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REVIEW ARTICLE

Valorization of faba bean (*Vicia faba*) by-products

Lina Maja Marie Krenz[1] · Sandra Grebenteuch[1,2] · Kathleen Zocher[1] · Sascha Rohn[1,2] · Daniel Pleissner[1,3]

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Abstract
Fromharvesting to consumption of the faba bean (*Vicia faba*), different plant residues such as stems, leaves, pods, and seed husks remain as by-products. The harvest residues constitute about 50% (w/w) of the whole aboveground biomass, while the empty pods and the seed husks account for 11% and 6% (w/w) on average, respectively. Due to the environmental and dietary benefits, the global production of faba beans is most likely to increase in the future. Concomitantly, the amounts of by-products will rise as well. So far, mainly the harvest residues have been widely studied, whereas the pods and husks have received less consideration. Therefore, the aim of this review was to provide an overview of the composition of the faba bean plant residues and to illustrate their potential of being used as feedstock in food, feed, or even non-food applications. This literature survey clearly reveals that all the residual materials of faba beans contain valuable compounds and might be suitable for a multitude of different applications. The residual material should thus not be disposed of but further valorized in order to exploit the full potential of the biomass.

Keywords Legumes · Faba bean · Biorefinery · Protein · Fibres · Feed · Food

1 Introduction

Faba bean (*Vicia faba* L.) is a versatile legume cultivated all over the world. *V. faba* crops are classified into three main varieties according to their seed size: (1) *V. faba* major with large seeds (also commonly called broad bean), (2) *V. faba* equina with medium seeds, and (3) *V. faba* minor with small seeds (also commonly called tick bean, field bean, or horse bean) [1, 2].

Highlights
- Fava bean by-products were identified as valuable raw materials for utilization.
- Transformation of by-products into valuable products was investigated.
- Wholistic utilization of by-products to foster the bioeconomy is possible.

✉ Daniel Pleissner
daniel.pleissner@leuphana.de

1 Institute for Food and Environmental Research e.V., Papendorfer Weg 3, 14806 Bad Belzig, Germany

2 Department of Food Chemistry and Analysis, Institute of Food Technology and Food Chemistry, Technische Universität Berlin, Gustav-Meyer-Allee 25, 13355 Berlin, Germany

3 Sustainable Chemistry (Resource Efficiency), Institute of Sustainable Chemistry, Leuphana University of Lüneburg, Universitätsallee 1, 21335 Lüneburg, Germany

The annual global production of faba beans is more than 5.5 million tons, with China, Ethiopia, Egypt, UK, and Australia being the main producers [3]. Cultivation of grain legumes in the European Union and especially Germany is currently negligible. About 1.4% of the German arable land and about 2.1% of the European Union are covered by grain legumes with around 30% being faba beans [4]. In recent years, however, there has been an upward trend in faba bean production due to associated environmental benefits and a kind of revival in human nutrition suggesting the consumption of more plant proteins and especially originating from legumes.

Like all legume genera, symbiosis with Rhizobia bacteria enables faba beans to fix atmospheric nitrogen, which is then used for faba bean metabolism. Parts of nitrogen are also released to the soil. The inclusion of legumes in farming systems can contribute to mitigating climate change as they reduce greenhouse gas emissions and play a key role in soil carbon sequestration [5]. Faba beans also contribute to the diversification of agroecosystems, either when being used in crop rotations or by using intercropping systems. Both increase biodiversity as they provide feed to pollinators and other beneficial insects [6].

With regard to nutrient composition, faba beans are rich in proteins, starch, dietary fibres, and have low fat contents (Table 1). They are a good source of dietary minerals and

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trace elements such as potassium, phosphorus, iron, and zinc [7] and vitamins such as folic acid (vitamin B9) and vitamin K [8]. They also contain considerable amounts of bioactive compounds such as phenolic compounds which are known for their antioxidant, anti-inflammatory, and anti-diabetic properties [9]. However, faba beans also contain various substances such as tannins, lectins, phytates, saponins, oligosaccharides, and protease inhibitors [10] that are regarded as anti-nutrients that may limit the use of faba beans, especially in animal nutrition. The chemical composition strongly depends on the cultivar [11–14], as well as on ecophysiological factors [12, 13] and management conditions [14, 15].

Faba beans are widely used for human consumption and animal nutrition [1]. Human consumption of faba beans in Northern Europe has been reported as far back as the Viking Age (700–1050 CE) [17]. The oldest seeds of faba beans were found in the late tenth millennium BP in north-west Syria [18], suggesting that the faba bean has been used for a much longer time. Faba beans can be consumed either fresh (raw or as a vegetable) or in dry form in a variety of foods [19]. Due to their high protein content, they can be included in the diets of ruminants, pigs, and poultry to a certain level, depending on the amount of anti-nutrients [1, 7].

Due to the environmental and dietary benefits, the global production of faba beans is most likely to increase. Simultaneously with increasing amounts of produced beans, the amounts of produced by-products will increase as well. From harvesting to consumption of the faba beans, several by-products such as stalks, leaves, pods, and seed husks occur, which are currently underutilized. This review provides an overview of the quantification and composition of by-products present and their potential use in food, feed, or non-food applications.

Table 1 Average composition of faba beans on a dry matter (DM) basis, compiled by Muschiolik and Schmandke [16]

Parameter	Amount [%, w/w]
Proteins	22–37
Starch	30–53
Fat	1–3
Carbohydrates	50–66
Crude fibre	6–8
Soluble sugar	6–11
Ash	3–5

2 By-product generation—harvesting and processing residues

Along the growing, the harvesting, and the processing of faba beans, different by-products are occurring (Fig. 1). The amount of by-products in faba bean processing depends on the maturity level. Faba beans can be harvested at a vegetative state when pods and seeds are fresh and green or at full maturity when pods dry out with only the seeds being of interest [9]. The beans are predominantly harvested in the dry state. In some production areas, for example, in Jordan [20], and in small-scale household gardening [21], the harvesting of fresh beans dominates.

When the faba bean is harvested in the dry state, the grains are removed from the pods by threshing. Large quantities of biomass residues, comprising stalks, leaves, and dried pods, remain in the field afterwards. In China alone, 4 million tons of faba bean stalks accumulate annually [22]. The amount of total residual biomass can be derived from the harvest index, which is an agricultural indicator that designates the ratio of the grain yield to the total aboveground biomass yield. The harvest index of faba beans has been measured in a large number of studies and ranges mostly from 40 to 60% (w/w, based on dry matter, DM) [23–34]. This implies that on average, around 40 to 60% (w/w) of the aboveground biomass remains unused and as residues in the field.

