A review of nutritional profile and processing of faba bean (Vicia faba L.)

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Abstract
Faba bean (Vicia faba L.), a nutritious leguminous cool tolerant crop, is widely cultivated throughout the world. China, Ethiopia, the United Kingdom, Australia, and France are the main producers of faba beans. In recent years, interest has been growing in health and nutritional benefits of faba beans and developments of different foods enriched with biomolecules with improved functionality, nutrition value, and health benefits. Faba beans are rich source of lysine rich proteins, carbohydrate, minerals, vitamins, and numerous bioactive compounds. It is also a good source of L-3,4-dihydroxyphenylalanine (L-DOPA), which is a precursor of dopamine and can be potentially utilized for Parkinson’s disease treatment. The seeds of faba beans can be consumed dry, roasted, soaked, cooked, frozen, or canned. However, a number of antinutritional factors such as phytic acid, trypsin inhibitors, saponins, vicin and con vicine (favism-inducing compounds), lectins, and condensed tannins negatively affect the biological value of faba beans resulting in its underutilization. For expanding the utilization of faba beans in human nutrition, the removal of these antinutrients is necessary. A number of methods including dehulling, soaking, germination, fermentation, and heat processing (cooking, boiling, extrusion, and autocaveling) have been used individually or in combination to eliminate or destroy the antinutritional factors in faba beans. This comprehensive review covers global production, nutritional profile, and processing of faba beans and its utilization in various product developments.

KEYWORDS
antinutrients, faba bean, global production, nutritional profile, processing, products

1 INTRODUCTION

Legume crops, a sustainable source of high-protein food, are grown widely throughout the world. Among legumes, faba bean (Vicia faba L.), also known as fava bean, broad bean, and horse bean, is one of the oldest crops cultivated worldwide (Mínguez & Rubiales, 2021). Mediterranean countries, Ethiopia, Egypt, China, Afganistan, India, Northern Europe, and Northern Africa, are major producers of faba bean (Rahate et al., 2020). Out of more than 50 faba bean-producing countries, about 90% production is concentrated in Asian, European Union (EU), and African region (FAO [Food and Agriculture Organization], 2020). Faba bean is considered as an important crop from ecological, nutritional, and economical point of view (Xiao et al., 2021). It is a multiuse crop providing various ecosystem
services, that is, cultivated primarily as a food source for human population residing in Asia and Africa, as animal feed/silage in the European region, and fixation of atmospheric nitrogen in agricultural soils thereby significantly reducing the application of synthetic fertilizers (Zhou et al., 2018).

Nutritionally, mature seeds of faba bean are rich in proteins (26.1%), carbohydrates (58.3%), and dietary fiber (25.0%) (US Dept of Agriculture, 2021). Faba bean also contains a variety of bioactive compounds, for example, total phenolics, and flavonoids with demonstrated antioxidant activity (Valente et al., 2018). Faba bean contains different antinutritional factors such as lectins, saponins, trypsin inhibitor, phytic acids, condensed tannins, and favism inducing factors that negatively affected its biological value (Revilla, 2015). Consuming faba beans may cause condition known as favism—a severe form of hemolytic anemia (Mínguez & Rubiales, 2021; Singh et al., 2013). Hulse (1994) reported that lectins (haemagglutinins) concentration is higher in faba bean than in other legumes. Similarly, oligosaccharides (stachyose, raffinose, and verbascose) are also present in faba beans (Toklu et al., 2021), which can ferment and produce flatulence causing abdominal discomfort. Lectins are destroyed during usual cooking processes due to high heat. Singh et al. (2013) and Labba et al. (2021) reported that besides cooking, sprouting also reduces many antinutritional factors in faba beans, thereby, improving the nutritional quality of faba beans for human consumption.

Faba beans can be used as a vegetable, green or dried, fresh, or cooked/canned. It is a common breakfast food in the Middle East, Mediterranean region, China, and Ethiopia. The most popular dishes of faba bean are Medamis (stewed beans), Falafel (deep fried cotyledon paste, with some vegetables and spices), Bissara (cotyledon paste), and Nabet soup prepared from boiled germinated faba beans (Singh et al., 2013). This review provides a perspective on faba bean’s global production/trade, nutritional profile, antinutritional factors, processing methods, and processed products.

