño et al., 2009; Jezierny et al., 2010; Hanczakowska and Świątkiewicz, 2014) have highlighted that the primary antinutrients in traditional faba beans are tannins, which are classified as polyphenols. Tannins exhibit significant chemical variability and are typically classified as hydrolysable or non-hydrolysable (condensed) and catechin tannins (characteristic of green tea leaves). These substances play a crucial role in protecting plants from pathogens, herbivores, and adverse environmental conditions. Condensed tannins, which are characteristic of legumes, are toxic to many fungi, bacteria, and viruses. They can also directly affect animals, contributing to the characteristic bitter taste of animal feed owing to the formation of tannin-protein conglomerates. The mechanism of toxicity involves astringent properties, effects on microbial cellular membranes, and their ability to bind metal ions. Zawadzki et al. (2010) emphasize that the effects of tannins comprise several varied aspects, mainly of antinutrient and even carcinogenic nature (Serrano et al., 2009). However, information on this matter is equivocal. Research conducted by Aerts et al. (1999) and Serrano et al. (2009) demonstrated that tannins have anticancer, antimicrobial, antifungal, and antiviral properties. Because of their affinity for proteins, they primarily lead to the formation of compounds that are difficult to access in the alimentary tract, reducing feed digestibility and consequently affecting animal productivity (Jansman 1995; Jamroz and Kubizna, 2008; Beltranena et al., 2009; Jezierny et al., 2010; Usayran et al., 2014; Osek et al., 2017; Biesek et al., 2020). Woyengo and Nyachoti (2012) stated that zero-tannin faba beans cultivars showed greater apparent ileal digestibility of amino acid in broilers than color-flowered, tannin-containing cultivars and may be a better source of starch and protein for broiler chickens.

Furthermore, the endogenous glycosides vicin and convicin are considered problematic (anti-nutritive), thereby limiting the use of faba beans in human and animal nutrition (Luzzatto and Arese, 2018; German Federal PlantVariety). Duc et al. (1997) asserted that the vicine and convicine content depends on the

specific cultivar. In contrast, Nolte et al. (2020) found no significant effects on the growth performance and carcass yield of three different breeds fed vicine and convicine-rich (0.14%) and vi-cine and convicine-poor (0.02%) soybean rations. These results agree with those observed by Laudadio et al. (2011), who determined their contents in the faba beans (0.01 and 0.11% convicine and vicine, respectively). Usayran et al. (2014) showed 0.67-0.70% dry matter vicine levels in faba beans. Hejdysz et al. (2016) suggested that the main factors determining the nutritional value of *Vicia faba* include phytic P and raffinose series oligosaccharides, which affect nutrient utilization, apparent metabolisable energy (AME), and endogenous losses. Extrusion cooking can enhance the nutritional value of faba beans by reducing the phytic acid and trypsin inhibitor content. Diaz et al. (2006) reported trypsin-inhibiting activity content in raw and extruded faba beans in the amount of 0.78 and 0.3, respectively.

Table 2. Amino acid content of the faba beans and soybean meal

Amino acid	Moschini et al. (2005) Diaz et al. (2006)		Usayran et al. (2014)	Proskina et al. (2021)	Biesek et al. (2020) Hejdysz et al. (2020)	
	Soybean meal	Faba beans	Faba beans	Faba beans	Faba beans	Soybean meal
	(g/kg dry matter)				(g/16g N)	
Alanine	22.35	12.00	11.7-13.7	11.0	3.89	4.22
Arginine*	39.06	26.16	27.2-33.6	25.4	9.77	7.51
Aspartic acid	55.20	27.97	30.8-34.7	28.2	10.2	11.0
Cystine*	7.56	3.74	1.19-2.2	3.3	0.98	1.42
Glutamic acid	96.62	48.58	44.4-51.6	44.2	14.90	18.00
Glycine*	21.56	12.00	10.8-14.5	11.7	4.00	4.20
Histidine*	13.43	7.13	6.9-8.4	6.9	2.78	2.50
Isoleucine*	25.62	12.57	10.6-14.9	11.4	3.85	4.63
Leucine*	39.73	21.29	18.1-23.1	20.5	7.08	7.18
Lysine*	32.06	18.00	17.3-21.1	17.1	6.67	5.51
Methionine*	7.34	2.38	2.2-2.7	2.1	0.89	1.19
Phenylalanine*	26.53	12.34	10.1-11.7	11.4	4.09	4.89
Proline	27.66	13.36	10.0-14.3	nd	4.01	5.21
Serine	28.67	14.95	11.6-14.7	12.2	4.41	5.13
Threonine*	20.32	10.19	9.3-1.13	9.7	3.46	3.48
Tyrosine	19.53	8.49	6.8-9.9	8.4	2.92	3.48
Valine*	25.74	13.81	12.8-14.9	12.1	4.35	4.17
Tryptophan*	6.89	2.60	nd	nd	nd	nd

* - essential amino acid; nd – not was given.

GROWTH PERFORMANCE OF BROILER CHICKENS

Many researchers took interest in the suitability of raw or refined faba beans for broiler chickens feeding (Osek et al., 2003; Brévault et al., 2003; Arija et al., 2006; Perella et al., 2009; Nalle et al., 2010; Gous 2011; Dal Bosco et al., 2013; Osek et al., 2013; Milczarek i Osek 2017; Cho et al., 2019; Kopmels et al., 2020; Biesek et al., 2020) (Table 3).

After introducing 10% faba beans into maize and soy starter diets and 20% faba beans into grower diets, with or without synthetic methionine, Osek et al. (2003) observed that broiler chickens supplemented with synthetic methionine weighed significantly more (2287 g vs. 2081 g) than control birds. However, they showed similar feed conversion rates (1.77kg vs. 1.80kg). Worse growth performance of chickens fed mixtures without synthetic methionine was consequential less amount (more than twice) methionine and cystine in faba beans in comparison to soybean meal (Moschini et al., 2005; Diaz et al., 2006; Hejdysz et al.,2020; Biesek et al., 2020). Nalle et al. (2010) and Gous (2011) reported positive results with the addition of 200 g or 250 g of faba beans per kg of feed at all growth stages in terms of energy balance and digestible amino acid content. Osek et al. (2013) noted a significant increase in the body weight of chickens at the second growth stage after introducing 13.5% (starter) and 19.5% (grower) tannin-rich faba beans into broiler chicken diets. Shargh and Azari (2010), and Laudadio et al. (2011) did not find any effect of adding 6% to 31% of faba beans to broiler chicken diets on growth performance, measured as body weight gain (BWG), and feed conversion rate per body weight gain unit (FCR).