When the faba bean is harvested in the fresh state, the whole pods including the seeds are removed either manually or mechanically. Accordingly, less harvest residues remain in the field. The pods constitute about 20% (w/w, based on

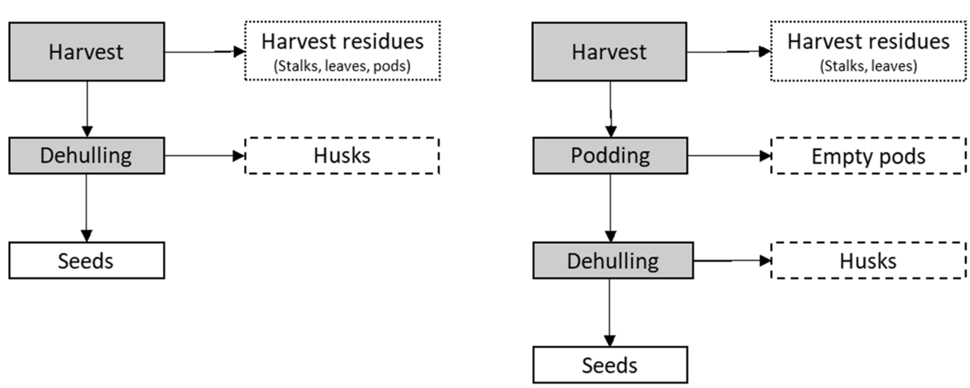

Fig. 1 By-products of faba beans harvested dry (left) and fresh (right). Harvest residues are outlined with a dotted and processing residues with a dashed frame

dry matter) of the harvest residues [34, 35]. The freshly harvested pods may be sold intact, but most commonly the grains are also released from the pods and are sold fresh, frozen, or canned [36]. These empty pods remain as residual material and constitute about 70–75% (w/w) of the fresh matter of the whole pod yield [36–40]. However, when only the dry mass of the fractions is considered, the seeds constitute about 80% (w/w) of the dry pod weight, while the empty pods only account for 20% (w/w) [35, 41, 42].

Both fresh and dried faba beans are generally consumed or further processed after the removal of the seed husk, in order to improve the nutritional value [43]. The husks constitute approximately 10–15% (w/w) of the seed DM [16, 19, 37, 44–46]. Dehulling of dry beans is usually done by industrial or small-scale milling [47]. Apart from the husks, other by-products such as broken grains, germs, and powder occur [47].

Figure 2 gives an overview of the mass fractions of the different residues and the final dehulled grains in relation to the total aboveground biomass. The calculation is based on mean values from the abovementioned references. It is apparent that the plant parts remaining in the field account for the majority of the residues, while the pods and husks make up smaller mass fractions. Besides, empty pods and husks might not always be generated from the processing. In the following sections, the use of harvest residues (leaves and straw) and process residues (pods and husks) is discussed.

3 Harvest residues—leaves and straw

The composition of faba bean harvest residues was determined in a large number of studies, and an overview of the proximate composition is given in Table 2. The composition may vary widely depending on cultivar [33, 34], cultivation conditions [30, 38], and the proportions of stems, leaves, and pods [37]. Faba bean harvest residues are very rich in fibres. On average, the major cell wall components hemicellulose, cellulose, and lignin together account for more than 60%

Table 2 Composition of faba bean plant residues [22, 30, 33, 34, 38, 42, 51–68]. All values given as g kg^{-1} DM (*n* number of observations, *SD* standard deviation)

	n	Mean	Minimum	Maximum	SD
Crude fibre	6	350.2	264.3	467.0	78.8
Hemicellulose	40	102.3	15.6	353.0	73.2
Cellulose	41	386.4	168.0	560.0	112.9
Lignin	42	114.6	39.0	324.0	48.9
Crude protein	26	80.7	43.0	188.0	38.5
Fat	4	12.2	10.0	14.0	2.1
Ash	26	82.6	46.0	184.2	31.6
N	7	20.0	11.6	29.6	7.4
P	9	2.6	1.0	5.3	1.6
K	6	16.5	13.2	25.2	4.5
Na	2	1.0	0.3	1.6	-
Ca	6	16.0	8.7	23.1	6.1
Mg	6	2.5	1.7	4.8	1.2

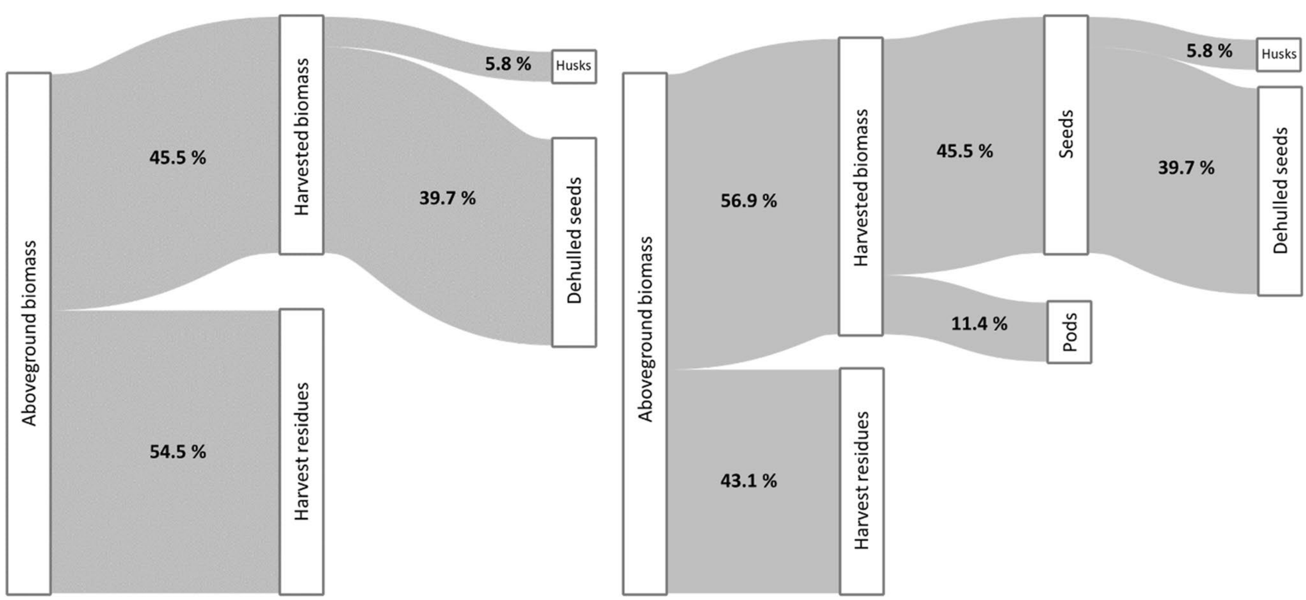

Fig. 2 Mass flow of faba bean biomass, harvested dry (left) and fresh (right), given in % (w/w) DM of aboveground biomass

(w/w) and, thus, constitute the main part of the plant residues. Cellulose makes up 40% (w/w), while hemicellulose and lignin are mostly below 15% (w/w). However, the straws studied showed a wide range in cellulose, hemicellulose, and lignin content. The average crude protein content of the straw is about 8% (w/w), ranging from 4 to 19% (w/w). While stems and pods have low protein contents, leaves can contain up to 35% (w/w) [48]. The ash content is mostly below 10% (w/w) with the leaves having a higher percentage than the stems [34]. The protein and ash contents are in the range of other legume straws but rather high compared to cereal straws [49, 50]. Faba bean residues contain considerable amount of nitrogen, potassium, and calcium (mostly above 1%, w/w) and smaller amounts of phosphorus, sodium, and magnesium (mostly below 0.5%, w/w).