### 2 | WORLD PRODUCTION AND TRADE

The world production of faba beans was 5.43 million metric tons in 2019, which represented about 25% increase compared with 4.35 million metric tons in 1990. Regionally, Asia leads with 33.55% of total faba bean production globally, followed by Europe (EU) and Africa, with 29.36% and 27.04% share, respectively (FAO, 2020). Leading faba beans producing, exporting, and importing countries are shown in Table 1. China was the leading producer of faba beans, followed by Ethiopia; these two countries represented about 50% of the total global production whereas among EU, the United Kingdom and France were among the top five producers. Also, in 2019, Australia was the leading exporter of faba beans with 265,543 metric tons or nearly 30% of total exports, followed by the United Kingdom, Lithuania, Egypt, and Latvia (FAO, 2020). Egypt led importers with 309,355 metric tons or 40.48% of total global imports, followed by Norway, Germany, Saudi Arabia, and France (FAO, 2020).

| Leading countries | Quantity (metric tons) |
|-------------------|-----------------------|
| Producers:        |                       |
| China             | 1,740,945             |
| Ethiopia          | 1,006,752             |
| UK                | 547,800               |
| Australia         | 327,000               |
| France            | 177,380               |
| Exporters:        |                       |
| Australia         | 265,543               |
| UK                | 119,071               |
| Lithuania         | 92,445                |
| Egypt             | 71,022                |
| Latvia            | 66,860                |
| Importers:        |                       |
| Egypt             | 309,355               |
| Norway            | 56,437                |
| Germany           | 46,707                |
| Saudi Arabia      | 43,397                |
| France            | 30,396                |

Source: FAO (2020).

### 3 | COMPOSITION AND NUTRITIONAL PROFILE

Faba bean, also known as broad bean, is an important nutrient-rich legume, especially, high amount of lysine-rich protein, complex carbohydrates, dietary fiber, non-nutrient secondary metabolites, and bioactive compounds (antioxidants, phenols, and γ-aminobutyric acid), which have several reported health benefits (Khazaei et al., 2019; Liu et al., 2022). Additionally, it is a good source of many macro- and microelements, including minerals (Hacseferogullari et al., 2003; Rahate et al., 2020). The composition of raw and cooked immature and mature faba beans is shown in Table 2 (Nutrition Data, 2021; USDA, 2021).

#### 3.1 | Protein

Faba beans contain almost twice the protein content as that in cereal grains with globulins (60%), albumins (20%), glutelins (15%), and prolamin (8%) (Rahate et al., 2020). Faba bean possesses high protein content from 20% to 41%; the wide variations are due to varietal differences and the source type, that is, flour, fraction, or isolate (Yang et al., 2018), as well as fertilization method, growth season, and planting site (Multari et al., 2015). In comparison with other beans such as lima, pinto, and red kidney beans, faba bean flour (FBF) had highest protein content of 29.76% (Gu et al., 2020). Alonso et al. (2000) reported that dehulling significantly improved the protein content of...
faba beans, whereas other processing methods (i.e., soaking, germination, and extrusion) had minimal effect on protein content (Figure 1). Among thermal processing, steam pressure toasting might be a suitable treatment to improve protein degradability more in comparison with microwave irradiation (Espinosa et al., 2020). High pressure processing (HPP) and heat treatment do not affect overall in vitro protein digestibility (IVPD) and protein quality of faba bean protein concentrate (FPC) (Hall & Moraru, 2021). However, HPP resulted in comparable or higher gastric digestibility than control and greater gastric proteolysis than heat treatment. Trypsin inhibitor activity was reduced slightly (~6%) after HHP but greatly reduced (~78%) after heat treatment of FPC (Hall & Moraru, 2021). Rosa-Sibakov et al. (2016) reported that salt soluble globulins, that is, legumin and vicilin, consisting of high molecular weight (MW) and complex structures, are the major storage proteins in faba bean. Yang et al. (2018) reported that the legumin–vicilin ratio plays an important role in physiological functions and functional properties in pulses, including faba bean. Faba bean is utilized for fortification of protein content in different food commodities, such as bread, biscuits, and oil-in-water emulsions (Liu et al., 2022; Osman et al., 2014; Rosa-Sibakov et al., 2016).

**TABLE 2** Nutritional composition of raw and cooked faba beans (per 100 g)

| Composition                  | Unit          | Immature seeds | Mature seeds |
|------------------------------|---------------|----------------|--------------|
|                              |               | Rawa           | Cookeda (with salt) | Rawa | Cookeda (no salt) |
| Proximate:                   |               | Rawb           | Cookedb (with salt) | Rawb | Cookedb (no salt) |
| Water                        | g             | 81             | 83.7         | 10.98 | --               |
| Energy                       | kcal/kj       | 72/301         | 62/259       | 341/1425 | 110/460          |
| Protein                      | g             | 5.6            | 4.8          | 26.12 | 7.6              |
| Total lipid (fat)            | g             | 0.6            | 0.5          | 1.53  | 0.4              |
| Ash                          | g             | 1.1            | 0.9          | 3.08  | --               |
| Carbohydrate, by difference  | g             | 11.7           | 10.1         | 58.29 | 19.6             |
| Fiber, total dietary         | g             | 4.2            | --           | 25    | 5.4              |
| Minerals:                    |               |                |              |       |                  |
| Calcium                      | mg            | 22             | 18           | 103   | 36.0             |
| Iron                         | mg            | 1.9            | 1.5          | 6.7   | 1.5              |
| Magnesium                    | mg            | 38             | 31           | 192   | 43.0             |
| Phosphorus                   | mg            | 95             | 73           | 421   | 124.7            |
| Potassium                    | mg            | 250            | 193          | 1,062 | 268.2            |
| Sodium                       | mg            | 50             | 277          | 13    | 5.0              |
| Zinc                         | mg            | 0.58           | 0.47         | 3.14  | 1.0              |
| Vitaminsa:                   |               |                |              |       |                  |
| Vitamin C, total ascorbic acid | mg         | 33             | 19.8         | 1.4   | 0.3              |
| Niacin                       | mg            | 1.5            | 1.2          | 2.832 | 0.7              |
| Folate, total                | μg            | 96             | 58           | 423   | 104.1            |
| Vitamin A                    | IU            | 350            | 270          | 53    | 15.0             |
| Vitamin K (phyloquinone)     | μg            | nr             | nr           | 9     | 2.9              |