In addition, Moschini et al. (2005), who included 25% and 50% unprocessed faba beans in the chicken's diet from 1 to 42 days, did not show differences in performance (BWG, FI, FCR). In contrast, Perella et al. (2009) and Dal Bosco et al. (2013) supplemented the diet of birds with 16% faba beans and observed lower weight gain and worse feed conversion in younger chickens, which was offset at later growth stages.

Brévault et al. (2003) observed a significant reduction in the body weight of chickens fed diets with a 20% addition of tannin-rich faba beans, while faba beans low in tannins yielded results similar to the control group. Hejdysz et al. (2016) analysed the effect of feed containing 30% raw or extruded faba beans on broiler chickens' productivity. They found that broilers fed extruded faba beans were characterized by decreased FI, as well as FCR, without any effect on BWG. However, Usayran et al. (2014) noted a significant improvement in body weight gain and feed conversion rate in chicken diets containing 30% low-tannin faba beans compared to control birds. According to Milczarek and Osek (2017), faba beans introduced into broiler chickens' diets, irrespective of the cultivar (high or low in tannins) and ratio (8%/15% or 16%/22% starter/grower, respectively), contribute to a similar final body weight (1864 g vs. 1925 g).

Arija et al. (2006) evaluated the suitability of 100 g, 200 g, and 300 g of raw or extruded faba beans per 1 kg of feed in broiler chickens from day 1 to 21 of bird life. They demonstrated that the inclusion of faba beans in diets decreased amino acid digestibility, reduced the size of the digestive organs, and led to a decline in the pH of the caecum. In contrast, Emiola et al. (2007) noted that it is possible to replace up to 50% of the protein from soybean meal with raw or processed (toasted, dehulled, and heated in water) faba beans, but soaked and heated faba beans gave the best results.

Palliyeguru et al. (2011) reported a positive impact of toasted soybean seeds on broiler chicken's productivity. In contrast, Rutkowski et al. (2016) argued that barothermal treatment not only determines chicken growth performance but also the proportion of legumes in the feed ratio. They demonstrated that 10% or 20% raw or extruded lupine in the diet does not affect the growth performance of chickens, but extrusion can improve it. They recommended barothermal processing only for a 25% or 30% proportion of lupine.

Table 3. Performance results of broiler chickens fed rations containing faba beans

Faba beans	Amount and period	Results	References*
Faba beans cv. Akord	10% in starter (3 weeks) and 20% in grower (3 weeks)	Improvement of the body weight ($P \leq 0.05$), similar feed conversion ratio after the addition of methionine into diets	Osek et al. (2003)
Low-tannin faba beans High-tannin faba beans	200 g/kg rations	Decrease of the body weight - high-tannin faba beans, similar results - low-tannin faba beans	Brévault et al. (2003)
Faba beans	25 or 50% in 3 periods: to 10 days-old, from 11 to 28 days-old and from 29 to 42 days-old	Similar body weight, feed intake and feed conversion ratio from 1 to 42 days	Moschini et al. (2005)
Raw faba beans Extruded faba beans	47.9% from 1 to 10 days-old and from 11 to 28 days-old 50% from 29 to 42 days-old	Similar body weight, feed intake and feed conversion ratio	Diaz et al. (2006)
Raw or extruded faba beans	100, 200 or 300 g/kg of diets from 1 to 21 days	Increasing the faba beans content in the diet reduced weight gain and feed consumption, and increased the feed conversion ratio	Arija et al. (2006)
Extruded faba beans	16% from 21 to 60 days grower period and next to 120 days finisher period	Similar (3.76 kg/kg) FCR, slightly worse ($P>0.05$) body weight and feed intake	Perella et al. (2009)
Low tannin faba beans cv.: PGGTic, Spec Tic, South Tic, Board	20% in diets to 21 day of life	Improvement of the body weight, similar feed intake and FCR	Nalle et al. (2010)
Raw faba beans Processed (heated) faba beans	6, 12 and 18% faba bean from 0-21 days and 22-42 days	Similar growth rate, feed intake and feed conversion ratio	Shargh and Azari (2010)
Faba beans cv. Fiord (mash or pellets)	0, 50, 100, 150, 200 and 250 g/kg diets	Similar performance results	Gous (2011)
Dehulled-micronized *Vicia faba* L. var. minor) cv. Prothabat,	31% from 14 to 49 days of age (total substitution SBM)	Similar growth rate, feed intake and feed conversion ratio	Laudadio et al. (2011)
Raw faba beans	16% in starter diets (1-21 days) and growing/finisher diets (22-120 days)	Similar feed intake, worse body weight gain and FCR	Dal Bosco et al. (2013)
High-tannin faba beans	13.5% in starter (3 weeks) and 19.5% in grower (3 weeks) rations	Improvement of the body weight ($P \leq 0.05$), similar feed conversion ratio	Osek et al. (2013)
Tannin-free fava beans	30% of rations	Improvement of the body weight and feed conversion ratio, similar FI	Usayran et al. (2014)
Raw and soaked faba beans	10% in starter (3 weeks) and 20% in grower (3 weeks) rations	Decrease of the performance results	Osek et al. (2017)
High-tannin faba bean or low-tannin faba beans	two levels: 8% in starter + 15% in grower, 16% in starter + 22% in grower	Similar BW, FI and FCR	Milczarek and Osek (2017)
Non-dehulled faba beans Dehulled faba beans (low and high tannin)	12% of diets from 0 to 12 days of age, 24% of diets from 13 to 25 days of age, 36% of diets from 26 to 41 days of age	No differences in BW, FI and FCR – dehulling no differences in BW, improvement of the FCR – low tannin faba beans	Cho et al. (2019)
Raw faba beans Extruded faba beans	30% in starter and grower diets	No differences in BWG, decreased FI and FCR after introducing extruded faba beans	Hejdysz et al. (2020)
Raw faba beans Extruded faba beans	300g/kg diets from 8 to 35 days of rearing	Similar BW, FI and FCR	Konieczka et al. (2020)
Zero-tannin faba beans	20, 30 or 40% of rations from 0 to 41 days of chicken life	No differences in BW, FI and FCR	Kopmels et al. (2020)
Faba beans (Olga)	25% of rations, 0-42 days	Decrease of BW (by 19%) and FCR (by 29%) and increase of FI (by 3%) in comparison to SBM diet	Biesek et al. (2020)

