PULSE CANADA

CANADIAN FABA BEAN

A GUIDE FOR THE LIVESTOCK AND AQUACULTURE INDUSTRY

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INTRODUCTION

Faba bean *(Vicia faba)* is a nutritious pulse used for human and animal consumption. Faba beans, a good yielding legume crop with a high nitrogen-fixation capacity, is an excellent rotation crop that is well adapted to the cool and moist environment in parts of Canada. Two major types of faba bean varieties are tannin and low tannin (zero tannin). New varieties with low vicine and convicine are also available on the market. Tannins are anti-nutrient compounds that can reduce palatability and digestibility. Therefore, low tannin beans are sought out by the feed industry and are the primary varieties grown in Canada for feeding purposes.

Low tannin faba beans are high in lysine and well accepted by livestock. Low tannin faba beans are an excellent protein and energy ingredient that can compete with soybean meal, canola meal, corn, etc. Faba beans can also be processed into protein and starch concentrates using fractionation technologies and are approved for use in Canada for livestock feed. Currently, the majority of faba beans are exported or fractionated to create food ingredients for human consumption. However, the market in animal feeds is expanding.

This guide aims to provide practical information to the industry on the use of faba bean and its fractions in farm animals. A review of the faba bean industry in Canada, faba bean and fractions nutrient and anti-nutrient compositions, and poultry, swine, ruminant, and aquaculture applications are included. Economics and sustainability impacts are also discussed. Continued research in the application of faba bean and fractions in farm animals would benefit producers to achieve ideal animal growth and health.

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1 Faba Bean Industry in Canada

The faba bean (*Vicia faba*, also called Fava bean) is an ancient pulse crop of the legume family which provides a high yield in cool and/or wet zones. Faba bean is grown and sold for human consumption and livestock feed or fodder (hay, silage, and straw). There are two major types of faba bean: tannin and low tannin (zero tannin). Tannin and low-tannin faba bean varieties are similar in crude protein, starch, and fat composition. However, the tannin varieties contain 0.66% condensed tannins, whereas the low-tannin varieties have only 0.01% condensed tannins. Low-tannin faba bean is also slightly lower in vicine and convicine content (Table 1.1). Low tannin faba bean is appropriate and mainly used for the livestock feed industry, whereas tannin types are primarily for human consumption.

In Canada, Snowdrop, Snowbird, Tabasco, and Imposa are the commonly used zero tannin cultivars, and Malik and FB 18-20 are the tannin containing cultivars. Recently, a new variety, Fabelle, which has high tannin, low vicine, and convicine levels, has also been registered and licensed for production. The "Double zero" variety, low tannin, vicine, and convicine cultivar, is registered as Fevita trademark. In the current guide, efforts have been made to differentiate between the faba bean varieties. However, not all the references clearly state the tannin level of the faba bean or the cultivar used in the studies.

Canada exports faba beans to many areas, including the Mediterranean, Middle East, and Asia. The production of faba bean in Canada for 2019 was 107,800 t (Statistics Canada, 2020). Faba bean seeded area in Canada for the previous several years is shown in Table 1.2.

Table 1.1 Mean chemical composition comparison of faba bean varieties at different tannin contents (Crepon et al., 2010; Duc et al., 1999)

Component (%, dry matter)	Tannin	Low tannin
Crude protein	31	31.9
Starch	41.2	42.7
Fat	1.5	1.3
Vicine + convicine	0.83	0.76
Condensed Tannins	0.66	0.01

Table 1.2 Canadian faba bean seeded area (Saskatchewan Pulse Growers, 2020)

Year	Seeded area (Thousand acres)
2008	10
2009	15
2010	9
2011	8
2012	15
2013	25
2014	95
2015	150
2016	105
2017	100
2018	36
2019	93

2 Faba Bean Nutrient Composition

Faba beans contain high levels of protein and starch, and other nutrients including, complex carbohydrates, dietary fibre, choline, lecithin, and minerals. The composition of nutrients and anti-nutrient factors of faba bean are listed in Table 2.1. The nutrient values used in this document are derived from many sources and are believed to represent the average nutrient values for faba bean. The dry matter basis values were converted into as fed basis values using an average moisture content (10.9%) for all the nutrients. In practice, the moisture level varies based on storage and growing conditions.

Table 2.1 The composition of nutrients and anti-nutrient factors of low-tannin faba beans[a]

Component	Average (as fed)	Average (dry matter)
Energy, kcal/kg		
AMEn (poultry)[b]	2662	2988
DE (swine)[c]	3470	3895
NE (swine)[c]	2270	2548
ME (ruminants)[b]	2854	3203
Ingredient, %		
Crude protein	27.6	31
Crude fat	1.2	1.3
Crude fiber	7.6	8.5
Starch	38.5	43.2
Ash	3.7	4.1
NDF	12.9	14.5
ADF	9.1	10.2

Table 2.1 The composition of nutrients and anti-nutrient factors of low-tannin faba beans[a] (continued)

Component	Average (as fed)	Average (dry matter)
Ingredient, %		
Phytic acid[d]	1.0	1.1
Vicine+covicine[e]	0.68	0.76
Condensed tannins[b]	0.01	0.01
Trypsin inhibitors activity[e] (TIU/mg)	2.6	2.9

[a]10.9% moisture basis; [b]Heuzé et al.,2018; [c]Ruurd Zijlstra et al., 2008; [d]Oomah et.al., 2011; [e]Crépon et al., 2010

AMEn: Apparent metabolizable energy, N-corrected; DE: Digestible energy; NE: Net energy

ME: Metabolizable energy; NDF: Neutral detergent fiber; ADF: Acid detergent fiber

PROTEIN AND AMINO ACIDS

Faba bean is a valuable source of protein, and the protein content is approximately 31% dry matter basis (DM, low tannin varieties). The amino acid composition (low tannin varieties) and standardized ileal digestibility (all cultivars) of faba bean in swine and poultry are listed in Table 2.2.

Similar to most other pulse proteins, faba bean is relatively low in some essential amino acids, including methionine, cysteine and tryptophan, but unlike other high energy grains like corn or wheat, it is rich in lysine. The protein in faba bean primarily consists of storage proteins which account for 80% of the CP. The main storage proteins of faba bean are albumin and globulin. The albumins of faba bean consist of trypsin inhibitor and phytolectin. Albumins contain more sulfur-containing amino acids than globulins (Mandal and Mandal, 2000; Karaca et al., 2011; Dan et al., 2012; Liu et al., 2012; Liu et al., 2017).

Table 2.2 The amino acid composition (low tannin varieties) and standardized ileal digestibility (all cultivars) of faba beans in swine and poultry

Anti-nutrient factors (g/100g)	Amino acid content (%)		% of CP (CP: 31% DM)	Standardized ileal digestibility (%)	
	As fed[a]	DM[b]		Swine[c]	Poultry[d]
Arginine	2.47	2.77	8.94	90	88
Histidine	0.69	0.78	2.52	79	87
Isoleucine	1.17	1.31	4.23	81	85
Leucine	2.01	2.26	7.30	82	86
Lysine	1.76	1.98	6.39	85	88
Methionine	0.23	0.26	0.84	73	86
Met+ Cys	0.56	0.63	2.03	68e	84 e
Phenylalanine	1.13	1.27	4.10	80	81
Threonine	1.04	1.17	3.78	78	80
Tryptophan	0.24	0.27	0.87	64	81
Valine	1.35	1.52	4.91	78	83
Alanine	1.15	1.29	4.16	78	
Aspartate	2.86	3.21	10.36	85	
Cysteine	0.33	0.37	1.19	62	82
Glutamate	4.70	5.28	17.05	88	
Glycine	1.19	1.33	4.29	76	79
Proline	1.10	1.23	3.97	87	
Serine	1.30	1.46	4.71	83	83
Tyrosine	0.60	0.67	2.16	82	83

[a]10.9% moisture basis

[b]The values are based on Duc et al.,1999

[c]NRC 2012

[d]Szczurek, 2009; Masey O'Neill et al., 2012;

[e]Mean of methionine and cysteine

DM: Dry matter; CP: Crude protein

FAT

Faba bean contains approximately 1.3 % crude fat (DM, Table 2.1), with saturated, monounsaturated and polyunsaturated fatty acids (Table 2.3). The highest proportion of n-3 polyunsaturated fatty acids is α-linolenic acid, whereas linoleic acid is the fatty acid that accounts for the highest proportion of n-6 polyunsaturated fatty acids.