*Thiamin, riboflavin, pantothenic acid, and vitamin B6: all <1.0 mg in raw and cooked faba beans.

bSource: USDA (2021).

cSource: Nutrition Data (2021).

![FIGURE 1](image1.png) Effect of different processing on protein content (dry-matter basis) of faba beans. Source: Adapted from Alonso et al. (2000)
sources of starch (41%–61%) of the total carbohydrates in faba beans. Faba beans are rich source of starch (22–45%), which is composed of mainly two components: amylose and amylopectin (Punia et al., 2019). Faba bean starch granules have round, oval, elliptical, irregular shapes, and cavity on surfaces as observed with scanning electron microscope (Sofi et al., 2013). The faba bean starch has low solubility (9.92 g/100 g) and swelling power (12.67 g/g), which can be attributed to the integration of starch granules due to strong binding forces (Zhang et al., 2019). Faba bean starch is resistant to enzymatic hydrolysis, which is evident from its high resistant starch (RS) content (46.7%) but low rapidly digestible starch (15.3%), and slowly digestible starch (34.5%) contents (Bello-Pérez et al., 2007). A lab-scale process to obtain RS from faba beans was developed and optimized by Suárez-Díéguez et al. (2021). An optimized retrogradation technique was used to increase RS content of faba beans. This study demonstrated that faba bean RS could be used as a potential functional ingredient due to its reduced and slower digestibility.

Singh et al. (2014) reported that faba bean is a very good source of dietary fiber, including both soluble and insoluble dietary fiber. Highest dietary fiber content was found in FBF in comparison with flours from lima, pinto, and red kidney beans (Gu et al., 2020). The dietary fiber in whole faba bean ranged from 15% to 30%, having hemi-cellulose as the major component along with cellulose and lignin. A significantly higher amount of dietary fiber (82.3%) is reported in seed coat of faba bean (Karataš et al., 2017; Vidal-Valverde et al., 1998). It is recommended to consume faba bean along with its seed coat, as the seed coat is reported to be rich source of dietary fiber, phenolic compounds, and minerals (Karataš et al., 2017).

### 3.3 Minerals and vitamins

Mineral and vitamin contents of faba bean are shown in Table 2. Diverse minerals (sodium, potassium, calcium, copper, zinc, iron, manganese, magnesium, phosphorus, and sulfur) are reported to be present in faba bean (Khalil & Mansour, 1995; Luo et al., 2008; Nosworthy et al., 2018; USDA, 2021). The high potassium (1,062 mg/100 g) and low sodium (13 mg/100 g) contents in mature faba bean seed are optimum for people suffering from hypertension and on a low-sodium diet. By contrast, immature faba bean seeds have higher sodium and lower potassium content, with 50 and 250 mg/100 g, respectively (USDA, 2021). Faba bean is a good source of folate, an essential cofactor involved in the synthesis of pyrimidines, purines, and amino acids (Hefni et al., 2015). Most of the phosphorus in faba bean is unavailable, as it exists as phytates responsible to pose adverse effects on human health (Luo et al., 2012).

### 3.4 Bioactive compounds

Several bioactive phytochemicals have been identified in faba bean, including phenolic compounds, flavonoids, lignans, and terpenoids. Both free and esterified phenolic compounds are present in faba beans, that is, protocatechuic acid, ferulic acid, vanillic acid, caffeic acid, sinapic acid, salvianolic acid, cis- and trans-p-coumaric acid, hydroxyeucuminic acid, eucomic acid, caffeyolquinic acid, and dichaffeoylquinic acid. Total phenolic content in faba bean pod extract of different varieties were in the range of 4.8 to 13-mg gallic acid equivalent (GAE)/g (Valente et al., 2018). The occurrence of phenolic compounds is variable in faba bean parts. The whole faba bean

| Amino acid | Immature seeds | Mature seeds |
|------------|----------------|--------------|
| Tryptophan | 0.056          | 0.247        |
| Threonine  | 0.208          | 0.928        |
| Isoleucine | 0.251          | 1.053        |
| Leucine    | 0.432          | 1.964        |
| Lysine     | 0.366          | 1.671        |
| Methionine | 0.043          | 0.213        |
| Cystine    | 0.077          | 0.334        |
| Phenylalanine | 0.228       | 1.103        |
| Tyrosine   | 0.196          | 0.827        |
| Valine     | 0.274          | 1.161        |
| Arginine   | 0.463          | 2.411        |
| Histidine  | 0.134          | 0.664        |
| Alanine    | 0.228          | 1.07         |
| Aspartic acid | 0.631       | 2.916        |
| Glutamic acid | 0.855       | 4.437        |
| Glycine    | 0.23           | 1.095        |
| Proline    | 0.252          | 1.099        |
| Serine     | 0.246          | 1.195        |