3.1 Harvest residues—food use

The use of faba bean plant residues for human consumption is not particularly widespread. For direct consumption, only the freshly harvested leaves, the faba greens, are considered. According to Renna et al. [48], faba greens are traditionally consumed as "unconventional vegetable" in Puglia, a region in south-east Italy. They can either be eaten raw in salads or cooked liked spinach in pasta dishes, quiches, or omelettes. On the internet, there are some recipes and instructions for faba greens, but scientific literature on their composition is scarce.

Faba greens have the potential as unconventional food due to their composition. Compared to spinach, faba greens have a significantly higher protein content, contain more carbohydrates and dietary fibres, and have a lower nitrate content [48]. Etemadi et al. [69] investigated the element accumulation in different parts of six faba bean varieties. The concentrations of nitrogen, phosphorus, potassium, and zinc were significantly lower in the leaves than in the seeds. However, the concentration of calcium and iron was more than eight times higher in the leaves than in the seeds. The accumulation of magnesium and manganese was also significantly higher. Faba bean leaves are thus supposed to be a good source of mineral and trace elements.

Besides, faba greens are a valuable source of phytochemicals, especially at a young age. In a comparative study, the leaves were shown to have significantly higher contents of vitamin C (four times higher), L-3,4-Dihydroxyphenylalanin (L-DOPA), being the precursor of dopamine (> 10 times), total flavonoid content (TFC) (> 40 times), and total phenolic content (TPC) (> 10 times) than the seeds [70]. Due to the higher concentrations of antioxidants, faba bean leaves exhibit a stronger antioxidant activity than the seeds.

However, the consumption of fresh faba bean leaves might be hampered by the presence of volatile organic compounds (VOC) inducing undesirable flavours. Duan et al. [71] detected a total of 69 different compounds in the fresh leaves with alcohols (72%), aldehydes (14%), ketones (5%), and esters (3%) accounting for more than 90%. The authors investigated the influence of four different domestic cooking methods on the composition of the leaves. A cooking time of 5 min was recommended, as it significantly reduced the content of VOC and improved the flavour without compromising the nutritional value. Microwaving and steaming were more effective than boiling and roasting although microwaving significantly increased the *p*-xylene content which might have harmful effects on the human health [71].

3.2 Harvest residues—feed use

In addition to the potentially food-relevant leaves, faba bean straw may either be fed as roughage or included in a mixed diet to a certain extent. The crude protein content of faba bean straw is about 8.7% (w/w) on average (Table 2). For optimum rumen microbial function of ruminants, the feed should contain at least 7% (w/w) crude protein [72]. This threshold is surpassed by most of the straws reported in literature. However, depending on the composition and the variety, the protein content can be significantly lower (e.g. 4.3% (w/w) in the cultivar Shallo [33]) or higher (e.g. 18.8% (w/w) in plant residues containing seeds [51]).

The metabolizable energy (ME) content of faba bean straw was reported to be between 6.2 and 9.2 MJ kg^{-1} DM for sheep [33, 52], between 6.3 and 6.7 MJ kg^{-1} in a rumen inoculum [34], and between 6.5 and 7.5 MJ kg^{-1} using a predictive model based on near-infrared spectrophotometry data [53]. Compared to other substrates, the ME content is rather low [72]. The amount of cell walls, measured by the neutral detergent fibre (NDF) content, is the primary chemical component that determines the rate of digestion [73]. The reported NDF content of faba bean straw ranges from 44.0 to 82.2% (w/w) with an average of 67.4% (w/w). According to Ellis et al. [74], fibrous feeds with NDF contents lower than 45% (w/w) can be classified as high-quality roughage, while those containing 45–65% (w/w) are categorized as of medium quality, and those with more than 65% (w/w) are considered low-quality roughage. Considering the fibre content, faba bean straw is thus of medium to low feeding quality.

Correspondingly to the high NDF content, the digestibility is rather low. In vitro dry matter digestibilities (IVDMD) between 54.7 and 58.8% (w/w) were reported [54, 55], while the in vitro organic matter digestibilities (IVOMD) of different faba bean varieties ranged from 45.1 to 62.6% (w/w) [33]. In comparison, the IVOMD of wheat bran and noug seed (*Guizotia abyssinica*) cake were 84.5% and 69.4% (w/w), respectively [33]. The in vivo digestibilities in sheep were found to be at 56% (dry matter) and 60% (organic matter) [56].

Feeding trials with faba bean straw have been carried out with sheep and rabbits. According to Fujihara and Nakao [75], the nutritive value of ensiled fibrous faba bean residues was higher than that of timothy hay, and the feedstock might be used as a roughage by sheep. Adding ensiled faba bean fibrous residues to low-quality timothy hay improved feed quality and increased ruminal ammonia concentration and the levels of the blood constituents in male Japanese Corriedale sheep [76].

In a study including 13 different straws (nine legume species, three rice varieties and rape) fed to adult merino sheep, faba bean straw showed average performance. Organic matter digestibility (48.3%) was moderate and dry matter intake (61 g kg^{-1} liveweight) was in the lower range of the studied legume straws but significantly higher compared to rice and rape straw. Feed quality of faba bean straw was improved by adding barley grain (20–40%, w/w) to the diet [52].

Asar et al. [57] investigated the effects of the inclusion of 25% (w/w) faba bean straw in the diet of weaned rabbits. Though the voluntary feed intake of diets containing faba bean straw was lower compared to the control diet, no significant differences in body weight gain were measured. The feed conversion ratio and the digestion coefficient values were significantly improved by including faba bean straw in the diet.

Feeding trials showed that faba bean straw can be used for animal nutrition. However, concerning nutritional value and digestibility, the biomass is considered of rather low quality. For optimum animal performance, the faba bean residues might require some nutrient supplementations or pre-treatments [54, 55]. Omar et al. [77] showed that microbial fermentation of faba bean by-products could enhance their nutritional value by increasing the concentration of crude protein and fat and decreasing the amount of crude fibre, lignin, and anti-nutrients. Similarly, the incubation of broad bean stalks with white-rot fungus *Pleurotus ostreatus* significantly improved their nutritive value [78].

In addition, to improve the forage quality, the cultivated variety can be selected appropriately, as the variety also has an impact on the suitability of the straw as feed. Wegi et al. [33] studied the effect of feeding five different varieties of faba bean straw to Arsi-Bale sheep in a diet consisting of 70% faba bean straw and 30% concentrate (wheat bran and noug seed cake). The straws showed great differences in composition and in intake, digestibility, feed conversion efficiency, and body weight gain.