* – from the oldest to the newest; nd – not was given; FCR – feed conversion ratio, BW – body weight, BWG – body weight gain, FI – feed intake per living bird, SBM – soybean meal

On the other hand, Osek et al. (2017) assessed the utility of soaking faba beans in broiler chicken diets. The authors demonstrated that including 10% soaked (for 12h or 24h) faba beans in starter diets and 20% in grower diets to replace soybean meal had an adverse effect on the productivity ratios of chickens.

RESULTS OF THE CARCASS YIELD ANALYSIS OF BROILER CHICKENS

The carcass yield of broiler chickens was measured by evisceration, muscularity, and fat content. Many researchers (Perella et al., 2009; Nalle et al., 2010; Laudadio et al., 2011; Osek et al., 2013; Milczarek et al., 2016, Milczarek and Osek, 2017; Biesek et al., 2020) pointed out that the ingredients of the birds' diets modify the carcass yield after slaughter (Table 4).

Arija et al. (2006) showed that extruded faba beans in chicken diets contributed to the deterioration of dressing percentage compared to that in the control group fed maize and soybean meal. However, most of the results of carcass yield analysis supported the positive effects of 10% / 20% faba beans with synthetic methionine in starter/grower diets for broiler chickens, showing significantly improved dressing percentage and muscularity (Osek et al., 2003). Similarly, Milczarek and Osek (2017), assessing the nutritional suitability of low-tannin and high-tannin faba beans cultivars for broiler chicken diets (8% / 15% and 16% / 22% starter/grower, respectively), confirmed improved muscularity in the carcasses of birds fed diets supplemented with faba beans. Additionally, Moschini et al. (2005) and Nalle et al. (2010), Shargh and Azari (2010), Laudadio et al. (2011), and Osek et al. (2013), Dal Bosco et al. (2013), and Biesek et al. (2020) did not observe any significant effect on dressing percentage or the proportion of breast and thigh muscles after supplementing the chicken's diet with 16% to 50% faba beans. In contrast, Diaz et al. (2006) and Cho et al. (2019) found a significant increase in the breast muscle percentage of carcasses in chickens fed diets with faba beans compared to control birds receiving diets without faba beans. Kopmels et al. (2020) claim that the highest percentage (40% vs. 0%, 20%, and 30%) of low-tannin faba beans in the feed ration contributes to a decline in broiler chickens' dressing percentage with no effect on the muscle percentage of the carcass. Osek et al. (2006) showed that including 10% soaked (for 12h or 24h) faba beans in starter diets and 20% in grower diets to replace soybean meal improved carcass muscularity and decreased fat content.

Usayran et al. (2014), Biesek et al. (2020), and Milczarek and Osek (2017) observed a decrease in the fat content of carcasses in chickens fed diets with faba beans included. Biesek et al. (2020) introduced 25% faba beans (*Vicia faba* cv. Olga) into chicken diets and subsequently found a reduced percentage of skin with subcutaneous fat (8.34% vs. 9.65%) and abdominal fat (0.59% vs. 1.00%). On the other hand, Shargh and Azari (2010), Laudadio et al. (2011), and Osek et al. (2013), and Dal Bosco et al. (2013) found no significant effect of faba beans on the percentage of abdominal fat. However, Shargh and Azari (2010) noted that its share was lowest in the carcasses of chickens fed diets with the highest faba beans level.

MEAT QUALITY OF BROILER CHICKENS

The poultry meat available in the market should be of adequate quality (Escobedo del Bosque et al., 2020). The most popular meat quality evaluation criteria are physical traits, such as muscle tissue acidity, water-holding capacity (WHC), and meat colour. Muscle reaction (pH) is an indicator of intensive glycolytic transformations in the muscle, providing a basis for differences in meat quality, its technological suitability, and firmness (Raach-Moujahed and Haddad, 2013; Zdanowska-Sąsiadek et al., 2013). A close relationship exists between muscle acidity and water-holding capacity, and as the pH increases from the isoelectric point, the WHC of muscle proteins increases, which leads to increased thermal drip and drip loss. In turn, increased meat juice drip in packaging increases microbiological contamination and the susceptibility to drying. Zdanowska-Sąsiadek et al. (2013) highlight a relationship between meat colour and acidity - the higher the pH, the darker the meat and vice versa. An extremely high pH leads to DFD (dark, firm, and dry) and a low pH leads to PSE (pale, soft, exudative)