Table 2.3 The composition of fatty acids in faba beans

Component	% of total fatty acids
Total saturated fatty acids	19.11
Total monounsaturated fatty acids	26.36
Total polyunsaturated fatty acids	54.54
Total n-3 polyunsaturated fatty acids	3.59
α-linolenic acid	3.48
Total n-6 polyunsaturated fatty acids	50.94
Linoleic acid	50.81

The values are based on Kudlinskienė et al., 2020

CARBOHYDRATES

The main carbohydrate component of faba bean is starch. Starch is primarily composed of amylose and amylopectin. Faba bean starch consists of 77.5% amylopectin and 22.5% amylose. A small proportion (21.5%) of amylopectin in faba bean is comprised of smaller branch chains (6–12 Degree of Polymerization, DP), whereas a larger proportion is accounted for by the longer branch chains with 13–24 DP. Starch digestibility decreases with the increasing length of the amylopectin branch chains. Compared to cereals, faba bean starch is more resistant to enzyme hydrolysis since the proportions of rapidly digestible starch and slowly digestible starch are relatively low (15.3 and 34.5%, respectively), whereas the proportion of resistant starch is relatively high (46.7%) (Sofi et al., 2013; Li et al., 2019; Punia et al., 2019). In addition, low molecular weight carbohydrates (glucose, fructose, and sucrose) and raffinose family oligosaccharides (raffinose, stachyose, and verbascose) are also present in faba bean as carbohydrate components and these may act as prebiotics (Table 2.4).

Table 2.4 The composition of carbohydrates in faba bean

Component	Average (%, as fed)[a]	Average (%, dry matter)
Starch	38.5	43.2
Free glucose	0.2	0.2
Sucrose	1.5	1.7
Raffinose	1.4	1.6
Stachyose	1.7	1.9
Verbascose	2.1	2.4
Total dietary fibre	12.3	13.8
Soluble dietary fibre	4.2	4.7
Insoluble dietary fibre	8.1	9.1

[a]10.9% moisture basis

The values are based on Heuzé et al., 2018; Adamidou et al., 2011; Landry et al., 2016; Millar et al., 2019

VITAMINS AND MINERALS

Limited data are available regarding the vitamin content of faba bean, but the mineral composition values are available in Table 2.5.

Table 2.5 The mineral composition of faba bean

Mineral	Average (as fed)[a]	Average (dry matter)
	%	
P	0.57	0.64
Non-phytate P, %	0.19	0.21
K	1.23	1.38
Ca	0.14	0.15
Mg	0.13	0.15
	mg/kg	
Fe	52	59
Na	69	78
Cu	12	14
Mn	21	24
Zn	36	41

The values are based on Etemadi et al., 2018; Millar et al., 2019; Khazaei and Vandenberg, 2020

[a]10.9% moisture basis

ENERGY

Faba beans are a good source of energy for livestock (Table 2.1). The apparent metabolizable energy (AMEn) in faba beans on a dry matter basis is estimated as 2988 Kcal/kg for poultry and 3203 kcal/kg metabolizable energy (ME) for ruminants. The net energy (NE) for swine is 2548 Kcal/kg, DM. Similar to peas, the energy value in faba bean can be overestimated for swine when the formulation is on the ME or digestible energy (DE) systems. The overestimation results in less actual energy available to the pigs when beans are incorporated into the diets, resulting in decreased performance in those studies. The NE system is recommended to formulate all swine diets.

ANTI-NUTRIENT FACTORS

The main anti-nutrient factors found in faba beans are tannins, which are a family of phenolic compounds concentrated in the hull of the seed. Tannins form a complex with dietary proteins which are less digestible, inhibit digestive enzymes, and may cause a bitter flavor. Tannins are chelating agents and form stable complexes with iron, reducing absorption. Due to modern breeding efforts, the low-tannin varieties of faba bean have only 0.01% condensed tannins, similar to 0.01% in feed pea and much lower than 0.49 % in chickpeas (DM basis) and should not be limited in animal feed due to the tannin levels when the low tannin varieties are used (Heuzé et al., 2018).

Vicine and convicine are other anti-nutrient factors in faba bean. They are stored in the cotyledons of faba bean. While vicine and convicine affect the metabolism of laying hens, causing reduced egg size and feed intake. there is less evidence of adverse effects in pigs and broilers (Crépon et al., 2010; Diaz et al., 2006). Low vicine and convicine cultivars have been developed and are becoming more available. Phytic acid in most plant-based ingredients potentially binds with divalent cations such as Ca, Fe, Mg and Zn, reducing their bio-availability in animals. The phytic acid content of faba bean is 1.1% (DM) which is significantly less than other protein sources such as soybean meal and canola meal. The use of phytase in monogastric diets can minimize the negative effects of phytic acid.

Trypsin inhibitor (TI) can cause growth depression by interfering with the digestion and absorption of nutrients in the digestive tract, but the level of TIs in faba bean is low and therefore unlikely to have any negative effects in practical diets (Adamidou et al., 2011; Emire et al., 2016; Multari et al., 2015; Millar et al., 2019).

NUTRIENT COMPARISON WITH OTHER INGREDIENTS

Comparison of the nutrient composition among feed ingredients is crucial to investigate alternative feed components that are commonly used in feed rations. Crude protein content in faba bean was higher than feed pea but lower than soybean meal (Table 2.6). Faba bean has lower AMEn in poultry and NE in swine, compared to feed pea and corn but is similar to soybean meal.

Table 2.6 Nutrient composition (%, as fed) comparison of faba bean (all cultivars) with other ingredients (NRC 2012, NRC 1994)

Nutrient (%, as fed)	Faba bean	Soybean meal	Feed pea	Corn
Dry matter	88.12	88.79	88.10	88.31
AME_n, kcal/kg (poultry)	2249	2230	2709	3350
NE, kcal/kg (swine)	2143	2148	2419	2672
Crude protein	27.16	43.90	22.17	8.24
Ether extract	1.30	1.24	1.2	3.48
Crude fibre	8.55	6.60	6.16	1.98
Ash	3.43	6.38	2.86	1.30
Starch	39.22	1.89	43.46	62.55
Neutral detergent fibre	13.29	9.82	12.84	9.11
Acid detergent fibre	10.33	6.66	6.90	2.88

AME_n: Apparent metabolizable energy, N-corrected

NE: Net energy

3 Faba Bean Fractions Used in the Feed Industry

The global demand for high-quality plant protein products for both human and animal consumption has led to rapid growth in the pulse air classification industry. Air classification is a relatively simple process that separates particles by density and air resistance. This process results in two primary products: protein concentrate (protein fractions, 55 to 70% of protein, dry matter basis) and starch (starch fractions,18-25% of protein, dry matter basis). In 2020, air classified faba bean protein concentrate (Schedule IV number 4.6.46) and faba bean starch (4.6.48) were approved by the Canadian Food Inspection Agency as feed ingredients in Schedule IV, Feeds Regulations, 1983.

Faba bean fractions can be produced using two different techniques, air classification and aqueous extraction. Aqueous extraction methods include alkaline, neutral, or acid extraction, followed by isoelectric precipitation or ultrafiltration, resulting in highly purified protein and starch isolates. In air classification, legumes are milled, and the particles are separated based on size and density into protein and starch fractions, resulting in concentrates rather than isolates. Air-classification is less expensive compared to aqueous extraction due to the lower use of energy and being a relatively simple process design. However, aqueous extraction can be superior to air classification in terms of the purity of the fractions, and the effective removal of anti-nutrient factors (Vogelsang-O'Dwyer et al., 2020).

NUTRIENT COMPOSITION OF FABA BEAN FRACTIONS

The nutrient composition, amino acid profile and anti-nutrient content of faba bean protein concentrate (FBPC) are shown in Table 3.1, 3.2 and 3.3, respectively. Crude protein and amino acids are concentrated in faba bean protein fractions compared to whole faba bean (Table 3.1 and 3.2).