Source: USDA (2021).
constitutes 2.9-mg GAE/g of total phenolics versus much higher concentration in the seed coat (22.5-mg GAE/g). Flavonoids, recognized as bioactive compounds having anti-inflammatory and antidiabetic properties, are also reported in faba beans (Zhang et al., 2019). Karataş et al. (2017) reported antioxidant activity of only 1.8-mg Trolox equivalent (TE)/g in the whole faba bean seeds, whereas seed coat exhibited a significantly higher antioxidant activity (22.9-mg TE/g).Johnson et al. (2020) evaluated 10 varieties of Australian faba beans and reported significant variation in their phenolic and anthocyanin content and antioxidant potential. Further, principal component analysis (PCA) was used to highlight variety-dependent differences in chemical composition of faba beans.

3.5 | Antinutritional factors

Faba beans have number of antinutrients present in mature seeds. These include phytates, vicine, convicine, saponins, lectins, oligosaccharides (raffinose, stachyose), condensed tannins, and trypsin inhibitors and protease inhibitors (Labba et al., 2021; Nosworthy et al., 2018; Sharma & Sehgal, 1992). Vicine and convicine are main antinutritional compounds present in faba beans that are known to cause haemolytic anemia (called favism). Favism is one of the prime reasons for restricted use of faba beans (Luzzatto & Arese, 2018). The digestibility of legume-based proteins is correlated with the presence of protease inhibitors, which are known to reduce the digestibility of proteins thereby leading to cause pancreatic hypertrophy (Sharma & Sehgal, 1992). Trypsin inhibitors in faba bean are comparatively lower than other legume crops such as soybean, chickpea, and lentil (Sharma & Sehgal, 1992). Recently, major progress on reducing vicine/convicine and seed coat tannins in faba bean has been recently achieved through plant breeding interventions, for example, gene discovery (Khazaei et al., 2021).

Phytic acid present in faba bean is reported to negatively influence the bioavailability of minerals and alter the absorption of proteins due to phytate–mineral–protein complexes. Phytate is a chelating agent considered to be responsible for reduction in the bioavailability of divalent cations (Luo et al., 2008).

3.5.1 | Favism

Consumption of faba beans is associated with the development of favism. The highest incidence of favism disease is reported in the Mediterranean region. It is generally understood that the causative agents of this disease (vicine, divicine, convicine, alkaloids, and aglycones) are derived directly from the faba bean or their digestive metabolites (Oliveira et al., 2000). Susceptible subjects demonstrate a biological deficiency of glucose-6-phosphate dehydrogenase (G6PD), which plays a key role in the pentose monophosphate shunt pathway (Figure 2), and is highly active in the red blood cells (RBCs). NADPH provides reduced glutathione, which eliminates free radicals that cause oxidative damage. When reduced glutathione is limited, active enzymes and functional proteins are damaged by prevailing oxidants (Luzzatto & Arese, 2018). Individuals deficient in G6PD are at risk of haemolytic anemia due to oxidative stress, which is acerbated by consumption of faba bean proteins—vicine, divicine, and convicine. This condition results in damage to RBC, which limits the transport of iron. Clinical symptoms are expressed as hemolytic anemia with yellow jaundice (hemoglobin metabolized to bilirubin), fatigue, and lack of energy, affected breathing with weak and rapid pulse (Oliveira et al., 2000). Appropriate preparation and processing procedures have consistently shown that typical heat treatments (boiling or roasting) used to soften the texture are sufficient to denature proteins and reduce alkaloids, thus reduced the toxicity of faba beans.

3.5.2 | Mitigation of antinutrients

A number of processing methods are used to eliminate or minimize antinutrients in faba beans. Phytate, a major antinutritional factor, was degraded by using exogenous phytase and discarding the soaking solution after treatment, and its effect on iron bioavailability was observed (Luo & Xie, 2012). The iron content was significantly reduced (39%) after soaking treatment, but lesser reduction (10%) in iron content of faba bean was recorded after additional treatment with phytase. In another study, effect of phytase treatment and lactic acid bacteria fermentation on phytic acid reduction as well as on the protein quality and digestibility of FBF was followed. A degradation of about 89% in phytic acid was observed after phytase treatment. This reduction in phytic acid resulted in a shift in the protein solubility curve and showed higher solubility at low pH. In first stage of simulated in vitro digestion process, digestibility of faba bean proteins and release of free amino nitrogen was considerably enhanced after enzyme-aided degradation of phytic acid (Rosa-Sibakov et al., 2018).