Table 4. Carcass yield analysis of broiler chickens

Faba beans	Amount and period	Results	References*
Faba beans cv. Acord	10% in starter (3 weeks) and 20% in grower (3 weeks)	Increase of dressing percentage ($P \leq 0.05$) and musculature, decrease fatness after addition of methionine	Osek et al. (2003)
Faba beans	25 or 50% in 3 periods: to 10 days, from 11 to 28 days and from 29 to 42 days-old	Similar dressing percentage and breast and leg share	Moschini et al. (2005)
Raw faba beans Extruded faba beans	47.9% from 1 to 10 days-old and from 11 to 28 days-old 50% from 29 to 42 days-old	Similar dressing percentage and an increase in breast muscles	Diaz et al. (2006)
Raw or extruded faba beans	100, 200 or 300 g/kg of diets from 1 to 21 days	Decrease of dressing percentage	Arija et al. (2006)
Extruded faba beans	16%; from 21 to 60 days grower period and next to 120 days finisher period	Similar dressing percentage, abdominal fat and share breast and thigh muscles	Perella et al. (2009)
Raw faba beans Processed (heated) faba beans	6, 12 and 18% faba beans from 0-21 days and 22-42 days	Similar dressing percentage and musculature and fatness	Shargh and Azari (2010)
Faba beans	200 g/kg diets	Similar dressing percentage	Nalle et al.(2010)
Dehulled-micronized *Vicia faba* L. var. minor) cv. Prothabat,	31% from 14 to 49 days of age (total substitution soybean meal)	Similar dressing percentage, breast and drumstick muscles share and abdominal fat	Laudadio et al. (2011)
Raw faba beans	16% in starter (1-21 days) and growing/finisher diets (22-120 days)	Similar dressing percentage and musculature	Dal Bosco et al. (2013)
High-tannin faba beans	13.5% in starter (3 weeks) and 19.5% in grower (3 weeks) rations	Similar dressing percentage, breast and leg share and fatness	Osek et al. (2013)
Tannin-free fava beans	30% of diets	Decrease of the abdominal fat	Usayran et al. (2014)
High-tannin faba beans Low-tannin faba beans	8% in starter (from 1 to 21 days) + 15% in grower (22 to 35 days) and 16% in starter (from 1 to 21 days) + 22% in grower (22 to 35 days)	Similar dressing percentage, breast, thigh and drumstick muscles share and decrease of skin with subcutaneous fat and abdominal fat	Milczarek and Osek (2017)
Raw and soaked faba beans	10% in starter (3 weeks) and 20% in grower (3 weeks) rations	Increase of musculature, decrease of fatness	Osek et al. (2017)
Non-dehulled faba beans Dehulled faba beans (low and high tannin)	12% from 0 to 12 days of age, 24% from 13 to 25 days of age, 36% from 26 to 41 days of age	No differences in dressing percentage, better musculature non-dehulled vs. dehulled seeds, as well as better musculature after introducing faba beans vs. SBM	Cho et al. (2019)
Zero-tannin faba beans	20, 30 or 40% of rations from) to 41 days of chicken life	Decrease of dressing percentage in chickens fed rations containing 40% of faba beans	Kopmels et al. (2020)
Faba beans (Olga)	25% of rations; 0-42 days	No differences in dressing percentage and musculature, decrease in fatness	Biesek et al. (2020)

* – from the oldest to the newest; nd – not was given

meat defects. Magdelaine et al. (2008) and Escobedo del Bosque et al. (2020) reported that meat of a darker colour resulting from an increased share of oxidised myoglobin is less desired by consumers.

Milczarek et al. (2016) and Milczarek et al. (2017a) demonstrated that faba beans meal, irrespective of the cultivar (high-tannin or low-tannin) and ratio (8% / 15% and 16% / 22%, respectively, for starter/grower), included in broiler chicken diets, does not affect the birds' breast and leg muscle acidity and their water-holding capacity (Table 5).

Osek et al. (2013), Biesek et al. (2020) and Kuźniacka et al. (2020) obtained similar results. In turn, Dal Bosco et al. (2013) reported that a diet containing 16% faba beans significantly increased the pH of breast muscles, but had no effect on the water-holding capacity and colour of meat.

Qiao et al. (2001) state that colour lightness (L*) in a normal breast muscle ranges from 48 to 53; values above 53 indicate lighter muscle colour, and below 46, darker. Laudadio et al. (2011) observed a significant decrease (44.62 vs. 46.77) in colour lightness after including 31%

Table 5. Meat quality of broiler chickens

Faba beans	Amount and period	Results	References*
Faba beans cv. Akord	10% in starter (3 weeks) and 20% in grower (3 weeks) rations	Similar basic nutrients, improvement the fatty acids profile (from a consumer point of view)	Osek et al. (2003)
Faba beans	40% of rations	Increase of protein content; increase of SFA and decrease of PUFA	Meluzzi et al. (2009)
Dehulled-micronized *Vicia faba* L. var. minor)	310 g/kg of diets from 14 to 49 days (slaughter age)	Similar basic nutrients (protein, fat, ash) content; an increase of total collagen ($P \leq 0.05$); lower L* (lightness) and higher a* (redness) and b* (yellowness) values; a significant decrease of water-holding capacity	Laudadio et al. (2011)
High-tannin faba beans	13.5% in starter (3 weeks) and 19.5% in grower (3 weeks)	Similar protein content, a decrease of fat; similar sensory scores	Osek et al. (2013)
Raw faba beans	16% in starter (1-21 days) and growing/ finisher diets (22-120 days)	Decrease of fat; an increase of SFA and decrease of PUFA; an increase of pH_{15}; similar WHC and colour	Dal Bosco et al. (2013)
Micronized-dehulled faba beans	13% of diet	Increase of essential fatty acids (decrease AI and TI index, improving the HH ratio)	Tufarelli and Laudadio (2015)
High-tannin faba beans Low-tannin faba beans	8% in starter (from 1 to 21 days) + 15% in grower (22 to 35 days) and 16% in starter (from 1 to 21 days) + 22% in grower (22 to 35 days)	Similar basic nutrients, increase of essential fatty acids, especially n-3 family, similar water-holding capacity, acidity, lightness (L*) and redness (a*)	Milczarek and Osek (2017a) Milczarek et al. (2016)
Faba beans (Olga)	25% of rations; 0-42 days	No differences in pH, colour, WHC, drip loss, protein and fat content	Biesek et al. (2020)
Faba beans	Feed based on faba bean (*Vicia faba* var. minor) vs. feed based on soybean meal (SBM)	No differences in colour, WHC, drip loss, protein and fat content of breast muscles, differences in fatty acids profile of muscles, less n-3 fatty acids in muscles of chickens fed faba bean	Kuźniacka et al. (2021)
Faba beans var. Lielplatone	10% of rations	Improving of nutritive value of meat (more protein, less fat and cholesterol content)	Proskina et al. (2021)

* – from the oldest to the newest; nd – not was given; SFA – saturated fatty acids, PUFA – polyunsaturated fatty acids, AI - atherogenic index, TI - thrombogenic index, HH - Hypocholesterolaemic/Hypercholesterolaemic ratio, WHC – water holding capacity

of faba beans in the diet fed to broiler chickens, and simultaneously, a deteriorated water-holding capacity of breast muscles.