3.3 Harvest residues—non-food use

The most widespread application of faba bean residues in the non-food sector is the (re-)incorporation into the soil, either fresh as green manure or dried as straw. Crop residues left on the field can exert several positive effects on the physical and chemical properties of the soil. Faba bean straw has shown to increase the water holding capacity, the field capacity, and the cation exchange capacity of a sandy soil [79]. Straw retention in the soil significantly improved soil organic carbon content (SOC), while straw removal remarkably reduced SOC [80]. Straw returning to a paddy and a dry-land soil in China promoted the aggregation of soil aggregates and increased the SOC content [81]. The incorporation of faba bean into the soil as green manure successfully reduced the weed emergence by up to 67% without compromising the emergence of maize [82] and significantly increased the potato tuber yield by up to 38% [83].

Apart from the benefits, there is a risk of elevated greenhouse gas emissions after application of legume residues due to their low *C/N* ratio which stimulates the formation and release of nitrous oxide (N_2O) [5]. While ammonia (NH_3) emissions are significantly reduced by applying faba bean green manure, N_2O emissions might be comparable to mineral fertilizers [84]. However, the removal of crop residues from the field can cause negative nitrogen balances resulting in a potential depletion of the soil [35].

The removal of legume residues for non-food applications represents a significant trade-off between the bioeconomy and the soil quality. The amount of biomass that is taken from the cropping system should be carefully determined with respect to the specific local conditions [5, 80]. Depending on the chosen process, biomass might be partially returned to the soil as stabilized co-product that is more recalcitrant to degradation than the raw biomass and can maintain or even increase SOC [85].

Nevertheless, a variety of different applications for material and energetic use of faba bean straw have been proposed. Faba bean straw may be used as feedstock for thermochemical conversion processes such as combustion. An overview on the quality parameters of faba bean straw pellets, partially blended with another biomass, compared to the average of woody pellets, is given in Table 3.

The lower heating value of faba bean residue pellets was approximately 17 MJ kg^{-1} DM. Blending with maize and hemp residues did not significantly influence the calorific value, while the addition of potato skin decreased the calorific value. The heating value is similar to that of other herbaceous material and not significantly lower than wood pellets [87]. Pellet density ranged between 1100 and 1350 kg m^{-3} and met the requirements for biofuels [87].

High ash content negatively affects fuel quality due to deposit formation, increased fly ash emissions and higher efforts for ash storage and deposition [90]. Though the ash content is higher than that of wood pellets, it still remains below the permissible ash content of 7% (w/w) for mixed biomass pellets [91] except for the pellets made from faba

Table 3 Quality parameters of pellets produced from faba bean residues in combination with other plant residues compared to wood pellets (*LHV* lower heating value)

Feedstock	LHV [MJ kg^{-1} DM]	Density [kg DM m^{-3}]	Ash [% DM, w/w]	N	Cl	S	Reference
Wood	18.4[1]		0.9	0.2	0.01	< 0.01	[86]
Faba bean	16.9–17.1	1276–1311	3.9–6.9	1.3–1.6	0.3–0.5	< 0.1	[87]
Faba bean	17.0	1311	3.9				[88]
Faba bean	17.1	1196	5.7	0.9	0.2	< 0.1	[89]
Faba bean + maize residues	16.8	1106	6.8	0.8	0.1	< 0.1	[89]
Faba bean + hemp residues	17.0	1128	5.8	0.9	0.1	< 0.1	[89]
Faba bean + potato skin	15.3–16.0	1223–1350	8.1–14.2	0.3–2.3	0.2–0.3	0.1–0.2	[88]

[1]Heating value given as MJ kg^{-1} FM and converted to MJ kg^{-1} DM using the moisture content

bean residues and potato skin. The ash melting temperature was similar to that of other plant pellets [92].

Compared to woody pellets, faba bean pellets contain higher contents of nitrogen, chloride, and sulphur. Emission levels of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxide (NO_x), sulphur dioxide (SO_2), and unburned hydrocarbons (C_xH_y) were mostly higher compared to wood pellets but did not exceed the limit values [87, 88, 92]. The authors conclude that faba bean plant residues are an appropriate feedstock for combustion. However, Jensen et al. [5] point out that combustion might not be a sustainable conversion technology for nitrogen-rich legume biomass due to the formation of nitrogen oxide emissions.

Faba bean straw was also examined as feedstock for low-temperature pyrolysis at 350 °C for 4 h. The produced biochar was incorporated in four acidic soils at 1% (w/w) and showed positive impact on soil pH and cation exchange capacity. Soil acidity was reduced, and soil fertility improved [58]. While leguminous straw generally yielded more promising chars than non-leguminous feedstock, biochar from faba bean straw showed the lowest performance among the studied legumes [93].

Owing to their high polysaccharide and low lignin content, faba bean residues represent a promising feedstock for biochemical conversion processes. Legume biomass is generally well suited for anaerobic digestion due to the valuable content of nitrogen, phosphorus, and other nutrients and has only slightly lower methane yields than maize and grass biomass [5]. Faba bean whole crop biomass (including the seeds) and straw have also mostly shown high methane production potential comparable to maize (Table 4). Neither ensiling nor wet oxidation of the feedstock improved the methane yield leading to the conclusion that pre-treatment of the biomass is not necessary [51, 59].

As faba bean residues contain high amounts of carbohydrates, they might represent an interesting feedstock in biorefinery processes in order to produce fermentable sugars [60]. Enzymatic hydrolysis resulted in a sugar yield of 28% (w/w) for untreated and 43% (w/w) for pre-treated (wet oxidation) faba bean straw. Simultaneous saccharification and fermentation yielded 6.5% (w/w) ethanol without pre-treatment and 52% (w/w) after pre-treatment [59]. According to Pakarinen et al. [61], the fresh material can even be reasonably well hydrolysed (30% (w/w) of dry matter and 37% (w/w) of total carbohydrates) without a pre-treatment. However, the ethanol yield calculated based on the hydrolysis was significantly lower (196 L t^{-1} DM) than the theoretical ethanol yield (356 L t^{-1} DM), owing to the inaccessibility of the materials without a pre-treatment. Accordingly, in order to fully exploit the potential of faba bean residues, a pre-treatment should be applied. Alkaline pre-treated faba bean residues showed significantly higher saccharification levels compared to water and acid pre-treatment [30].