Osman et al. (2014) investigated the effect of 0.5- and 1.0-kGy gamma irradiation on the proximate/mineral composition, antinutrients (tannins and phytic acid) content, and IVPD of faba beans.

![Figure 2](image-url)
The results showed that gamma irradiation had minimal effect on proximate/mineral composition; however, it significantly reduced tannin content but increased the IVPD. It was concluded that irradiation can potentially improve the faba beans’ nutritive quality by reducing antinutrients and increasing IVPD.

4  |  FABA BEAN PROCESSING

Besides traditional cooking of faba beans, dehulling, soaking, germination, fermentation, extrusion cooking, and enzymes treatment are some of the common treatment and processing methods used (Figure 3). Effect of cooking on the nutritional quality and antinutrients of faba beans is summarized in Table 4.

4.1  |  Traditional cooking and consumption

Home cooking of faba beans involves soaking prior to cooking. Faba beans require long cooking time to achieve a satisfactory softness and palatability and to improve protein digestibility, which has impeded its utilization in human diets. As an economical but valuable source of good quality protein, faba bean is consumed largely in Middle East countries. In Egypt, it is used in preparation of four most popular Egyptian dishes, namely, Medammis (stewed beans), Falafel (deep fried dough), Bissara (poured paste), and Nabet soup (germinated boiled beans) (Bakr, 1996). In West Asia and North Africa, mature dry seed of faba beans is used in preparation of several, similar traditional dishes such as Medammis, bean burger or Falafel, Bissara, and Nabet soup. Generally, several pretreatments such as dehulling and soaking and processing including cooking, autoclaving, extrusion, roasting, and germination are used to prepare all the dishes (Hamza et al., 1987).

4.2  |  Dehulling

Dehulling, a commonly used process for legumes, can detach the hull or seed coat from whole grain. Dehulling results in an increase in protein and amino acid content (Figure 1), whereas fat, reducing sugar, and crude fiber contents are decreased. Dehulling also resulted in increased level of phytic acid while tannins and polyphenols were decreased (Alonso et al., 2000; Bakr, 1996). Pretreatments such as soaking and roasting improved the hull recoveries (Anderson et al., 1994). An improvement of in vitro protein and starch digestibility after dehulling is achieved, which could be attributable to the partial loss of some antinutrients, for example, phytic acid, condensed tannins, and polyphenols (Alonso et al., 2000).

4.3  |  Soaking

Soluble antinutritional compounds in faba beans can be removed by soaking and discarding the soaking water or solution. Kader (1995) studied some factors (temperature, concentration of sodium bicarbonate, protein content, size, and density of seeds) affecting the rate of water absorption during soaking of faba beans. The water absorption rate increased with temperature and decreased with sodium bicarbonate addition. Soaking is shown to reduce ash content and trypsin inhibitor activity of faba beans (Anderson et al., 1994). In one another study, soaking of faba beans followed by dehulling increased total protein content, with no effect on crude fat and crude fiber, whereas sugars, ash content, tannins, phytic acid, and trypsin inhibitors were decreased (Bakr, 1996). Alonso et al. (2000) reported that phenolic content and antioxidant activities of faba bean also decreased significantly after soaking, which can be due to leaching of these bioactive compounds from hull into the soaking medium.

![Faba Beans Processing and Products](image)

**FIGURE 3** Faba bean typical processing methods and selected products and quality evaluation
4.4 Cooking and autoclaving

Soaking and open-kettle cooking have been utilized as the most common processing methods in home preparation of faba beans. Anderson et al. (1994) cooked faba beans to a soft texture by boiling in deionized water for 40 min, which resulted in significant reduction of ash content and slight reduction of total proteins. Kmiecik et al. (2000) also observed reduction of ash content after blanching and cooking. Cooking was not shown to affect the chemical composition and mineral content of faba beans, but antinutritional factors, such as tannins and phytic acid, were reduced. Further, IVPD also improved significantly (Osman et al., 2014).

The effect of cooking and autoclaving on nutritional quality of faba beans was evaluated by Khalil and Mansour (1995); their results showed that stachyose, phytic acid, tannins, trypsin inhibitor, vicine, and haemagglutinin activity were significantly reduced after heat processing (Table 4). However, autoclaving had less effect on phytic acid in comparison with cooking (Sharma & Sehgal, 1992). Total essential amino acids were not affected while IVPD and protein efficiency ratio value of faba bean was improved after cooking and autoclaving. Autoclaving for longer period improved protein digestibility more in comparison with short time autoclaving (Sharma & Sehgal, 1992). This improvement may be attributed to protein denaturation, reduction of trypsin inhibitors, or decrease in phytic acid and tannin contents. Interestingly, higher contents of leucine, tyrosine, threonine, and histidine were reported in cooked faba bean as compared with raw seeds (Table 5). A significant decrease in vicine and convicine content was observed after boiling and dehulling of faba beans, whereas L-3,4-dihydroxyphenylalanine (L-DOPA) was removed completely (Cardador-Martínez et al., 2012).