The essential nutrient content and fatty acid profile of muscle lipids are indicators of poultry meat quality and dietary value. The results of experiments conducted by Osek et al. (2003), Milczarek et al. (2016), and Laudadio et al. (2011) indicated that faba beans in broiler chicken diets did not affect the content of essential nutrients (crude fat, crude protein, and minerals) in the muscles. In the opinion of Meluzzi et al. (2009) replacing soybean meal with faba beans in chicken diets can significantly increase the protein content. In turn, Dal Bosco et al. (2013) and Osek et al. (2013) found a significant decline in the crude fat content of muscles in chickens fed diets with faba beans. A significant decrease in saturated fatty acids (SFA) and an increase in polyunsaturated fatty acids (PUFA) in the breast muscles of chickens fed faba beans diets, which is beneficial from the point of view of human nutrition, was observed by Tufarelli and Laudadio (2015), Osek et al. (2003), Milczarek et al. (2017a) and Milczarek and Osek (2017a). Quite the contrary, Meluzzi et al. (2009) and Dal Bosco et al. (2013) found increased SFA and decreased PUFA in the lipid profile of breast muscles in chickens receiving diets supplemented with faba beans. According to Milczarek et al. (2016), the significantly lower calculated atherogenic index (AI) and thrombogenic index (TI) confirmed the positive effect of diets supplemented with faba beans on the dietary value of chicken meat. Laudadio et al. (2011) found no effect on the value of the above lipid ratios of breast muscles. However, further studies (Tufarelli and Laudadio, 2015) showed that these indices declined in the breast muscle. According to Kuźniacka et al. (2020), faba beans in broiler chicken diets reduce the proportion of omega-3 acids in the muscles.

Poultry consumers consider sensory traits, such as smell, juiciness, tenderness, and palatability, to be important meat qualities. Osek et al. (2003) showed that supplementing methionine deficiency of starter/grower diets with faba beans (10% / 20%) significantly improved meat flavour. Another experiment by Osek et al. (2013) did not show any significant effect of high-tannin faba beans added to chicken diets on the sensory evaluation of meat; however, the breast muscles of chickens fed diets with faba beans scored higher for the evaluated sensory characteristics. Similarly, in the study by Milczarek and Osek (2017a), the muscles of chickens fed diets with a higher share of faba beans (of any cultivar) scored the highest for juiciness and showed the highest mean values for sensory qualities. The difference was significant compared to the muscles of the control chickens. This should be associated with increased intramuscular fat content, which significantly affects palatability, tenderness, and juiciness of the muscles.

CONCLUSIONS

In conclusion, the nutritional value of faba beans depends on several factors, including cultivar (low-tannin vs. high-tannin) and refining treatments (raw vs. extruded, de-hulled, and soaked seeds). Growth performance (body weight gain, feed intake, and conversion) and carcass composition (dressing percentage, carcass muscularity, and fatness) of broiler chickens fed diets containing faba beans depended to the greatest extent on their share of the diet and less on the cultivar and refining treatments of seeds. Considering the quality of broiler chicken meat (its physical, chemical, and sensory traits), the present results provide a basis for recommending faba bean meal as a partial substitute for soybean meal in the broiler chicken diet.

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REFERENCES

Aerts, R.J., McNabb, W.C., Molan, A., Brand, A., Barry, T.N., Peters, J.S. (1999) Condensed tannins from Lotus corniculatus and Lotus pedunculatus exert different effects on the in vitro rumen degradation of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) protein. Journal of the Science of Food and Agriculture, 79, 79-85. DOI: https://doi.org/10.1002/(SICI)1097-0010(199901)79:1<79::AID-JSFA187>3.0.CO,2-K

Arija, I., Centeno, C., Viveros, A., Brenes, A., Marzo, F., Illera, J. C., Silvan, G. (2006) Nutritional evaluation of raw and extruded kidney bean (*Phaseolus vulgaris* L. var. Pinto) in chicken diets. Poultry Science, 85, 635-644. DOI: https://doi.org/10.1093/ps/85.4.635

Bangar, S.P., Kajla, P. (2022). Introduction: Global Status and Production of Faba-Bean. In: Punia Bangar, S., Bala Dhull, S., eds. Faba Bean: Chemistry, Properties and Functionality. Springer, Cham. DOI: https://doi.org/10.1007/978-3-031-14587-2_1

Beltranena, E., Hooda, S., Zijlstra, R.T. (2009) Zero-tannin faba bean as a replacement for soybean meal in diets for starter pigs. Canadian Journal of Animal Science, 89 (4), 489-492. DOI: https://doi.org/10.4141/CJAS09034

Biesek, J., Kuźniacka, J., Banaszak, M., Kaczmarek, S., Adamski, M, Rutkowski, A., Zudzińska, A., Perz, K, Hejdysz, M. (2020) Growth Performance and Carcass Quality in Broiler Chickens Fed on Legume Seeds and Rapeseed Meal. Animals, 10, 846. DOI: https://doi.org/10.3390/ani10050846

Brévault, N., Mansuy, E., Crépon, K., Bouvarel, I., Lessire, M., Rouillére, H. (2003) Utilisation de différentes variétés de féveroles pour l'alimentation du poulet biologique. In: 5éme Journées Techniques Avicoles, ITAVI, Paris, 221-224.