Table 4 Methane yield from faba bean whole crop and straw (*VS* volatile solids)

Feedstock	Pre-treatment	Inoculum	Methane yield [L CH_4 kg^{-1} VS]	Reference
Maize	-	Digested sewage sludge	379	[61]
Faba bean whole crop	-	Digested sewage sludge	387	[61]
Faba bean whole crop	-	Digested sewage sludge	~ 380	[51]
Faba bean whole crop	Ensiling	Digested sewage sludge	~ 250 – 350	[51]
Faba bean whole crop	Ensiling	Digested corn-silage and cattle slurry	~ 250 – 330	[94]
Faba bean straw	-	Digested manure	440	[59]

Faba bean waste was also considered as source of carbohydrates for a microbial fuel cell. Microbial fuel cells are emerging technologies that produce bioenergy by using microorganisms to degrade biological substrates. Mamani-Asqui et al. [62] dissolved faba bean residues in industrial wastewater inoculated with a bacterial consortium containing the exoelectrogenic bacteria *Pseudomonas aeruginosa*, resulting in an efficient fuel cell. Under optimized conditions (pH 5.5, residue concentration of 6 g L^{-1}, temperature 32 °C), the fuel cell yielded a maximum potential of 802 mV and a maximum power density of 283 mW m^{-2}. According to the authors, the developed fuel cell might be promising for rural areas with limited access to electricity.

The production of biohydrogen from faba bean residues proved only moderately fruitful. Faba bean stems were subjected to an acid hydrolysis using phosphoric acid up to 7% (v/v), followed by fermentative biohydrogen production using *Clostridium butyricum* and *Enterobacter cloacae*. Compared to corn cobs, faba bean stems showed significantly lower sugar production potential (166 vs. 427 g kg^{-1} raw material) and hydrogen yields (0.33 vs. 0.52 mol H_2 per mol hexose) [60, 95].

Faba bean residues have rarely been investigated for their suitability for material and chemical applications. Álvarez-Iglesias et al. [96] explored the phytotoxic potential of aqueous extracts of faba bean straw in an in vitro study. The effect of extracts of varying concentration (10 to 67 g faba bean residues L^{-1}) on the germination and growth of the forage crops maize and soybean and three representative summer weeds was measured. At low concentrations (<50 g L^{-1}), the extracts inhibited the germination and early growth of the weeds while not negatively affecting maize and soybean growth. The effectiveness was higher than that of the synthetic pre-emergence herbicide metolachlor. Faba bean straw extracts might thus be a promising agent for weed control in a sustainable agriculture, albeit experiments under field conditions are needed to corroborate the results [96].

Ground faba bean shoots were investigated for their potential to remove chromium(VI) from aqueous solutions in order to remediate industrial wastewaters. The maximum adsorption capacity (Q_m) was about 19.4 mg g^{-1}. Date palm leaves, however, provided higher removal efficiency ($Q_m = 22.5$ mg g^{-1}) and were more tolerant to different pH levels in the solution [97].

Faba bean stalks have shown to be a promising material for the production of biocomposites. Stalks were successfully liquefied in order to produce biopolyols and polyurethane foam, replacing fossil resources [22]. Faba bean stems were used to produce pulp and paper for corrugated cardboard using a soda semi-chemical pulping process. Biomass chips were digested with an aqueous solution of sodium hydroxide (95 g L^{-1}) at 10% (w/w) solid content for 3 h, and the resulting pulp was pressed and refined. The produced papers had properties related to compression resistance similar or superior to secondary fibres and miscanthus fibres, yet the burst index and the tensile strength index were inferior. It was concluded that faba bean residues represent a promising feedstock for the paper industry. Additionally, hemicelluloses and lignin could be recovered from the spent cooking liquors for the production of value-added chemicals [63].

4 Processing residues—pods

Compared to the harvesting residues, only little research was conducted concerning the composition of the pods. An overview on the composition of the pods based on the existing data is given in Table 5. The main components of faba bean pods are fibres. On average, hemicellulose, cellulose, and lignin together account for almost 55% (w/w). Cellulose makes up the major part (about 36%, w/w), while hemicellulose and lignin are mostly below 10% (w/w). As in the case of the harvesting residues, the cellulose, hemicellulose, and lignin contents show a fairly high variability. Faba bean pods are rich in dietary fibres (40.1% (w/w) [98]–57.5% (w/w) [99]). The crude protein content is rather high at about 14% (w/w), while the fat content is low (about 1%, w/w). The ash content is 8% (w/w) on average and is mainly composed of potassium, phosphorus, sodium, magnesium, calcium, and some trace elements like iron, copper, and zinc [99]. Unlike nitrogen and phosphorus, potassium is mainly accumulated in the pods leading to significantly higher concentrations compared to the seeds and leaves [69]. Faba bean pods contain appreciable amounts of bioactive phytochemicals such as flavonoids and tannins [99–101]. More than 100 phenolic

Table 5 Composition of faba bean pods [34, 36, 42, 69, 98, 99, 101, 103, 104]. All values given as g kg^{-1} DM (*n* number of observations, *SD* standard deviation)

	n	Mean	Minimum	Maximum	SD
Crude fibre	4	424.0	370.0	479.0	51.0
Hemicellulose	5	100.2	49.0	146.0	44.1
Cellulose	5	372.6	305.2	432.0	50.0
Lignin	5	94.4	76.0	116.0	17.2
Crude protein	20	138.8	74.0	291.1	57.9
Starch	2	59.5	2.0	117.0	-
Fat	4	9.2	2.4	13.0	4.8
Ash	9	80.0	46.7	116.0	19.4
N	7	15.4	12.9	17.9	1.8
P	8	4.1	0.7	5.4	1.5
K	11	26.5	19.5	36.7	5.5
Na	5	2.9	0.5	4.8	2.0
Ca	11	4.1	0.7	5.9	1.4
Mg	11	3.5	1.2	5.6	1.5

compounds, mostly flavonoids and their glycosylated forms, were detected in the pods [100]. Total phenolic content (57–149 mg g^{-1} as gallic acid equivalents, GAE), flavonoid content (10.2–45.9 mg g^{-1} as rutin equivalents, RE), and antioxidant activity (0.7–4.5 Fe (II) mmol g^{-1}) showed to be highest in the pods, compared to the seeds and the seed husk [102].

4.1 Pods—food use

Historically, the culinary use of faba pods, for example, in Italy, occurred in times of poverty and food scarcity and allowed the valorization of by-products as "unconventional vegetables" [36, 48]. Today in particular, bean pods as unconventional vegetable could enrich conventional dishes and thus satisfy the current increasing demand for high-quality food [105] and moreover serve as a source of other food-relevant ingredients.

Fresh bean pods are an important food source of protein, energy, and trace elements (Table 5). However, as already described for faba bean seeds, the content of both, macromolecular components and secondary metabolites, can vary quite strongly depending on origin, variety, environmental conditions, time of harvest, and much more [11–15]. For example, Mejri et al. [99] found significantly different fat, ash, and carbohydrate contents in bean pods than described by Mateos-Aparicio et al. in a previous publication [98] and attributed this to the growing location. In the same study, Mejri et al. [99] identified eleven fatty acids, with unsaturated fatty acids (UFA) being the most abundant fraction. The latter were predominantly composed of polyunsaturated essential linoleic acids (39.74%, w/w) and linolenic acids (24.99%, w/w). Palmitic acid (18.2%, w/w) and stearic acid (6.72%, w/w) are the most important saturated fatty acids, accounting for 30.78% (w/w) of the total fatty acids. A similarly large variance is evident when looking at the published values for the protein and carbohydrate contents of faba bean pods (Table 5).