Table 3.1 Nutrient composition of faba bean protein concentrate (Gunawardena et al., 2010)

Nutrient	As fed (%) [a]	Dry matter (%)
Starch	1.30	1.45
Crude protein	63.0	70.7
Crude fibre	0.55	0.61
Ether extract	3.26	3.65
Ash	5.70	6.39
Ca	0.12	0.13
P	0.82	0.92

[a]10.9% moisture basis

Table 3.2 Amino acid profile of faba bean protein concentrate (Gunawardena et al., 2010)

Amino acid	As fed (%) [a]	Dry matter (%)
Arginine	5.47	6.13
Histidine	1.58	1.77
Isoleucine	2.58	2.89
Leucine	4.77	5.35
Lysine	4.18	4.69
Methionine	0.45	0.50
Phenylalanine	2.74	3.07
Threonine	2.20	2.46
Tryptophan	0.63	0.70
Valine	2.82	3.16
Alanine	2.51	2.81
Aspartic acid	6.70	7.51
Cysteine	0.70	0.78
Glutamic acid	10.20	11.44
Glycine	2.50	2.80
Serine	3.00	3.36
Tyrosine	2.11	2.36

[a]10.9 % moisture basis

The concentration of trypsin inhibitors is higher in faba bean protein concentrates than in whole faba bean (Table 3.3) due to the concentration of proteins. Nevertheless, the level of trypsin inhibitors is still much lower than the level in soybean meal, therefore, should not limit the utilization of FBPC in animal feeds.

Table 3.3 Anti-nutrient factors of zero-tannin faba bean protein fraction (with hulls) (Gunawardena et al., 2010)

Anti-nutrient factors	As fed (%)[a]	Dry matter (%)
Tannins,%	1.20	1.34
Trypsin inhibitor activity, mg/g	4.5	5.05

[a]10.9 % moisture basis

The nutrient composition, amino acid composition and the content of anti-nutrient factors in zero-tannin faba bean (var. Snowbird) starch fractions (FSC) are shown in Tables 3.4, 3.5 and 3.6, respectively. The content of starch is higher in the faba bean starch fraction than the whole faba bean (Table 3.4).

Table 3.4 Nutrient composition of zero-tannin faba bean starch concentrate (Gunawardena et al., 2010)

Anti-nutrient factors	As fed (%)[a]	Dry matter (%)
Starch	46.1	51.7
Crude protein	18.4	20.6
Crude fibre	8.61	9.66
Ether extract	0.96	1.07
Ash	2.44	2.73
Ca	0.13	0.14
P	0.27	0.30

[a]10.9 % moisture basis

Table 3.5 Amino acid profile of zero-tannin faba bean starch concentrate (Gunawardena et al., 2010)

Anti-nutrient factors	As fed (%)[a]	Dry matter (%)
Arginine	1.43	1.60
Histidine	0.46	0.51
Isoleucine	0.74	0.83
Leucine	1.32	1.48
Lysine	1.21	1.35
Methionine	0.13	0.14
Phenylalanine	0.76	0.85
Threonine	0.63	0.70
Tryptophan	0.16	0.17
Valine	0.83	0.93
Alanine	0.76	0.85
Aspartic acid	2.06	2.31
Cysteine	0.24	0.26
Glutamic acid	2.91	3.26
Glycine	0.81	0.90
Serine	0.76	0.85
Tyrosine	0.53	0.59

[a]10.9 % moisture basis

Table 3.6 Anti-nutrient factors of zero-tannin faba bean starch concentrate (with hulls) (Gunawardena et al., 2010)

Anti-nutrient factors	As fed (%)[a]	Dry matter (%)
Tannins,%	0.60	0.67
Trypsin inhibitor activity, mg/g	1.3	1.46

[a]10.9 % moisture basis

4 Faba Bean and Faba Bean Fractions in Poultry Diets

Faba bean can be used as a valuable source of protein, energy and other nutrients in poultry production. Older varieties of faba bean contained anti-nutrient factors, including tannins, protease inhibitors, vicine and convicine that affected nutrient utilization and performance. Tannins can reduce feed intake, protein digestibility, and energy utilization. However, selective breeding of faba bean has resulted in low tannin varieties, often called zero tannin, or white-flowered faba bean. These now comprise the vast majority of faba beans that are produced in Canada for feed applications.

PRACTICAL CONSIDERATIONS OF FEEDING FABA BEAN TO POULTRY

Faba beans are rich in lysine and arginine, although deficient in methionine, cysteine, and tryptophan. Therefore, faba bean can be incorporated with other ingredients having a high level of sulfur-containing amino acids (i.e., canola meal) while complementing the low levels of lysine and arginine in other ingredients. The presence of glycosides, vicine, and convicine affects the metabolism of laying hens, causing reduced egg size and feed intake, currently restricting the amount that can be practically used in these rations. However, faba bean cultivars having low vicine and convicine content are now becoming available in the feed industry to be used for laying hen feed. Faba bean can be included in poultry diets at the following inclusion levels (Table 4.1).

Table 4.1 Recommended dietary low-tannin faba bean levels in poultry

Type of poultry	Recommended level in the diet (%)
Layers	15
Broiler chickens	30
Turkeys	30

PROCESSING

The processing of faba bean seeds has shown improved animal performance and nutrient utilization by reducing or eliminating anti-nutrient factors in faba beans.

Extrusion of faba bean increased apparent metabolizable energy corrected for nitrogen (AMEn) and apparent total tract ether extract digestibility in broiler chickens given 40% low-tannin faba bean based diets (Hejdysz et al., 2016). This was attributed to reduced phytic acid, trypsin inhibitors and resistant starch content in low-tannin faba bean as reported in the same study (Hejdysz et al., 2016).

The incorporation of micronized-dehulled faba bean meal (31% in broiler diets; 15% in laying hen diets), as a substitute for soybean meal, did not affect broiler growth performance and meat quality (Laudadio et al., 2011), and laying hen performance, egg quality and feed conversion ratio at 10 weeks (Prothabat variety, no indication on tannin levels) was also not impacted (Laudadio and Tufarelli, 2010). According to Luo and Xie (2013), processing methods, including soaking, microwaving, ordinary cooking and autoclaving, increased the in vitro protein digestibility of both green and white faba beans.

BROILER CHICKENS

Faba bean is a significant source of protein for broiler chickens. The digestibility of lysine in low tannin varieties is excellent in broiler chickens.

It has been proven that apparent ileal digestibility values of amino acids in zero-tannin faba bean were higher than tannin-containing faba beans and comparable to soybean meal (Woyengo and Nyachoti, 2012). Therefore, zero-tannin faba bean is a better source of amino acids for poultry than tannin-containing varieties.

Zero-tannin faba beans can be added to broiler diets at relatively high levels (Table 4.2). Previous studies have shown that up to 36% faba bean can be fed to broiler chickens assuming the AMEn and digestible lysine levels are maintained (Cho et al., 2019). According to Diaz et al. (2006), dietary inclusion of 50% faba bean (0.05% condensed tannin level, as fed) did not affect body weight gain and feed intake of broiler chickens compared to a soybean meal control diet. This agrees with work by Nalle et al., (2010) and Usayran et al., (2014), who observed no negative effect of up to 30% low-tannin faba bean on broiler performance (Nalle et al., 2010;Usayran et al., 2014).

High temperatures used for pelleting can reduce the anti-nutrient factors, resulting in increased nutrient utilization and performance in broilers. For example, Ivarsson and Wall (2017) found the inclusion of white-flowered faba bean (low tannin) up to 20% in broiler diets did not affect broiler performance when the diets were pelleted, whereas the feed intake was lower in mash diet. The addition of 31% micronized faba bean (var. Prothabat) in broiler diets did not negatively affect bird performance and carcass traits compared to soybean meal. This was attributed to the reduction of anti-nutrient factors due to dehulling and micronization of faba beans (Laudadio et al., 2011).