Cho, M., Smit, M.N., He, L., Kopmels, F. C., Beltranena, E. (2019) Effect of Feeding Zero- or High-Tannin Faba Bean Cultivars and Dehulling on Growth Performance, Carcass Traits and Yield of Saleable Cuts of Broiler Chickens. Journal of Applied Poultry Research, 28, 1305-1323. DOI: https://doi.org/10.3382/japr/pfz099

Crépon, K., Marget, P., Peyronnet, C., Carrouee, B., Arese, P., Duc, G. (2010) Nutritional value of faba bean (*Vicia faba* L.) seeds for feed and food. Field Crops Research, 115, 329-339. DOI: https://doi.org/10.1016/j.fcr.2009.09.016

Dal Bosco, A., Ruggeri, S., Mattioli, S., Mugnai, C., Sirri, F., Castellini, C. (2013) Effect of faba bean (*Vicia faba* var. minor) inclusion in starter and growing diet on performance, carcass and meat characteristics of organic slow-growing chickens. Italian Journal of Animal Science, 12 (4), 76, 472-478. DOI: https://doi.org/10.4081/ijas.2013.e76

Diaz, D., Morlacchini, M., Masero, M., Moschini, M., Fusconi, G., Piva, G. (2006) Pea seeds (*Pisum sativum*), faba beans (*Vicia faba* var. minor) and lupin seeds (*Lupinus albus* var. multitalia) as protein sources in broiler diets: effect of extrusion on growth performance. Italian Journal of Animal Science, 5, 43-53. DOI: https://doi.org/10.4081/ijas.2006.43

Duc, G. (1997) Faba bean (*Vicia faba* L.). Field Crop. Research, 53, 99-109. DOI: https://doi.org/10.1016/S0378-4290(97)00025-7

Emiola, I.A., Ologhobo, A.D., Gous, R.M. (2007) Performance and histological responses of internal organs of broiler chickens fed raw, dehulled, and aqueous and dry-heated kidney bean meals. Poultry Science, 86,1234-1240. DOI: https://doi.org/10.1093/ps/86.6.1234

Escobedo del Bosque, C.I., Altmann, B.A., Ciulu, M., Halle, I., Jansen, S., Nolte, T., Weigend, S., Mörlein, D. (2020) Meat quality parameters and sensory properties of one high-performing and two local chicken breeds fed with *Vicia faba*. Foods, 9, 1052. DOI: https://doi.org/10.3390/foods9081052

FAO. 2021. World Food and Agriculture - Statistical Yearbook 2021. Rome. DOI: https://doi.org/10.4060/cb4477en

FAOSTAT (2022) Statistics database of the food and agriculture organization of the united nations. http://www.fao.org/statistics/databases/en/

Fordoński, G., Pszczółkowska, A., Krzebietke, S., Olszewski, J., Okorski, A. (2015) Yield and mineral composition of seeds of leguminous plants and grain of spring wheat as well as their residual effect on the yield and chemical composition of winter oilseed rape seeds. Journal of Elementology, 20(4), 827-838. DOI: https://doi.org/10.5601/ jelem.2015.20.2.877

German Federal PlantVarietyO_ce. Beschreibende Sortenliste Getreide, Mais, Öl- und Faserpflanzen, Leguminosen, Rüben, Zwischenfrüchte 2019, German Federal Plant Variety O_ce: Hannover, Germany, 2019, pp. 254-259.

Gous, R.M. (2011) Evaluation of faba bean (*Vicia faba* cv. Fiord) as a protein source for broilers. South African Journal of Animal Science, 41, 2, 71-78.

Hanczakowska, E., Księżak, J. (2012) Krajowe źródła białkowych pasz roślinnych jako zamienniki śruty sojowej GMO w żywieniu świń. Roczniki Naukowe Zootechniki, 39, 2, 171-187.

Hanczakowska, E., Świątkiewicz, M. (2014) Legume seeds and rapeseed press cake as replacers of soybean meal in feed for fattening pigs. Annals of Animal Science, 14 (4), 921-394. DOI: https://doi.org/10.2478/aoas-2014-0068

Hejdysz, M., Kaczmarek, S.A., Rutkowski, A. (2016) Extrusion cooking improves the metabolisable energy of faba beans and the amino acid digestibility in broilers. Animal Feed Science and Technology, 212, 100-111. DOI: https://doi.org/10.1016/j.anifeedsci.2015.12.008

Hejdysz, M., Kaczmarek, S. A., Kubiś, M., Adamski, M., Perz, K., Rutkowski, A. (2019) The effect of faba bean extrusion on the growth performance, nutrient utilization, metabolizable energy, excretion of sialic acids and meat quality of broiler chickens. Animal, 13, 8, 1583-1590. DOI: https://doi.org/10.1017/S175173111800366X

Hejdysz, M., Kaczmarek, S. A., Kubiś, M., Wiśniewska, Z., Peris, S., Budnik, S., Rutkowski, A. (2020) The effect of protease and Bacilluslicheniformis on nutritional value of pea, faba bean, yellow lupin and narrow-leaved lupin in broiler chicken diets. British Poultry Science, 61, 3, 287-293. DOI: https://doi.org/10.1080/00071668.2020.1716303

Jamroz, D., Kubizna, J. (2008) Harmful substances in legume seeds – their negative and beneficial properties. Polish Journal of Veterinary Sciences, 11, 389-404.

Jansman, A.J.M., Verstegen, M.W.A., Huisman, J., van den Berg, J.W.O. (1995) Effects of hulls of faba beans (*Vicia faba* L.) with a low or high content of condensed tannins on the apparent ileal and fecal digestibility of nutrients and the excretion of endogenous protein in ilealdigesta and feces of pigs. Journal of Animal Science, 73, 118-127. DOI: https://doi.org/10.2527/1995.731118x

Jezierny, D., Mosenthin, R., Bauer, E. (2010) The use of grain legumes as a protein source in pig nutrition: A review. Animal Feed Science and Technology. 157, 111-128. DOI: https://doi.org/10.1016/j.anifeedsci.2010.03.001

Kasprowicz-Potocka, M., Gulewicz, P., Zaworska-Zakrzewska, A. (2022) The content of raffinose oligosaccharides in legumes and their importance for animals. Journal of Animal and Feed Sciences, 31(3), 265-275. DOI: https://doi.org/10.22358/jafs/149656/2022