In a cross-comparison of the ingredients of faba bean seeds with bean pods carried out by Renna et al. [36], the authors point out that, in contrast to the seeds, the faba pods have a significantly lower content of the anti-nutrient vicine, with an average of 0.9 g kg^{-1} DM. In comparison, for immature seeds of faba beans, a vicine content ranging between 4.5 and more than 20 g kg^{-1} DM was reported [106, 107]. As already mentioned, and in addition to vicine, other secondary plant compounds are contained in faba bean pods in not insignificant quantities, for example, phenolic compounds, **L**-DOPA and certain vitamins. Although the ascorbic acid content with an average of 0.4 g kg^{-1} FM in the bean pods is ten times lower than the reported values for immature seeds of faba beans, faba pods can still be estimated as a good source of vitamin C, when the recommended daily intake of 45–70 mg is considered [36].

In summary, the studies to date conclude that bean pods should not only be considered a by-product but should also be recognized as a new vegetable in the general food supply in the future or even functionally used in diets for certain diseases. As a possible further application for bean pods in the food industry, both pod flours and dietary fibres isolated from them have so far been investigated for their ability to positively influence baked goods by Belghith-Fendri et al. in 2016. In the first study, the authors investigated the effect of adding up to 1% (w/w) bean pod fibres to white bread doughs [108]. For the fibre extraction, pod flours were maintained in hot water at 70 °C for 15 min and filtrated to discard the insoluble residue. The fibre extracts were subsequently dried at 100 °C. Regarding the effects of dietary fibre (DF) on the texture of baked goods, the proportion of soluble dietary fibre (SDF) or insoluble dietary fibre (IDF) is decisive. While SDF, such as ß-glucan and arabinoxylan, have viscous and gelling properties, IDF primarily bind water. Thus, a positive effect of SDF on bread quality has already been described repeatedly, while a certain concentration of IDF had rather opposite effects. The total DF content for pea pods after extraction was 91.61% (w/w) DM with a proportion of SDF of 5.23% (w/w) and IDF of 86.38% (w/w) each based on dry matter. As a result, the values for broad been pod DF are in a similar range as reported for apple fibre [109]. The proportion of soluble and insoluble DF is also similar for both. In baking tests, a positive change in the rheological and textural properties of the dough was observed. At low concentrations (0.25 and 0.5% (w/w), the loaf volume of the breads was significantly reduced, while higher concentrations of the fibres did not cause differences compared to the control breads. The springiness of the breads was increased up to a fibre content of 0.75% (w/w), while it decreased again from 1% (w/w). Similar observations were also made for the adhesiveness and cohesiveness. The second publication describes the determination of the influence of flours from faba bean pods on the texture and sensory properties of cakes [103]. It was shown that pod flour up to a proportion of 15% (w/w) in the baking mix is suitable as a baking agent, also regarding acceptance in the sensory panel.

The content of bioactive compounds in faba bean pods offers another conceivable use in the food sector. By processing bean pods into extracts, it is possible to use them for food enrichment and functional food production or even to find applications in the pharmaceutical or fine chemical sector.

In 2018, Mejri et al. [99] published a study that investigated the ingredients of broad bean pods in depth. In addition to the study of mineral and lipid content as well as fatty acids and their nutritional quality, the content of bioactive phytochemicals such as phenols, flavonoids, and tannins was investigated. The review should serve to provide fundamental knowledge for the functional use of BBP, for example, as an ingredient in health-promoting bioproducts based on previously unused residues. Within their studies, Mejri et al. examined the most efficient solvents for extracting phenolic compounds from faba bean pods. Methanol proved to be the solvent of choice with the highest recovery of both TPC (115.2 mg GAE g^{-1} extract) and TFC (47.4 mg quercetin equivalents (QE) g^{-1} extract), followed by ethanol, butanol, and ethyl acetate. The highest TPC and TFC values in the methanol extract indicated that the phenolic and flavonoid compounds in the bean pods were of high polarity, including flavonoid glycosides and more polar aglycones. The use of ethyl acetate allowed the greatest proportion of condensed tannins to be extracted (4.6 mg catechin equivalents (CE) g^{-1} extract). Lu et al. [110] could demonstrate that in immature faba bean seeds, both TPC and TFC are strictly dependent on the stage of maturity of the plant. Comparable studies, particularly referring to the content and analytical detection of phenolic compounds from faba pods, have also been published by Chaieb et al. [102], Abu-Reidah et al. [100], and Loizzo et al. [111]. Loizzo et al. [111] showed that (+)-catechin and (−)-epicatechin are the two most prominent smaller phenolic compounds, with syringic acid also being detected. Furthermore, this study showed that significantly higher amounts of the two dominant compounds were found in the pods compared to bean seeds.

Faba bean pods are also considered to be a good material for the extraction of other considerable nutrients, such as glucans and pectins. While the maximum glucan yield (45 mg g^{-1}) was attained at later maturity, the highest pectin yield (17.2%, w/w) was recovered at the first stage of maturation [112].

4.2 Pods—feed use

As shown in Table 5, pods are rich in cellulose and hemicellulose and eventually also in fibres. The protein content is compared with the fibre content relatively low (55.5% vs. 13.8%, w/w) [99]. Due to its high fibre content, it may only be suitable as feed for animals able to handle a high fraction of fibres in their feed. Furthermore, a high fibre content may hinder the digestion of the other compounds [113]. Additionally, to the composition shown in Table 5, pods contain compounds such as phenolic compounds which can exhibit among others antimicrobial and radical scavenging effects [99]. The bioactive compounds obtainable from pods make it even an effective functional food [99].

Valente et al. [114] also investigated the presence of phenolic compounds in faba bean pods and found various derivates of caffeic and coumaric acids. Like Mejri et al. [99], they highlighted the high TPC and the beneficial properties as natural antioxidants for animal and human nutrition and health. It was concluded that pods "may have a key role for both ruminant's condition and dairy products' enhanced quality" and that pods as feed source for ruminants may fulfil "the current demand for alternative feed sources and more sustainable supply chains" [114].

Despite the functional properties associated with faba bean pods, their digestibility and use as feed was described only in a few studies. For instance, Malushi et al. [104] compared the digestibility of different underutilized biomasses. Using defined in vitro methods, pepsin-cellulase digestion or the Tilley and Terry method, they evaluated the digestibility of alfalfa hay, cereal, and pea straws as well as faba bean pods. Depending on the digestion method, 59% and 72% (w/w) of Alfalfa hay, 30% and 47% (w/w) of cereal straw, 43% and 59% (w/w) of pea straw, as well as 39% and 61% (w/w) of faba bean pod was digestible. As a significant fraction of faba bean pods could be digested, the authors concluded that pods should not be underutilized and can be used as feed source.