Table 4.2 Effect of dietary low-tannin faba bean inclusion on broiler chicken performance and nutrient utilization (Nalle et al., 2010)

Item		Low tannin faba bean cultivar			
		PGG Tic	Spec Tic	South Tic	Broad
Ingredient, %					
Maize	56.7	44.8	42.4	46.2	44.8
Soybean meal	31.7	22.6	23.5	22.3	22.6
Faba bean	0.0	20.0	20.0	20.0	20.0
Soybean oil	0.60	1.52	3.04	0.50	1.52
L-Lysine HCl	0.11	0.12	0.11	0.11	0.12
DL-Methionine	0.29	0.35	0.36	0.36	0.35
Nutrient, %					
AME_n, kcal/kg	2913	2913	2913	2913	2913
Crude protein	24.5	24.7	24.7	24.6	24.7
Digestible Lysine	1.25	1.25	1.25	1.25	1.25
Digestible Met+Cys	0.88	0.89	0.89	0.90	0.88
Performance[a]					
Weight gain, g/bird	933	973	978	967	948
Feed intake, g/bird	1240	1270	1247	1248	1254
Feed per gain	1.328	1.306	1.275	1.291	1.325

AME_n: Apparent metabolizable energy, N-corrected

[a]P>0.05

LAYERS

Few laying hen production studies with the use of faba bean, especially those describing the tannin levels, are available in the literature. Based on the findings of Abd El-Hack et al., (2017) and Fru-Nji et al., (2007) faba bean can be included up to 16% of the diet without negatively affecting egg production (Table 4.3). In another study, the highest values for hen-day laying rate, egg mass and feed efficiency were reported for 25% replacement of soybean meal by faba bean (5.5% in total diets), however complete replacement of soybean negatively affected these production parameters (Alagawany et al., 2019). Therefore, until more research is available on the use of new improved varieties of faba bean in laying hen diets, limited amounts of faba bean should be used in this application.

Table 4.3 Effect of faba bean inclusion level in the diet on laying hen performance (Fru-Nij, 2007)

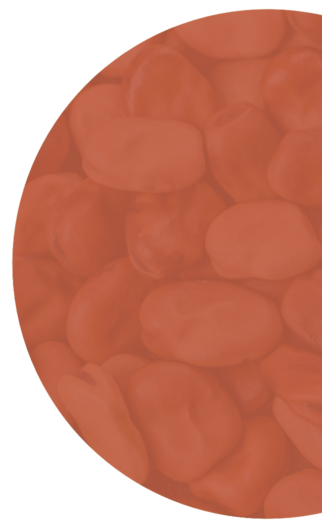
Item	Faba bean level (%)					
	0	8	16	240	320	400
Ingredient, %						
Faba bean	0	8	16	24	32	40
Wheat	66.6	61.9	57.1	52.1	47.6	42.9
Soybean meal	17.4	13.8	10.4	7.0	3.5	0
Vegetable oil	3.0	3.2	3.4	3.8	3.8	3.9
DL-Methionine	0.0	0.04	0.07	0.09	0.11	0.13
Nutrient, %						
Crude protein	18.2	18.2	18.3	18.5	18.6	18.6
GE, kcal/kg	4111	4159	4135	4111	4111	4111
Hen-day egg production, %	85.3[a]	87.1[a]	85.2[a]	78.2[b]	77.2[bc]	74.9[c]
Egg mass, g egg/(hen*day)	50.8[a]	52.6[a]	49.8[ab]	46.3[b]	44.6[bc]	43.5[c]
Weight gain, g/hen	287[c]	353[abc]	371[abc]	429[a]	386[ab]	314[bc]
Feed/egg, g/g	2.19[c]	2.19[c]	2.28[bc]	2.46[ab]	2.56[a]	2.58[a]

Values within a row not sharing a common superscript are significantly different ($P<0.05$)

GE: Gross energy

TURKEYS

Low tannin faba beans can be effectively used in turkey diets primarily as a source of protein. According to Przywitowski et al. (2016), both low- and high tannin (condensed tannins: 0.08 and 0.80%, respectively) faba beans can be included in turkey finisher diets up to 30% as a substitution for soybean meal without negatively affecting performance, carcass traits or breast meat quality parameters. However, tannins in earlier high tannin varieties reduce protein retention. Therefore only low tannin varieties should be used in turkey diets (Mikulski et al. (2017).



5 Faba Bean and Faba Bean Fractions in Swine Diets

Soybean meal is a commonly used protein source in pig diets due to the favorable nutrient profile. However, finding alternative protein ingredients, including faba beans for swine diets, is important in terms of food security and sustainability.

PRACTICAL CONSIDERATIONS OF FEEDING FABA BEAN TO PIGS

The main issue of feeding faba bean to pigs is tannin in the seed coat that affects the utilization of amino acids and energy in the swine diet. However, this problem can be solved by either dehulling faba bean seed or using low tannin varieties. As discussed above in the poultry section, the availability of tannin-free faba bean cultivars is an important advancement for their utilization in monogastric diets.

Similar to other pulses, it is important to use net energy (NE) when formulating faba bean-based diets for swine. It is recommended to formulate the diets for NE and to ensure that the ratio of standardized ileal lysine digestibility and energy is in an optimal range to minimize the negative effects on performance. If the NE system was used (Table 5.1), research indicates that faba bean can be fed to pigs in different stages at the following levels (Zijlstra et al., 2008; Beltranena et al., 2009; Degola and Jonkus, 2018).

Table 5.1 Recommended dietary low-tannin faba bean levels in swine

Type of swine	Recommended level in the diet (%)
Starter pigs	30
Growing and finishing pigs	30
Sows	15

STARTER DIETS

Research is limited regarding faba bean in starter pig diets. The inclusion of zero-tannin faba bean up to 40% in the diet by substituting for soybean meal did not affect weight gain, feed intake or feed conversion of starter pigs (5 wks old) for the entire 21d period when the diets were balanced for net energy, standardized ileal digestible lysine, and other amino acids as a ratio to lysine (Table 5.2). Further, apparent total tract digestibility of crude protein and P increased with the increasing level of faba bean (Beltranena et al., 2009).

Table 5.2 Effect of low-tannin faba bean levels in the diet on growth performance of starter pigs (Beltranena et al., 2009)

Item	Low tannin faba bean (%)				
	0	10	20	30	40
Ingredient, %					
Wheat	62.88	57.55	52.63	47.84	42.95
Soybean meal	22.10	16.60	11.10	5.50	0.00
Faba bean	0.00	10.00	20.00	30.00	40.00
Canola oil	1.10	1.80	2.10	2.40	2.70
L-Lysine HCL	0.15	0.15	0.15	0.15	0.15
DL-Methionine	0.00	0.02	0.04	0.06	0.09
Nutrient, %					
GE, kcal/kg	3606	3606	3658	3670	3645
NE, kcal/kg*	2374	2408	2421	2435	2449
Crude protein, %	23.81	22.61	21.99	21.40	21.40
Growth Performance[a]					
Average daily feed intake, g					
0-7 d	670	638	637	614	621
7-14 d	890	859	870	868	849
14-21 d	1079	1025	1024	1020	1056
0-21 d	879	841	844	835	842

Table 5.2 Effect of low-tannin faba bean levels in the diet on growth performance of starter pigs (Beltranena et al., 2009) (Continued)

Item	Low tannin faba bean (%)				
	0	10	20	30	40
Average daily gain, g					
0–7 d	487	455	458	463	455
7–14 d	581	569	575	580	554
14–21 d	666	677	657	664	692
0–21 d	579	572	560	556	569
Feed efficiency					
0–7 d	0.73	0.72	0.72	0.75	0.73
7–14 d	0.66	0.67	0.66	0.67	0.66
14–21 d	0.62	0.67	0.65	0.65	0.66
0–21 d	0.67	0.68	0.68	0.70	0.68

*Calculated based on NRC 2012 and Zijlstra et al. 2008. Diets also contained 5.0% whey and 6.0 % fishmeal. [a]P>0.05

GROWER AND FINISHER DIETS

According to Zijlstra et al. (2008), zero-tannin faba bean inclusion up to 30% in the diet did not affect average daily feed intake and gain in grower-finisher pigs. However, feed efficiency was lower in the pigs given faba bean compared to soybean meal diets. The loin depth was also lower in faba bean treatments. The diets had been formulated to contain the same net energy and standardized ileal digestible amino acid content, as shown in Table 5.3.