Kiarie, E., Lopez, P., Furedi, C., Nyachoti, C. M. (2013) Amino acids and energy utilization in zero-tannin faba bean and co-fermented wheat and corn dried distillers grains with solubles fed to growing pigs. Journal of Animal Science, 91, 1728-1735. DOI: https://doi.org/10.2527/jas.2012-5485

Koivunen, E., Partanen, K., Perttilä, S., Palander, S., Tuunainen, P., Valaja, J. (2016) Digestibility and energy value of pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.) and blue lupin (narrow-leaf) (*Lupinus angustifolius*) seeds in broilers. Animal Feed Science and Technology, 218, 120-127. DOI: https://doi.org/10.1016/j.anifeedsci.2016.05.007

Konieczka, P., Kaczmarek, S.A., Hejdysz, M., Kinsner, M., Szkopeka, D., Smulikowska, S. (2020) Effects of faba bean extrusion and phytase supplementation on performance, phosphorus and nitrogen retention, and gut microbiota activity in broilers. Journal of the Science of Food and Agriculture, 100, 4217-4225. DOI: https://doi.org/10.1002/jsfa.10461

Kopmels, F.C., Smit, M.N., Cho, M., He, L., Beltranena E. (2020) Effect of feeding 3 zero-tannin faba bean cultivars at 3 increasing inclusion levels on growth performance, carcass traits, and yield of saleable cuts of broiler chickens. Poultry Science, 99, 4958-4968. DOI: https://doi.org/10.1016/j.psj.2020.06.034

Księżak, J., Bojarszczuk, J., Świątkiewicz, M., (2020) Uprawa bobiku i wykorzystanie nasion w żywieniu zwierząt gospodarskich. Instrukcja upowszechnieniowa nr 242, IUNG Puławy, pp.56.

Kuźniacka, J., Banaszak, M., Biesek, J., Maiorano, G., Adamski, M. (2020) Effect of faba bean-based diets on the meat quality and fatty acids composition in breast muscles of broiler chickens. Scientific Reports, 10, 5292. DOI: https://doi.org/10.1038/s41598-020-62282-7

Laudadio, V., Ceci, E., Tufarelli, V. (2011) Productive traits and meat fatty acid profile of broiler chickens fed diets containing micronized fava beans (*Vicia faba* L. var. minor) as the main protein source. Journal of Applied Poultry Research, 20, 12–20. DOI: https://doi.org/10.3382/japr.2010-00173

Luzzatto, L., Arese, P. (2018) Favism and glucose-6-phosphate dehydrogenase deficiency. The New England Journal of Medicine, 378, 60-71. DOI: https://doi.org/10.1056/NEJMra1708111

Magdelaine, P., Spiess, M.P., Valceschini, E. (2008) Poultry meat consumption trends in Europe. World's Poultry Science Journal, 64, 53-63. DOI: https://doi.org/10.1017/S0043933907001717

Meluzzi, A., Sirri, F., Castellini, C., Roncarati, A., Melotti, P., Franchini, A. (2009) Influence of genotype and feeding on chemical composition of organic chicken meat. Italian Journal of Animal Science, 8 (Suppl. 2), 766-768. DOI: https://doi.org/10.4081/ijas.2009.s2.766

Milczarek, A., Osek, M. (2017) The impact of faba bean (*Vicia faba* var. minor) with high or low content of tannins on the results of rearing and carcass quality of broiler chickens. Part I. Performance and slaughter results of chickens. Annales UMCS sec. EE, Zootechnica, XXXV (1), 1-9. DOI: https://doi.org/10.24326/jasbb.2017.1.1

Milczarek, A., Osek, M. (2017a) The impact of faba bean (*Vicia faba* var. minor) with high or low content of tannins on the results of rearing and carcass quality of broiler chickens. Part II. Meat quality of chickens. Annales UMCS sec. EE, Zootechnica, XXXV (1), 11-18. DOI: https://doi.org/10.24326/jasbb.2017.1.2

Milczarek, A., Osek, M. (2019) Effectiveness Evaluation of Use of Various Protein Feeds for Broiler Chicken Feeding. Annals of Animal Science, 19, 1063-1081. DOI: https://doi.org/10.2478/aoas-2019-0056

Milczarek, A., Osek, M., Pachnik, M. (2016) Meat quality of broiler chickens fed mixtures with varied levels and varieties of faba bean. Acta Scientiarum Polonorum s. Zootechnica, 15 (4), 27-38. DOI: https://doi.org/10.21005/asp.2016.15.4.03

Moschini, M., Masoero, F., Prandini, A., Fusconi, G., Morlacchini, M., Piva, G. (2005) Raw Pea (*Pisum sativum*), raw Faba bean (*Vicia faba* var. minor) and raw Lupin (*Lupinus albus* var. multitalia) as alternative protein sources in broiler diets. Italian Journal of Animal Science, 4, 59-69. DOI: https://doi.org/10.4081/ijas.2005.59

Nalle, C.L., Ravindran, V., Ravindran, G. (2010) Evaluation of faba beans, white lupines and peas as protein source in broiler diets. International Journal of Poultry Science, 9 (6), 567-573.

Nolte, T., Jansen, S., Weigend, S., Moerlein, D., Halle, I., Link, W., Hummel, J., Simianer, H., Sharifi, A.R. (2020) Growth Performance of Local Chicken Breeds, a High-Performance Genotype and Their Crosses Fed with Regional Faba Beans to Replace Soy. Animals, 10, 702. DOI: https://doi.org/10.3390/ani10040702

Osek M., Milczarek A., Klocek B., Turyk Z., Jakubowska K. (2013) Effectiveness of mixtures with the *Fabaceae* seeds in broiler chicken feeding. Annales UMCS, sec. EE, Zootechnica, VOL. LXVIII (4), 77-86.

Osek, M., Janocha, A., Milczarek, A. (2003) Wpływ dodatku metioniny do mieszanek z udziałem bobiku odmiany Akord na wyniki odchowu i wartość poubojową kurcząt brojlerów. Annales UMCS, sec. EE, Zootechnica. XXI, 2, 207-213.