Results of feeding experiments with faba bean pods fed to ruminants were published already in 1940 by Woodman and Evans [115]. They fed pod-meal to sheep. As already stated above, the authors also found satisfactory digestibility of roughly two-thirds of the feed. In particular, about 75% (w/w) of the nitrogen-free extractives (about 60%, w/w) of the total dry substance is digestible. The authors noted that "the process of lignification has not proceeded far in young pea-pods". Young pods are therefore easier to digest and to utilize as feed.

4.3 Pods—non-food use

Faba bean pods have been considered for a wide range of applications, although the investigations were primarily proof-of-concept or screening studies, often consisting of an initial comparison of different agricultural residues. A focus has not yet emerged, and research is needed to further develop the applications suggested.

Faba bean pods were inspected for their general suitability as feedstock for the extraction of different chemicals and substances. The biomass showed to be a promising novel, eco-friendly source of cellulose and cellulose derivatives. Vallejo et al. [116] investigated a multi-step solvent extraction procedure to produce cellulose that can be applied in the biomedical field as a reinforcing material of composite scaffolds. Four sequential extraction steps eventually yielded 11.4% (w/w) of cellulose. Kassab et al. [117] evaluated the suitability of faba pods for the production of cellulose derivatives. Cellulose microfibres and cellulose nanocrystals were successfully extracted from the pods with a yield of 18% (w/w) of the raw pod weight and 66% (w/w) of the cellulose microfibre weight, respectively. The produced cellulose microfibres and nanocrystals might be used in various technological applications such as in the biomedicine, cosmetics, or electronics industry.

Additionally, faba bean pods showed to be a rich source of peroxidase enzymes that could potentially be applied in the environmental, biotechnological, chemical, or food industry. The percentage recovery after purification of peroxidases was at 8.9% and higher than for pea pods (4.3%) and artichoke stems (7.2%) [118]. Tyrosinase inhibitory peptides could successfully be extracted from the pods by enzymatic proteolysis. The generated peptides exhibit potential to be used in the nutraceutical field in order to cure or prevent diseases that are caused by high tyrosinase levels [119].

A few studies have also investigated the application of products derived from faba bean pods. Faba pod extracts were assessed for their nematicidal activity against three nematode species. Compared to seven other agricultural wastes, faba bean pods and cabbage leaves, hydro-alcohol extracts showed the highest in vitro nematistatic properties, which were additionally corroborated by in vivo assays. It was supposed that the nematicidal activity was derived from the presence of phenolic compounds [120]. A natural dye for wool fabrics could successfully be extracted via alkaline aqueous extraction from the pods. The aqueous extract was characterized by a dark brown colour, which is related to low molecular weight phenolic compounds and tannins [121].

Bouatay et al. [122] investigated the valorization of faba pods mucilage as a natural flocculent for the treatment of textile wastewater. At optimal experimental conditions, the decolorization, the chemical oxygen demand (COD) removal, and the turbidity abatement were of 92.3%, 97.5%, and 81.8%, respectively. The mucilage showed good flocculation performance. Compared to two commercial flocculants, COD removal was higher, while decolorization and turbidity removal were somewhat lower. Beyond that, faba bean pods were tested as sorption agent for the removal of heavy metals from wastewater. Q_m for cadmium was 147.7 mg g^{-1} and thus significantly higher than that of peas and medlar peel and fig leaves (118.9, 98.1, and 103 mg g^{-1}, respectively) [123].

5 Processing residues—husks

Similar to the pods, there is sparse information on the general composition of the faba bean husks. Table 6 gives an overview on a couple of data. The major fraction are carbohydrates, including dietary fibres, which make up to almost 80% (w/w) of the husk dry mass and starch, which amounts to only 3% (w/w) on average. The husks contain high-fibre fractions, which are mostly made of cellulose and to a lesser extent of hemicellulose and lignin. The average crude protein and fat contents are rather low at about 8% (w/w) and below 1% (w/w), respectively. The ash content is only 3% (w/w), but nonetheless, husks are considered to have a high mineral content [19].

Table 6 Composition of faba bean husks [16, 19, 45, 124–137]. All values given as g kg^{-1} DM (*n* number of observations, *SD* standard deviation)

	n	Mean	Minimum	Maximum	SD
Crude fibre	12	457.5	302.2	628.0	103.9
Dietary fibres	4	781.0	731.0	823.0	41.5
Hemicellulose	11	49.9	12.3	108.7	33.4
Cellulose	10	614.7	435.1	747.5	105.0
Lignin	15	64.0	5.6	175.0	56.5
Crude protein	28	81.5	43.0	207.9	43.8
Starch	2	23.4	9.0	37.7	-
Fat	7	6.8	1.0	32.0	11.2
Ash	19	31.8	23.0	55.0	8.0

TPC of husks was found to be between 21.5 and 110.3 mg GAE g^{-1} [19, 102, 138]. Compared to the seeds, TPC was four (*V. faba* major) to eight times higher (*V. faba* minor) in the husks [46]. Tannins contribute the most to TPC (55–80%) [46, 139]. Dehulling reduced the tannin content in the seeds by 72% (*V. faba* major) and 27% (*V. faba* minor) [46]. Flavonoid content in the husks ranges from 5.7 to 17.6 mg RE g^{-1} [102], being fivefold higher than in the seeds [46]. Owing to the high phenolic and tannin content, the husks show a strong antioxidant activity [19, 46].

5.1 Husks—food use

Dehulling harvested faba beans is useful to increase the nutritive benefits of the beans in various foods as the husks are rich in tannins, often believed being anti-nutrients or of low nutritional value because of their astringency, the possibility of complexing trace elements, decreasing feed intake, growth rate, protein digestibility, etc. [140–142]. However, due to their antioxidative character, tannins have also anticarcinogenic and antimutagenic potentials [141, 142].

As mentioned above, faba bean husks are rich in dietary fibres. One important fibre is pectin, which is used in many ways in food and pharmaceutical products due to its gelling, stabilizing, and emulsifying properties [143, 144]. As the global demand for pectin is steadily increasing and more and more industries emerge that require pectin [145], faba bean husks can be an excellent natural alternative to produce pectin [143, 146].

Faba bean husks can be a useful way to integrate phenolic compounds into foods as natural antioxidants, as they contain up to 110 mg GAE g^{-1} [19, 102, 138]. Due to the high TPC, husks of faba beans have high antioxidant properties. In experiments with enriched burger patties, results showed that faba bean husks improved cooking properties, delayed lipid and protein oxidation, prevented colour changes, and decreased the microbiological load of burger patties [147].