Table 5.3 Effect of dietary zero-tannin faba bean on grower and finisher pig performance and carcass quality (Adapted from Zijlstra et al. 2008)

Item	Grower (35-60kg)		Early Finisher (60-90kg)				Late Finisher (90kg to slaughter)			
			Gilt		Barrow		Gilt		Barrow	
	Faba	SBM	Faba	SBM	Faba	SBM	Faba	SBM	Faba	SBM
Ingredient, %										
Barley	–	–	37.21	27.68	37.43	27.16	48.08	40.30	72.86	66.75
Wheat	59.66	75.56	29.00	53.74	29.70	54.38	23.30	43.73	3.60	19.80
Faba bean	30.00	–	30.00	–	29.30	–	25.00	–	20.00	–
SBM	5.90	20	–	15.00	–	15.00	–	12.50	–	10.00
Calculated Nutrients, as fed										
NE, kcal/kg	2400	2400	2380	2380	2380	2380	2380	2380	2350	2350
SID Lysine, %	0.95	0.95	0.75	0.75	0.66	0.66	0.69	0.69	0.60	0.60
Calcium, %	0.74	0.74	0.65	0.65	0.65	0.65	0.63	0.63	0.63	0.63
Available P, %	0.30	0.30	0.32	0.32	0.32	0.32	0.28	0.28	0.28	0.28

Table 5.3 Effect of dietary zero-tannin faba bean on grower and finisher pig performance and carcass quality (Adapted from Zijlstra et al. 2008)

Total growth performance					
Item	**Grower (35-60kg)**			**Early Finisher (60-90kg)**	
	Gilt			**Barrow**	
	Faba	**SBM**		**Faba**	**SBM**
ADG, kg/d	0.977	0.961		1.004	1.017
ADFI, kg/d	2.552	2.491		2.922	2.878
Feed efficiency	0.388	0.392		0.354	0.365
Final BW, kg	102.81	102.04		107.80	109.99
Carcass characteristics					
Dressing, %	78.4	80.3		79.2	80.0
Back fat, mm	16.7	16.0		20.8	19.0
Loin depth, mm	64.1	69.1		58.3	61.2
Lean yield, %	61.3	62.2		59.5	60.4

SBM: Soybean meal; SID: Standardized ileal digestibility; NE: Net energy; ADG: Average daily gain; ADFI: Average daily feed intake; BW: Body weight

BREEDING SWINE DIETS

Faba beans can partially replace soybean meal at a moderate level in breeding swine diets. Gestating and lactating sows given 12 and 14% high- or low-tannin faba bean in the diets as a substitution for soybean meal had comparable reproductive rates and litter weight and piglet body weights, as shown in Table 5.4 (Swiatkiewicz et al., 2018).

Table 5.4 Effect of dietary high/low-tannin faba bean on pregnant and lactating sow reproductive performance (Swiatkiewicz et al., 2018)

Item	Pregnant sows			Lactating sows		
	SBM	HT-FB	LT-FB	SBM	HT-FB	LT-FB
Ingredient, %						
Soybean meal	6	2	2	18	13	13
Faba bean	0	12	12	0	14	14
Wheat	30	30	30	30	30	30
Barley	36.9	28.9	28.9	33.3	30.2	21.3
Nutrient, %						
ME, kcal/kg	2985	2985	2985	3057	3081	3057
Crude protein	13.4	13.6	13.5	17.6	17.6	17.5
Lysine	0.60	0.61	0.61	0.92	0.94	0.94
Methionine + Cysteine	0.46	0.44	0.43	0.55	0.53	0.51
Tryptophan	0.17	0.16	0.15	0.23	0.21	0.21
Threonine	0.45	0.45	0.45	0.60	0.60	0.60

Reproductive rates, kg	SBM	HT-FB	LT-FB
BW at mating	163.6	160.9	163.0
BW after farrowing	172.6	178.2	180.7
BW at weaning	142.4	154.3	154.2
Mean feed consumption	525.7	511.4	507.6
Number of piglets weaned per litter	10.0	9.9	9.5

Table 5.4 Effect of dietary high/low-tannin faba bean on pregnant and lactating sow reproductive performance (Swiatkiewicz et al., 2018) (Continued)

Ingredient, %	**SBM**	**HT-FB**	**LT-FB**
Litter weight	13.90	13.96	13.68
BW of piglets at 1 d	1.39	1.41	1.44
BW of piglets at 35 d	7.28^{a}	8.08^{b}	7.81^{b}
ADG: 1-35 d	0.173^{b}	0.196^{b}	0.188^{ab}

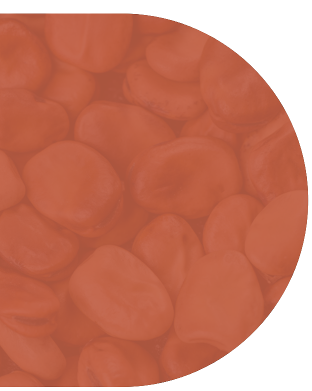
SBM: Soybean Meal; HT-FB: High-tannin faba bean; LT-FB: Low-tannin faba bean

BW: Body weight; ADG: Average daily gain

Values within a row not sharing a common superscript are significantly different ($P<0.05$)

FABA BEAN FRACTIONS FOR SWINE DIETS

Air classification of faba bean generates protein and starch fractions. Limited research has been conducted on the utilization of faba bean fractions in swine diets. The inclusion of air-classified faba bean protein concentrate in the diet (35%) increased apparent total tract digestibility and apparent ileal digestibility of energy, protein and amino acids in grower pigs compared to pigs given soy concentrate based diet. Further, the starch in faba bean starch concentrate (93.27%) was also highly digestible in grower pigs, although it was not comparable to corn starch concentrate (Gunawardena et al., 2010).



6 Faba Bean in Ruminant Diets

Faba bean is an excellent ingredient option for various classes of cattle. The beans contain protein levels between 25–33% DM, and starch levels between 40–49% DM (Heuzé et al., 2018), making them a potential substitute for ingredients such as soybean meal, canola meal, corn, or cereal grains. To date, faba bean research has focused on dairy cow applications; however, there are clear opportunities for incorporating faba beans into calf and beef cattle diets as well.

PRACTICAL CONSIDERATIONS FOR FEEDING FABA BEANS TO CATTLE

Table 6.1 Maximum feeding recommendations for faba beans in ruminant diets.

Animal Type	Maximum % of diet DM	Special Considerations
Nursing calves over 2 months of age	10	• Low-tannin varieties
Weaned calves	10	• Low-tannin varieties • Heat processing tannin-containing varieties recommended
Backgrounding beef cattle	20	
Finisher beef cattle	20	
Lactating dairy cattle	20	• Heat processing at >130 °C recommended to reduce rumen degradation of crude protein and increase rumen escape starch • Supplemental lysine and methionine may be required when replacing protein sources like soybean meal and canola meal with pulse grains

RUMEN DEGRADABILITY OF RAW FABA BEANS

Faba bean protein is highly degradable within the rumen, regardless of tannin content (Table 6.2). The protein is comprised primarily of albumin (water soluble) and globulin (salt soluble), which contributes to its high rate of rumen degradation (Yu et al., 1998 and 2002). Soluble protein can be effectively used for rumen microbial protein synthesis when combined with fermentable carbohydrates.

Faba bean starch is also highly degradable within the rumen (Table 6.3). The starch degradation rates of faba beans range between 5.0–14.7%/hr, and the starch degradability ranges between 71–92% of total starch (Yu et al., 2002; Rodriguez Espinosa, 2018).