Osek, M., Milczarek, A., Pachnik, M. (2017) Wpływ moczenia nasion bobiku na ich wartość odżywczą dla kurcząt brojlerów. Zeszyty Problemowe Postępów Nauk Rolniczych, 588, 73-82. DOI: https://doi.org/10.22630/ZPPNR.2017.588.7

Palliyeguru, M.W.C.D., Rose, S.P., Mackenzie, A.M. (2011) Effect of trypsin inhibitor activity in soya bean on growth performance, protein digestibility and incidence of sub-clinical necrotic enteritis in broiler chicken flocks. British Poultry Science, 52, 359-367. DOI: https://doi.org/10.1080/00071668.2011.577054

Perella, F., Mugnai, C., Dal Bosco, A., Sirri, F., Cestola, E., Castellini, C. (2009) Faba bean (*Vicia faba* var. minor) as a protein source for organic chickens: performance and carcass characteristics. Italian Journal of Animal Science 8, 575-584. DOI: https://doi.org/10.4081/ijas.2009.575

Proskina, L., Cerina, S., Valdovska, A., Pilvere, I., Alekneviciene, V. (2021) The possibility of improving meat quality by using peas and faba beans in feed for broiler chickens. Potravinarstvo Slovak Journal of Food Sciences, 15, 40-51. DOI: https://doi.org/10.5219/1451

Qiao, M., Fletcher, D.L., Smith, D.P., Northcutt J.K. (2001) The effect of broiler breast meat color on pH, moisture, water holding capacity, and emulsification capacity. Poultry Science, 80, 676-678. DOI: https://doi.org/10.1093/ps/80.5.676

Raach-Moujahed, A., Haddad, B. (2013) Performance, livability, carcass yield and meat quality of Tunisian local poultry and fast-growing genotype (Arbor Acres) fed standard diet and raised outdoor access. Animal Production Research Advances, 3(3), 75-85. DOI: https://doi.org/10.5455/japa.20130305122741

Rutkowski, A., Kaczmarek, S.A., Hejdysz, M., Jamroz, D. (2016) Effect of extrusion on nutrients digestibility, metabolizable energy and nutritional value of yellow lupine seeds for broiler chickens. Annals of Animal Science, 16, 1059-1072. DOI: https://doi.org/10.1515/aoas-2016-0025

Serrano, J., Puupponen-Pimia, R., Dauer, A., Aura, A.M., Saura-Calixto, F. (2009) Tannins: Current knowledge of food sources, intake, bioavailability and biological effects. Molecular Nutrition and Food Research, 53, 310-329. DOI: https://doi.org/10.1002/mnfr.200900039

Shargh, M.S., Azari, M.A. (2010) Determination of the optimum inclusion level of faba beans in diet of broiler chicks. The Indian Journal of Animal Sciences, 80(9), 940-942.

Smit, M.N., Ketelaar, R.F., He, L., Beltranena, E. (2021) Ileal digestibility of energy and amino acids in three faba bean cultivars (*Vicia faba* L.) planted and harvested early or late in broiler chickens. Poultry Science, 100, 101332. DOI: https://doi.org/10.1016/j.psj.2021.101332

Szpunar-Krok, E., Bobrecka-Jamro, D., Tobiasz-Salach, R., Kubit, P. (2009) Chemical composition of naked grains oat and faba bean seeds in pure sowing and mixtures. Fragmenta Agronomica, 26(2), 152-157.

Tufarelli, V., Laudadio, V. (2015) Feeding dehulled-micronized Faba bean (*Vicia faba* var. minor) as substitute for soybean meal in Guinea Fowl broilers: Effect on productive performance and meat quality. Asian-Australasian Journal of Animal Sciences, 28, 1471-1478. DOI: https://doi.org/10.5713/ajas.15.0245

Usayran, N. N., Sha'ar, H., Barbour, G. W., Yau, S. K., Maalouf, F., Farran, M. T. (2014) Nutritional value, performance, carcass quality, visceral organ size, and blood clinical chemistry of broiler chicks fed 30% tannin-free fava bean diets. Poultry Science, 93 (8), 2018-2027. DOI: https://doi.org/10.3382/ps.2014-03872

Vilariño, M., Métayer, J.P., Crépon, K., Duc, G. (2009) Effects of varying vicine, convicine and tannin contents of faba bean seeds (*Vicia faba* L.) on nutritional values for broiler chicken. Animal Feed Science and Technology, 30, 114-121. DOI: https://doi.org/10.1016/j.anifeedsci.2008.08.001

Woyengo, T.A., Nyachoti, C.M. (2012) Ileal digestibility of amino acids for zero tannin faba bean (*Vicia faba* L.) fed to broiler chicks. Poultry Science, 91, 439-443. DOI: https://doi.org/10.3382/ps.2011-01678

Zawadzki, W., Wincewicz, E., Biowska, M., Graczyk, S., Malicki, A., Kozak, M. (2010) Investigation on the effect of high- and low- tannin horse bean seeds on selected hematological and bio-chemical parameters of rats. Medycyna Weterynaryjna, 66 (10), 711-715.

Zdanowska-Sąsiadek, Z., Michalczuk, M., Marcinkowska-Lesiak, M., Damaziak, K. (2013) Factors determining the sensory quality of poultry meat. Bromatologia i Chemia Toksykologiczna, LVI, 344-353.

Zduńczyk, Z., Mikulski, D., Jankowski, J., Przybylska-Gornowicz B., Sosnowska, E., Juskiewicz, J., Amarowicz, R., Slominski, B.A. (2018) Effects of dietary inclusion of high- and low-tannin faba bean (*Vicia faba* L.) seeds on microbiota, histology and fermentation processes of the gastrointestinal tract in finisher turkeys. Animal Feed Science and Technology, 240, 184-196. DOI: https://doi.org/10.1016/j.anifeedsci.2018.04.006

Zijlstra, R.T., Lopetinsky, K., Beltranena, E. (2008) The nutritional value of zero-tannin faba bean for grower-finisher pigs. Canadian Journal of Animal Science, 88 (2), 293-302. DOI: https://doi.org/10.4141/CJAS07146