4.5 Germination

Germination has been investigated widely as a suitable processing treatment to obtain nutrient-rich FBF. Germination resulted in a slight decrease in starch (15%), greater reduction in phytates and α-galactosides (45% and 94%, respectively), and improved dietary fiber appreciably (Alonso et al., 2000; Hamza et al., 1987; Vidal-Valverde et al., 1998). About 6% increase was observed for calcium content (in germinated versus cooked samples), which could be related to the decrease in phytic acid (Table 5). The improved bioavailability of calcium was also attributed to reduction in hemicelluloses content, which can interfere in its bioavailability. The phytic acid serves as a reserve of phosphorus, which is liberated by phytase action during germination thereby improving phosphorus bioavailability (Vidal-Valverde et al., 1998).

Germination was shown to result in a gradual increase in the protein content of faba bean during 24–72 h of germination, which could be due to starch utilization as energy source during germination (Alonso et al., 2000). Increased in vitro starch digestibility, causing starch digestion through amylolytic enzymes, was also observed during germination, which supported the above findings. Germination for 24–72 h showed decrease in the phytic acid, polyphenols, and...
condensed tannins contents as well as reduction in activities of trypsin, chymotrypsin, and α-amylase inhibitors (Beleia et al., 1993). Haemagglutinating activity showed no differences in germinated seeds in comparison with raw faba beans. Due to decrease in different antinutritional factors, IVPD was improved during germination. The increase in digestibility produced by germination was higher in starch than in protein (Alonso et al., 2000). Folate, an essential cofactor, as donor as well as acceptor, involved in purines, pyrimidines, and amino acids synthesis, was increased significantly (>40%) in faba bean during germination (Hefni et al., 2015).

4.6 | Extrusion

Extrusion processing of legumes has been used to remove the antinutritional factors and improve the physical (palatability and texture) and chemical (starch gelatinization, protein, and starch digestibility) properties. Extrusion of faba beans has been reported to have minimal effect on the nutritional value, that is, protein, lipids, and ash contents (Adamidou et al., 2011; Nosworthy et al., 2018).

Extrusion processing at different preconditioning and dryer temperatures resulted in slight reduction in the total as well as soluble and insoluble nonstarch polysaccharides in faba beans (Adamidou et al., 2011). Extrusion processing resulted in increase in starch level, which might be due to compositional changes in RS and easier hydrolysis of extruded starch granules by amylases during analysis. Starch was gelatinized after heat treatment (extrusion) in which crystalline structure of starch was disrupted and starch granules ruptured under high temperature, making them more accessible and readily hydrolysable by enzymes (Alonso et al., 2000). Further, it was observed that preconditioning and extrusion eliminated the activities of trypsin, chymotrypsin, α-amylase inhibitors, and haemagglutinating activity without affecting the protein level (Table 4). Also, thermal processing was most effective in improving the protein and starch digestibility (Francis et al., 2001) and destruction of amylase and protease inhibitors. However, irrespective of preconditioning and dryer temperature, phytic acid and total tannin level were reduced after extrusion (Adamidou et al., 2011), whereas Francis et al. (2001) reported that no effect was observed on the bioavailability of minerals bound by phytic acids.

Gu et al. (2020) employed extrusion processing to process flours from faba, lima, pinto, and red kidney beans. FBF had higher protein and crude fiber and lower nonfiber carbohydrate content compared with flours from three other bean types (Table 6). Higher protein content in FBF made it suitable for developing plant-based protein products (Liu et al., 2022; Osman et al., 2014; Rosa-Sibakov et al., 2016).

4.7 | Roasting

Roasting has been utilized traditionally for faba bean processing at home for production of flour for further application. Low roasting temperature produced low protein content compared with high roasting temperatures. Roasting has been shown to be most effective

| Compounds     | Raw   | Soaked | Cooked | Autoclaved | Germinated |
|---------------|-------|--------|--------|------------|------------|
| Lysine        | 6.01  | 5.81   | 5.73   | 5.58       | 5.91       |
| Methionine    | 0.20  | 0.19   | 0.19   | 0.18       | 0.20       |
| Tryptophan    | 1.09  | 0.98   | 1.07   | 1.08       | 1.16       |
| Leucine       | 6.00  | 5.88   | 6.04   | 6.02       | 6.30       |
| Isoleucine    | 3.20  | 2.79   | 3.05   | 3.01       | 3.25       |
| Pheny alanine | 4.36  | 4.24   | 4.20   | 4.06       | 4.32       |
| Valine        | 3.01  | 2.94   | 2.92   | 2.85       | 3.44       |
| Tyrosine      | 2.63  | 2.58   | 2.81   | 2.73       | 2.83       |
| Threonine     | 2.05  | 2.00   | 2.96   | 2.90       | 2.85       |
| Cysteine      | 0.55  | 0.39   | 0.29   | 0.29       | 0.50       |
| Arginine      | 9.70  | 9.43   | 9.17   | 9.60       | 9.61       |
| Histidine     | 2.39  | 2.44   | 2.40   | 2.40       | 2.55       |
| Sodium        | 298.0 | 293.0  | 293.0  | 298.0L     | 285.0      |
| Potassium     | 649.0 | 508.0  | 469.0  | 547.0      | 475.0      |
| Calcium       | 221.0 | 210.0  | 209.0  | 199.0      | 221.0      |
| Iron          | 5.8   | 5.0    | 5.1    | 5.6        | 6.0        |
| Zinc          | 11.6  | 11.2   | 11.0   | 11.5       | 11.3       |
| Manganese     | 2.4   | 2.1    | 2.4    | 2.3        | 2.2        |
| Copper        | 2.6   | 2.0    | 2.2    | 2.1        | 2.5        |
| Magnesium     | 280.0 | 210.2  | 279.0  | 288.0      | 251.0      |