Table 6.2 Rumen degradation of crude protein (CP) of different faba bean varieties grown in western Canada (Rodriguez Espinosa, 2018)

Tannin Classification	Variety Name	CP (%DM)	S (%)	D (%)	Kd (%/hr)	RUP (%)
Low tannin						
	Snowbird	27.1	43.2	56.8	10.6	5.6
	Snowdrop	28.7	37.2	62.8	10.4	6.6
	219_16	28.5	37.3	62.7	10.8	6.4
Normal tannin						
	Fatima	28.3	40.4	59.6	10.2	6.3
	Vertigo	26.8	37.7	62.3	9.9	6.3
	FB9_4	29.0	39.3	60.7	10.3	6.5
	346_10	29.5	34.5	65.6	11.4	6.8
	SSNS_1	28.6	33.6	66.4	9.2	7.5

S: soluble fraction – % of crude protein

D: potentially degradable fraction– % of crude protein

Kd: rate of degradation– % of crude protein/hour

RUP: rumen undegraded crude protein– % of crude protein

As previously discussed, condensed tannins (secondary compounds with antinutritional properties) can influence the degradation and digestibility of faba bean nutrients. When condensed tannins are present in the rumen, it can form tannin-protein complexes. These complexes may reduce the rate of rumen protein degradability (Mangan, 1988; Hagerman et al., 1992; Frutos et al., 2004), but there is little evidence of faba bean tannins affecting cattle performance. More research is needed to better understand the effects of faba bean tannins on the degradation of nutrients in the rumen and animal performance.

Table 6.3 Rumen degradation of starch of different faba bean varieties grown in western Canada (Rodriguez Espinosa, 2018)

Tannin Classification	Variety Name	Starch (%DM)	S (%)	D (%)	Kd (%/hr)	RUSt (%)
Low tannin						
	Snowbird	36.8	32.5	67.5	13.8	8.4
	Snowdrop	38.7	31.5	68.5	13.5	9.1
	219_16	36.8	26.9	73.1	11.4	10.3
Normal tannin						
	Fatima	35.8	32.5	67.7	14.7	7.8
	Vertigo	35.9	29.0	71.0	13.0	9.0
	FB9_4	34.3	32.4	67.6	13.7	7.9
	346_10	35.4	35.6	64.4	15.6	7.0
	SSNS_1	34.5	26.9	73.1	10.6	10.1

S: soluble fraction - % of total starch

D: potentially degradable fraction- % of total starch

Kd: rate of degradation- % of total starch

RUSt: rumen undegraded starch- % of total starch

PROCESSING FABA BEANS FOR RUMINANT DIETS

Feed processing methods can be used to improve the nutritional value and rumen degradation characteristics of faba beans. Extruding faba beans increased amino acid availability in the small intestine of dairy cattle (Benchaar et al., 1994). Table 6.4 describes the results of other studies reporting reduced protein degradation rates in faba beans following heat treatments. Starch degradability is also reduced through heat processing (Table 6.5). Dry roasting faba beans at temperatures > 130 °C for 45 minutes increase levels of starch escaping the rumen (Yu et al., 1998). However, roasting did not improve milk production or nitrogen efficiency (Hansen et al., 2021).

Table 6.4 Effects of heat treatment on rumen degradable crude protein (CP) characteristics in faba beans (adapted from Yu et al., 2002)

Treatment	Temp /Time	CP (% DM)	S (%)	D (%)	Kd (%/hr)	RUP (%)
Extruded	Raw	28.8	67.9	31.1	13.1	10.8
	120°C /NR	29.9	38.5	60.6	6.6	29.8
Autoclaved	Raw	34.1	33.1	66.2	8.6	14.3
	120°C/30 mins	34.1	15.3	84.7	4.1	27.8
Roasted	Raw	NR	49.0	50.7	21.4	11.3
	130°/30 mins	NR	47.1	52.6	19.4	12.8
	150°C/30 mins	NR	35.7	64.3	10.4	23.5

NR = Not reported

S: soluble fraction – % of crude protein

D: potentially degradable fraction– % of crude protein

Kd: rate of degradation– % of crude protein/hour

RUP: rumen undegraded crude protein– % of crude protein

Table 6.5 Effect of dry roasting whole faba beans on rumen degradation characteristics of starch (adapted from Yu et al., 1998)

	Raw	110°C	130°C	150°C
S (%)	50.9	52.7	39.7	24.8
D (%)	49.9	47.3	60.3	75.2
Kd (%/ hour)	9.8	10.6	9.7	6.6
RUSt (%)	23.9	22.4	27.0	39.4

S: soluble fraction – % of total starch

D: potentially degradable fraction– % of total starch

Kd: rate of degradation– % of total starch

RUSt: rumen undegraded starch– % of total starch

Processing is also useful for managing antinutritional factors present in faba beans. In high concentrations, condensed tannins may reduce feed intake in cattle (Frutos et al., 2004), which is of particular concern for growing calves. Processing by extrusion reduced the activity of condensed tannins in feed products up to 83% (Imran et al., 2014; Moats et al., 2018). Therefore, the application of heat processing may be useful when considering conventional faba beans for use in calf diets. However, increasingly, the primary varieties sold into the feed market are low tannin varieties, so processing is not required

There is limited information on the benefits of mechanically processing faba beans; however, rolling the beans may improve nutrient digestibility in beef cattle. Early work on faba beans in finishing cattle reported a 10% improvement in total tract digestibility of nutrients when faba beans were fed dry-rolled versus whole (MacLeod, 1972).

FABA BEAN IN DAIRY COW DIETS

Faba beans can be used as an effective protein and starch source for lactating dairy cows when fed up to 20% of the diet DM. Heat processing the beans is recommended for high producing dairy cattle to increase rumen escape starch and support the endogenous synthesis of glucose and lactose, substrates that drive milk yield (Masoero et al., 2006). Faba beans have lower methionine concentrations than canola or soybean meals and thus, diets should account for this difference. Most of the research available on the use of faba beans in dairy rations focuses on early-lactation and uses older high tannin varieties. While more research using western Canadian faba bean varieties is warranted, the data available suggests that faba beans can replace soybean meal and other protein sources in lactating dairy cow rations.

There is a misconception that faba beans reduce DMI, especially if the variety of faba bean contains greater concentrations of tannins. While the tannin content of faba beans can vary, research suggests that DMI in dairy cattle is not affected (Heuzé et al., 2017). Early-lactating Holstein dairy cows had similar DMI when raw, tannin-containing faba beans replaced soybean meal, rapeseed meal and wheat in the concentrate (Johnston et al., 2019). Others have reported similar results. Therefore, faba beans can be considered a palatable ingredient that will not reduce feed intake (Tufarelli et al., 2012; Volpelli et al., 2016; Cherif et al., 2018; Mendowski et al., 2019).

Faba beans can effectively replace soybean meal in dairy rations (Table 6.6). Substituting soybean meal for coarsely ground faba beans at an inclusion rate of 17% of ration DM did not impact milk or milk component yields in Holstein dairy cattle (Cherif et al., 2018). These results are supported by other studies that replaced soybean meal with either raw, steam-flaked, coarsely ground, or extruded faba beans (Tufarelli et al., 2012; Volpelli et al., 2016; Mendowski et al., 2019).

Whenever one feed ingredient replaces another, the dairy cow diet should be adjusted to compensate for differences in ingredient nutritional profiles. For example, one study reported decreased milk fat and milk protein yields when faba beans replaced soybean meal and canola meal up to 40% of ration DM (Johnston et al., 2019). Another study reported reduced milk yields when faba beans replaced rapeseed meal up to 18% of ration DM (Puhakka et al., 2016). In both cases, deficits in limiting amino acids (particularly methionine) were believed to be the reason for reduced milk yields and milk proteins (Puhakka et al., 2016; Johnston et al., 2019), while an increase in total dietary starch was believed to have contributed to reduced milk fat yields (Johnston et al., 2019).