Source: Adapted from Khalil (2001).
method to reduce trypsin inhibitor activity (Anderson et al., 1994). Hamza et al. (1987) reported that the patterns of proteins in standard PAGE were not affected by roasting. Also, SDS-PAGE showed a degradation of high molecular weight proteins to smaller subunits during roasting. Phytic acid content was reduced during roasting, which might be due to formation of insoluble phytins between phytic acid and some minerals. Vidal-Valverde et al. (1998) reported that dry heating causes noticeable reduction in most nutrients (soluble sugars, starch, dietary fiber, and calcium) and antinutritional factors (α-galactosides and phytic acid) of fababeans. Roasting was shown to initially decrease the antioxidant capacity of faba beans; however, roasting at 150°C for prolonged time (∼60 min) generated new phenolic compounds, which increased the antioxidant capacity (Siah et al., 2014).

### TABLE 6
Proximate composition (%) of flours from extruded faba and other beans

| Bean type            | Protein  | Carbohydrate± | Crude fiber | Fat  | Ash   |
|----------------------|----------|---------------|-------------|------|-------|
| Faba bean            | 29.76    | 60.48         | 5.27        | 1.58 | 2.91  |
| Lima bean            | 24.03    | 66.37         | 3.50        | 1.57 | 4.53  |
| Pinto bean           | 21.62    | 69.64         | 2.96        | 1.67 | 4.11  |
| Red kidney bean      | 25.34    | 66.75         | 2.50        | 1.41 | 4.00  |

Source: Gu et al. (2020).

±Nonfiber.

5 | FABA BEAN PRODUCTS

Faba beans can be utilized to produce nutrient-rich diverse products. For example, the use of FBF and protein or starch isolates has been reported in pasta (Rosa-Sibakov et al., 2016; Tazrart et al., 2016), spaghetti (Giménez et al., 2013), bread (Sozer et al., 2019), tofu (Jiang et al., 2020; Zee et al., 1987), yogurt (Jiang et al., 2020), as a partial meat/fat replacer in beef patties (Sulaiman et al., 2018), egg yolk replacer in mayonnaise (Ouraji et al., 2020), and meat analog products (do Carmo et al., 2021).

5.1 | Pasta and spaghetti

Fresh pasta from semolina fortified with 10%, 30%, and 50% FBF was prepared by Tazrart et al. (2016). The FBF fortified pasta showed lower cooking time but higher dry matter loss. A significant increase in protein levels was observed, that is, 21% in enriched pasta at 50% level versus 13.7% in the control sample. Similarly, fiber, RS, and mineral (calcium, iron, and zinc) contents were also increased in FBF fortified pasta. IVPD improved proportionally with the increasing FBF fortification levels. Rosa-Sibakov et al. (2016) studied the effects of processed FBF on textural, structural, and sensory properties of gluten-free pasta, which was prepared from FBF, starch-rich faba bean flour fraction (FBF-S), or faba bean flour fermented (FBF-F). Pasta prepared with FBF and FBF-F had significantly higher cooking loss (10.8–11.5%) and lower water absorption than semolina (control) pasta. The texture of FBF pasta was comparable with that of control pasta, but fermentation adversely affected the FBF-F pasta texture as observed by higher hardness and chewiness.

Giménez et al. (2013) prepared corn-broad (faba) bean spaghetti with 30:70 ratio of corn and broad bean flour. Broad beans were extruded to produce flour using process variables of 80°C, 90°C, and 100°C temperature and 28°C, 31°C, and 34% moisture content. The quality of pasta-like product (expansion, cooking-related losses, water absorption, firmness, and stickiness) was assessed. The extrusion process at 100°C and 28% moisture was found to be optimum to develop corn-broad bean spaghetti/pasta with high content of protein and dietary fiber content and satisfactory quality attributes. It was shown that the cooking attributes and resistance to overcooking was dependent on the degree of gelatinization; the critical degree of gelatinization point was 46.5%, beyond which the product quality declined significantly.

5.2 | Bread

Lactic acid fermentation as a nutrient enhancing process for FBF was investigated for use in the preparation of gluten-free bread, and the quality of bread was compared with that made from soy flour (Sozer et al., 2019). Both unfermented and fermented FBF breads were softer and exhibited higher porosity, 82% and 72%, respectively, compared with 61% for soy flour bread. Sensory evaluation showed that fermentation had minimal effect on the crumbliness, pore-size evenness, and springiness of bread crumb. Fermentation was shown to increase IVPD from 64.8% to 72.3%. The nutritional index and PER were enhanced by fermentation from 33 to 36 and 1.6 to 2.7, respectively.

5.3 | Tofu and yogurt

Jiang et al. (2020) prepared two protein-based emulsion gel foods, that is, yogurt and tofu analog products. The processing steps involved thermal pretreatment of the beans, dehulling, milling, adding plant oil, homogenization, prevention of starch gelation, and inducing protein gelation. Both starch-gelation prevention methods (starch removal or starch hydrolysis) produced yogurt and tofu with typical emulsion gel properties. The starch hydrolysis was a better process for producing the yogurt because the hydrolysates were shown to
improve the viscosity and gel strength. However, starch removal was slightly better than hydrolysis for producing tofu because the hydrolysates lowered water-holding capacity and tofu’s gel strength. Zee et al. (1987) prepared a tofu product from faba beans using different experimental conditions to optimize tofu yield, protein content, and sensory properties. An optimum weight-basis yield of 66.8% and 44.8% protein was obtained with 1:10 bean–water ratio by the decantation versus enzymatic process. Increasing the amount of ascorbic acid used resulted in higher protein content and firmer texture and decreased discoloration of the product.

5.4 Protein isolates and other products

Singhal et al. (2016) prepared faba bean protein isolates (FPls), with ~94% protein content, from seven genotypes using alkaline extraction followed by isoelectric precipitation. Selected functional properties of FPl, that is, solubility, emulsifying activity/stability, foaming capacity, emulsion capacity/stability, and oil holding capacity, were also evaluated. Functional properties of FPl were found comparable with those of commercially available isolates from soybean, pea, whey, and egg. Vogelsang-O’Dwyer et al. (2020) produced faba bean protein-rich flour by milling/air classification (dry fractionated) and protein isolate using acid extraction, followed by isoelectric precipitation; a comparison of composition (flour and isolate) is shown in Table 7.

Felix et al. (2018) prepared protein concentrates by an eco-friendly process known as densification, which produced a protein concentrate suitable for the development of food emulsions having pH dependent microstructure. Isoelectric precipitation followed by spray drying sometimes produces proteins with impaired functionality as well as large quantity of waste. Due to dependence of microstructure and hence stability of emulsion on pH, best results in terms of small droplet sizes and high viscoelastic properties were obtained at pH 2.5. This could be attributed to the development of a suitable protein network at this pH. By contrast, poor rheological response by emulsions was observed at pH 8.0, which is due to low protein solubility at high pH. On the other hand, results from droplet size distribution indicated lack of surface charge leading to high coalescence index of 41% at pH 5.0.

Minced beef patties were prepared by Sulaiman et al. (2018) by adding 20% faba bean protein, which improved the product yield significantly and also increased dietary fiber content compared with the 100% beef patties. Ouraji et al. (2020) used enzymatic extraction of faba beans protein (FBP) for potential use as a partial replacer of egg yolk powder (EYP) in mayonnaise. Based on the quality evaluation, formulations containing equal amount of FBP and EYP (0.37% each) and the one with 0.50% FBP and 0.25% EYP were suggested. do Carmo et al. (2021) reported that it was possible to produce meat analog product from FPC obtained by dry fractionation. The developed meat analog exhibited good firmness, elasticity, fibrousness, and bite-feeling, which are important attributes for sensory acceptance.

6 CONCLUSIONS

Faba bean is an agronomically viable alternative crop to cereal crops as it can fix free nitrogen enabling the farmers to practice sustainable agriculture for achieving environment friendly development goals. Being a legume, faba beans are an excellent source of lysine-rich protein along with diverse essential nutrients. L-DOPA, a precursor of dopamine, is also found in faba beans, which can be used as a bioactive compound, with potential for the treatment of Parkinson’s disease. Faba beans are commonly consumed in diverse regions of the world, with the highest per capita consumption in India. Different processing methods such as dehulling, soaking, cooking, autoclaving, germination, extrusion, fermentation, and enzymatic treatment can be used to reduce different antinutritional factors and making it more acceptable as nutrient-rich ingredient in different foods. After undergoing various processing methods, faba beans offer potential to be used in diverse protein-rich products as an alternative to displace animal-derived proteins, which aligns well with changing consumer trends and current ecological needs.

CONFLICT OF INTEREST

No conflict of interest exists.

DATA AVAILABILITY STATEMENT

The manuscript reviewed previously published research; therefore, data sharing/accessibility statement does not apply.

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