Table 6.6 Effects of faba bean inclusion on lactating dairy cow performance" (Hugman et al., 2020)

Form	Processing Conditions	Treatment Details	Inclusion level (%DM)	Milk Yield (kg/d)	Milk Fat Yield (kg/d)	Milk Protein Yield (kg/d)	Reference
Early Stage of Lactation							
Raw	N/A	Control	0	29.7	0.93	0.88	Mendowski et al., 2019
		Faba bean blend (90% faba bean + 10% linseed) replacing soybean meal & corn	25	28.7	0.99	0.84	
Raw	N/A	Control	0	35.7	1.52	1.20	Johnston et al., 2019
		Faba bean replacing soybean meal, canola meal, wheat & corn	20	33.2	1.39*	1.11*	
		Faba bean replacing soybean meal, canola meal, wheat & corn	40	33.9	1.39*	1.09*	
Coarsley ground	N/A	Control	0	27.2	0.99	0.86	Tufarelli et al., 2011
		Faba bean replacing soybean meal & corn	20	27.1	0.96	0.85	
Pelleted	Steam conditioned at 100˚C for 25 mins; pelleted at 80˚C	Control	0	32.0	1.29	1.08	Puhakka et al., 2016
		Faba bean replacing rapeseed meal	9	31.1	1.30	1.02*	
		Faba bean replacing rapeseed meal	18	28.9*	1.23	0.933*	

Table 6.6 Effects of faba bean inclusion on lactating dairy cow performance" (Hugman et al., 2020)

Form	Processing Conditions	Treatment Details	Inclusion level (%DM)	Milk Yield (kg/d)	Milk Fat Yield (kg/d)	Milk Protein Yield (kg/d)	Reference
Early Stage of Lactation							
Extruded	Extrusion temperature of 140°C	Control	0	29.7	0.93	0.88	Mendowski et al., 2019
		Faba beans blend (90% faba bean + 10% linseed) replacing Soybean meal & corn	25	31.5	0.90	0.91	
Mid-late Stage of Lacation							
Coarsely ground	1.00 to 0.50-mm particle size	Control	0	36.5	1.43	1.25	Cherif et al., 2018
		Faba bean replacing soybean meal & corn	17	35.8	1.38	1.21	
Rolled	2.00-mm particle size	Control	0	36.5	1.43	1.25	Cherif et al., 2018
		Faba bean replacing soybean meal & corn	17	36.0	1.40	1.22	
Steam-flaked	N/A	Control	0	22.2	0.86	0.75	Volpelli et al., 2016
		Faba bean replacing soybean meal & corn	10	22.4	0.88	0.75	

N/A= information not available

* Statistically different from control

FABA BEAN IN BACKGROUNDING AND FINISHING BEEF CATTLE DIETS

There is little information on the use of faba beans in beef cattle diets, especially as it relates to western Canadian varieties of the crop. However, a few studies conducted in Italy give us insight into the bean's potential.

The growth rate, feed efficiency, and carcass quality of Marchigiana bulls were maintained when fed either faba beans or soybean meal as the main protein source from weaning to slaughter (Cutrignelli et al., 2008). Meat quality was unaffected in Mediterranean Buffalo when low-tannin faba beans replaced soybeans up to 28% of diet DM (Calabrò et al., 2014). Overall, these studies suggest that faba beans can be used as an alternative protein source in growing and finishing beef cattle diets.

FABA BEAN IN CALF DIETS

Very little information is available on the use of pulse seeds in pre-ruminant calves. One older study suggested that pea protein concentrates could replace up to 30% of the protein in milk replacer for Holstein calves less than 45 days of age (Mbugi et al., 1989). However, a review evaluating the use of pulse protein isolates in milk replacers indicates that calf performance may be compromised due to the calf's reduced ability to digest pulse proteins at that age (Lalles, 1993). Therefore, until further research can refine these recommendations the use of faba beans in calf diets is only proposed for animals over 2 months of age.

For older calves, there is limited information on the use of faba beans in calf starter or creep feeds. This might be partially explained by concerns related to the antinutritional effect of tannins on calf performance. However, advances in crop genetics have yielded several low-tannin faba bean varieties and they now comprise the majority of production in Canada and have been demonstrated to be suitable for use in other livestock species typically sensitive to tannins (Zijlstra, 2004).

Early work demonstrated that low-tannin faba beans can be used as an alternative protein source in calf diets up to 30% of diet DM. Young calves (weighing 50 kg) maintained daily live weight gains when faba beans replaced soybeans and fish meal at 30% of diet DM (MacLeod, 1972). Similarly, replacing soybean meal with faba beans (up to 30% of diet DM) in the starter feed of bottle-fed Holstein calves did not affect growth performance or feed intake (Ingalls et al., 1980).

7 Faba Bean and Faba Bean Protein Concentrate in Aquafeed

Faba beans are an emerging protein and energy source as an aquafeed ingredient. They are high in lysine and are palatable (Hodgson, 1974). Weight gain in fish is positively correlated with faba beans fed at or below ideal dietary inclusion levels for that species. Optimal feeding rates for plant protein products vary among fish species and research regarding faba beans as an aquafeed ingredient is ongoing. Table 7.1 provides a compilation of production data related to the dietary inclusion levels of faba bean protein products on fish performance.

PRACTICAL CONSIDERATIONS OF FEEDING FABA BEANS IN AQUACULTURE

As with all plant-based feed ingredients, the anti-nutrients in faba beans must be considered when formulating diets. These include tannins, vicine, convicine, phytoestrogens, trypsin inhibitors, and haemagglutinins (Caygill and Mueller-Harvey, 1999; Duc et al., 1999; Gatta et al., 2013). Faba bean varieties low in tannins and other anti-nutrients, such vicine and convicine, have been developed through genetic improvements. Faba bean protein concentrate (FBPC; 64.4% CP; Collins et al., 2006) and faba bean protein isolate (77.8% CP; De Santis et al., 2016b) are additional high-protein options for use in fish diets.

The starch composition of whole faba beans ranges from 41.2-42.7%. Low tannin faba beans tend to be slightly higher in starch (Duc et al., 1999). Dehulling will also increase starch content (42.6% vs 49.7%; Kraugerud et al., 2011). Provided the correct extrusion parameters are met, the starch in faba beans has the capacity to gelatinize and form an expanded pellet, or conversely, expansion may be reduced to increase pellet durability (Kraugerud et al., 2011). Heat-treating faba beans also improve the digestibility of nutrients, such as lipids, which has been observed in Nile tilapia and rainbow trout (Collins et al., 2006).

Faba beans and faba bean products have been successfully included in aquafeeds at the following inclusion levels (Table 7.1). Further research into feed processing techniques may provide production data for fish performance at higher dietary inclusion levels of faba beans and faba bean protein products.

Table 7.1 Range of dietary inclusion levels tested and maximum dietary inclusion levels of faba bean products recommended for use in aquaculture species.

Fish species	Faba bean product	Levels tested	Maximum levels recommended	Notes	Reference
Tilapia					
Juvenile Nile tilapia	Faba bean meal (high tannin variety)	12–36%	24%	Isonitrogenous, isolipidic diets	Azaza et al., 2009
Cyprinids					
Grass carp (crisp grass carp)	Faba bean (unknown variety; assumed high tannin)	100%	N/A	Upregulation of muscle firmness and calcium metabolism genes and downregulation of glycolysis/ gluconeogenesis pathway genes	Yu et al., 2014
Yellow river carp (crisp carp)	Faba bean (unknown variety; assumed high tannin) soaked in water 12h, then broken into pieces	100%	N/A	Muscle and fillet quality tested	Song et al., 2020

Table 7.1 Range of dietary inclusion levels tested and maximum dietary inclusion levels of faba bean products recommended for use in aquaculture species. (Continued)

Fish species	Faba bean product	Levels tested	Maximum levels recommended	Notes	Reference
Salmonids					
Rainbow trout (fingerlings)	Dehulled faba bean meal (low tannin product)	15–45%	15%	Isonitrogenous, isolipidic diets	Ouraji et al., 2013
Atlantic salmon	Faba bean protein isolate (low tannin product)	7–14%	14%		De Santis et al., 2016
Atlantic salmon	Faba bean protein concentrate (air-classified; low tannin product)	8.6–77.4%	5–20% (optimal) 34% (maximum)	16 diets with equal nutrient composition	De Santis et al., 2015

N/A: Data was not provided or not extractable.

GROWTH, DEVELOPMENT AND FILLET QUALITY OF FISH FED FABA BEANS

“Crisp,” or, “crispy,” carp are carp (ex. grass and Yellow River carp) that have had faba beans included in their rearing diets, resulting in improved fillet quality and texture in both raw and cooked fillets (Song et al., 2020). These favorable sensory characteristics include hardness, springiness and chewiness. This is due to compact muscle tissue caused by a high density of small-diameter muscle fibers, increased intramuscular collagen and reduced water-holding capacity (Ma et al., 2020; Song et al., 2020; Tian et al., 2020; Xu et al., 2020; Tian et al., 2019; Yu et al., 2014).

The mechanisms behind this phenomenon involve decreased protein levels in the mitochondrial electron transport chain, decreased creatine metabolism, and abnormal energy metabolism. This redirects fat accumulation from the muscle to the hepatopancreas and mesenteric adipose tissue (Tian et al., 2020).

Faba beans are low in methionine and cystine (Hodgson, 1974), which must be taken into account during feed formulation. Feeding 100% faba bean diets will reduce fish growth, and may increase mortalities, as compared with fish fed a nutritionally balanced diet due to a deficiency of sulfuric amino acids (Song et al., 2020; Tian et al., 2020).

Processing techniques provide opportunities to achieve the improved textural benefits from feeding faba beans, while optimizing carp growth. Ma et al. (2020) determined that diets containing faba bean produced by either alcohol extraction or water extraction significantly improved weight gain, while increasing textural parameters, texture quality, collagen content, and fiber density in crisp grass carp. Further research involving faba bean products in combination with a nutritionally balanced diet may maintain fillet crispiness and muscle firmness, while maintaining fish growth and reducing mortality.

Dietary inclusion levels of faba bean meal (high tannin variety) up to 24% corresponded well with growth and feed conversion in juvenile Nile tilapia (Azaza et al., 2009). Beyond this level, growth performance may be negatively affected, which can be linked to reduced feed intake or, higher levels of anti-nutrients (such as condensed tannins), impairing the absorption of essential amino acids and reduced palatability (Azaza et al., 2009).

In carnivorous species (salmonids), research suggests an inclusion level of 5-20% faba bean protein products will not negatively impact development and performance. High (45%) dietary inclusion levels of faba bean impaired growth performance in rainbow trout fingerlings (Ouraji et al., 2013). An optimal dietary inclusion level of 21% air-classified FBPC (Faba Bean Protein Concentrate) is recommended for post-smolt Atlantic salmon. FBPC can be used as a substitute for fish meal and soy protein concentration without compromising fish performance up to a maximum dietary inclusion of 34% FBPC. Higher FBPC dietary inclusion levels result in mild intestinal inflammation in Atlantic salmon, although not as excessively as when similar levels of soy protein concentrate are fed (De Santis et al., 2015).

SUMMARY RECOMMENDATIONS

The sustainable use of plant-based feed ingredients in aquaculture diets is an important area of research that is dependent on aquaculture species, environment, and economics. Dietary inclusion levels of faba beans in aquaculture diets may be informed by the research summarized in this guide. In many fish species, when fed at optimal inclusion levels, growth and survival rate are unaffected by dietary faba beans. Continued research in this area would be beneficial to fish producers in order to achieve ideal fillet quality and texture, health, and growth. To achieve maximum fish production, quality, and nutrition, the combination of feed ingredients in the development of plant-based aquaculture diets should be well-formulated and monitored.

Table 7.2 Specific growth rate (SGR), feed conversion ratio (FCR) and additional production data associated with aquaculture species fed faba bean protein products

Fish species	Faba bean product	Dietary inclusion level	SGR	FCR	Notes	Reference
Tilapia						
Juvenile Nile tilapia	Faba bean meal (high tannin variety)	0%	2.54 ± 0.03	1.56 ± 0.07	Isonitrogenous, isolipidic diets	Azaza et al., 2009
		12%	2.56 ± 0.05	1.62 ± 0.08		
		24% (optimal)	2.53 ± 0.09	1.58 ± 0.05		
		36% (decrease)	2.35 ± 0.08	1.79 ± 0.10		
Cyprinids						
Grass carp	Faba bean (unknown variety; assumed high tannin)	0%	N/A	N/A		Yu et al., 2014
		100% (crisp grass carp)	N/A	N/A	Upregulation of muscle firmness and calcium metabolism genes and downregulation of glycolysis/ gluconeogenesis pathway genes	
Yellow river carp (crisp carp)	Faba bean (unknown variety; assumed high tannin) soaked in water 12h, then broken into pieces	0%	1.11	N/A	Focus on muscle and fillet quality	Song et al., 2020
		100% (crisp grass carp)	.54	N/A		

Table 7.2 Specific growth rate (SGR), feed conversion ratio (FCR) and additional production data associated with aquaculture species fed faba bean protein products (Continued)

Fish species	Faba bean product	Dietary inclusion level	SGR	FCR	Notes	Reference
Salmonids						
Atlantic salmon	Faba bean protein isolate (low tannin product)	0%	N/A	0.88 ± 0.03	TGC = 3.97 ± 0.03, 4.16 ± 0.11 and 2.97 ± 0.03, respectively	De Santis et al., 2016
		7%	N/A	0.91 ± 0.03		
		14%	N/A	0.98 ± 0.05		
Atlantic salmon	Faba bean protein concentrate (air-classified; low tannin product)	8.6–77.4% fed 5–20% (optimal range) 34% (maximum inclusion)	N/A	N/A	16 diets with equal nutrient composition	De Santis et al., 2015
Rainbow trout (fingerlings)	Dehulled faba bean meal (low tannin product)	0%	2.07 ± 0.02	0.78 ± 0.02	Isonitrogenous, isolipidic diets	Ouraji et al., 2013
		15% (optimal)	2.09 ± 0.10	0.74 ± 0.03		
		30% (decrease)	1.90 ± 0.11	0.84 ± 0.05		
		45% (decrease)	1.77 ± 0.05	0.93 ± 0.03		

SGR (%/day) = (100(Ln(Mean final body weight)-Ln(Mean initial body weight))/time (days).
SGR calculated when not available and additional growth data provided.
N/A = Not analyzed. N/A: Data was not provided or not extractable. TGC = Thermal Growth Coefficient.

8 Economics of Feeding Faba Bean

It is important to investigate alternative feed ingredients, including faba bean, to minimize the feed cost associated with animal production. Similar to peas, faba beans are a good source of protein and starch and can replace corn and soybean meal in diets. To estimate the feeding value of faba beans, a set of ten commercial prices from February 2020 to February 2021 of each feed ingredient were used in a least-cost feed formulation of a swine grower diet. The faba bean feeding value was then derived based on the nutritional composition and the competing feed ingredient prices. The shadow value of faba bean can be obtained using the following formula:

Price of faba beans = (corn price × 65%) + (soybean meal price × 34 %)

9 Sustainability of Feeding Faba Bean

Faba bean provides the opportunity to increase the production and sustainability of rotational cropping systems, especially inter-cropping systems. It has been reported that faba bean provides 44 to 50 kg N/ha in temperate areas (Köpke and Nemecek, 2010). The ability to fix nitrogen is a well-known and important attribute of legumes, reducing the utilization of nitrogen fertilizer for the faba beans and other crops in the rotation. This minimizes environmental pollution due to greenhouse gas emissions reduction (Yang, 2021). Faba bean is considered a pulse crop with one of the highest nitrogen fixation abilities, resulting in elevated levels of available soil nitrogen, and this is attributed to the low rooting density and rooting depth of faba bean compared to other pulses.

The nitrogen uptake by faba bean as nitrogen derived from the atmosphere ranges up to 96% of required nitrogen and varies from 60 to 80% for fertile soils (Köpke and Nemecek, 2010). It has been found that faba bean inoculated with Rhizobium leguminosarum fixed approximately 90% of their nitrogen requirement (Barker and Ag, 2019). The symbiotically fixed nitrogen ranges from 15 to 648 kg N/ha under field conditions. Biological nitrogen fixation is correlated with the seed yield and the amount of nitrogen bound in the grain (Köpke and Nemecek, 2010). Faba bean resulted in the highest nitrogen fixation capacity, 45.35 ± 10.9 kg N/ha, and the highest seed yield (1948 ± 264 kg/ha) compared to chickpea, dry bean, field pea and lentil grown in western Canada (Hossain et al., 2016).

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