Husks of faba beans among other legumes were incorporated into the recipe of Turkish noodles with the results that there were slight changes in texture, but sensory acceptability was still present at 10% (w/w) enrichment [148]. Another possible application of faba beans husks is to incorporate them into bread and, thus, enrich it with dietary fibres. While satiating effects increased compared to non-enriched bread, consumer acceptance decreased slightly [149]. Further studies have shown that up to 21% of wheat flour can be substituted with faba bean husks without affecting the texture and volume of the bread. Unfortunately, subjective sensory acceptance was not investigated by a panel in this study [124]. The enrichment of corn-based extruded snacks with husks or ground-fermented faba beans increased the nutritional value and did not influence consumers' acceptance [150].

In general, faba bean husks can improve the nutritional profile of foods, meeting increasing consumer demand for healthier foods with nutritionally valuable ingredients. In addition, it is advisable to improve the technofunctional and functional properties of the husks in the future through targeted technological processing and preparation, thus expanding their use in food.

5.2 Husks—feed use

As mentioned before, the anti-nutritional tannins limit the use of faba bean husks. In growing broiler chickens, it was shown that the addition of tannins to the basic feed significantly reduced protein digestibility and that this effect increased with increasing tannin content [151, 152]. The same could be observed for other animal species such as sheep [125] and pigs [126, 127]. In a group of sheep fed with husks, at least a slight increase in the nitrogen retention could be proven [125]. Rubio et al. [128] have not been able to find any effect from the inclusion of husks or autoclaved husks in the feed of broiler chickens compared to husk-free feed. This is also in line with the results from an experiment in which the feed of sheep was substituted with up to 33% (w/w) husks and no significant differences could be detected [129].

In feeding experiments with faba bean seeds with varying levels of tannin in the diet of turkeys, the body weight gains of the turkeys were independent of the diet. However, feed conversion was lower in the groups fed with seeds low in tannin content than in the groups fed with high tannin seeds. The authors state that tannin-containing seeds can be mixed into the feed up to 30% (w/w) without negative effects [153]. Furthermore, Trevino et al. confirmed in their studies that the weight of the chickens, the feed intake, and feed efficiency were reduced by adding tannins to the feed [154]. In other studies, it was shown that chicken feedstuff with husks from tannin-rich varieties of faba beans caused a reduction in the digestion of amino acids, starch, and lipids compared to non-tannin-rich varieties [155]. The authors explained this with the inactivation of digestive enzymes through the formation of tannin-enzyme complexes in the digestive tract. The addition of husks or beans to piglet feed modified the microflora, with the potential to prevent intestinal diseases through targeted legume supplements to the feed [156]. In further studies on the milk performance of dairy cows, it was found that the addition of 30% (w/w) field bean husks to the feed improved the milk yield, feed conversion, and fat content of the milk compared to the other treatments. In addition, the author described that up to 13.6% of the costs can be saved through this proportional substitution [130].

Considering these facts, it seems important to analyse the tannin content of faba bean husks and seeds in order to add the appropriate amounts to animal feed to have beneficial and cost-saving effects. Another possibility could be to focus on low-tannin varieties in cultivation and breeding.

5.3 Husks—non-food use

The focus of the non-food utilization of faba bean husks has so far been on the application as low-cost and environmentally friendly sorption agent to remove heavy metals and synthetic dyes from wastewaters. Q_m derived from the Langmuir mono-layer adsorption model of different studies is given in Table 7. Activated carbon (AC) prepared from different feedstock is listed for comparison of the adsorption capacities as it is the most commonly used adsorbent. Admittedly, the capacities cannot be compared directly with each other, due to differing experimental conditions that influence Q_m such as the temperature [157] and the pH value [158], yet a general evaluation can be obtained. It is

Table 7 Comparison of adsorption capacity of different contaminants of faba bean husk and activated carbon (Q_m maximum adsorption capacity, *AC* activated carbon)

Contaminant	Sorption agent	Q_m [mg g^{-1}]	Reference
Methylene blue	Faba bean husk	192.7	[160]
	Faba bean husk	140.0	[161]
	Bamboo AC	454.2	[162]
Brilliant green	Faba bean husk	21.7	[159]
	Pine fruit shell AC	211.7–298.5	[163]
Eriochrome black T	Faba bean husk	5.6	[159]
	Rice hull AC	160.4	[164]
Cobalt	Faba bean husk	0.9	[165]
	Apricot stone AC	111.1	[166]

evident that the untreated faba bean husks have significantly lower adsorption capacities than activated carbon, but they provide a low-cost and low-tech adsorption option. Nahali et al. [159] nevertheless deem it a promising adsorbent due to its regional abundance and the possibility to increase the adsorption capacity by experimental protocols that activate more sites. However, no concrete suggestions for procedures are given.

Other than adsorption, faba bean husks have been investigated as a natural colouring agent. Polyamide fabric samples were dyed with the aqueous extracts of husk powder, and different mordants were added. A colour gamut and a satisfactory dyeing performance could be achieved [167]. A variety of crop hull wastes, including faba beans, have been examined for their suitability as replacer of bleaching clays for the bleaching of crude soybean oil. The carbonized and activated husks could compete with the industrially used materials Fuller's Earth and Tonsil N [168]. Furthermore, it was shown that the husks are suitable as substrate for the production of edible mushrooms, which in turn can be used for food and animal feed [131].

6 Conclusion

Several residual materials are produced throughout the harvesting and processing of faba beans. The plant residues constitute about 50% (w/w) of the whole aboveground biomass, while the empty pods and husks account for about 11% and 6% (w/w) on average, respectively. This paper highlighted the food, feed, and non-food valorization of those residues.

The most widespread application of the plant residues is the reincorporation into the soil as green manure. Removal of residues could adversely affect soil quality; thus, consideration must always be given to what quantities can be reasonably removed. Nevertheless, a variety of bioeconomic applications have been investigated, including conventional processes such as combustion, anaerobic digestion, or ethanol production but also novel applications such as wastewater remediation, production of biocomposites, or production of pulp and paper. The fresh faba greens have potential as an unconventional vegetable due to their nutrient-rich composition. The straw might be used as roughage or in a mixed diet for animals, but since the metabolizable energy content and the digestibility are rather low, supplementation or pre-treatment might be necessary to attain optimum animal performance.

Faba bean pods are only produced as a separate fraction when the beans are freshly harvested; otherwise, they are part of the harvest residues. Owing to their nutrient-rich composition, the pods should be recognized as a new vegetable for human consumption. Likewise, the pods constitute a source for the extraction of several value-added compounds, such as cellulose, peroxidases, or bioactive substances. The use of faba pods in the feed sector has been little studied so far. Despite their high-fibre content, they can be beneficial for animal nutrition as a source of bioactive substances. In addition, it was shown that the pods might be effective in remediating wastewater.

Both when consuming fresh and dry beans, the husks are usually removed in order to increase the nutritive benefits of the beans, as the husks contain high contents of antinutrients. Therefore, they should only be included in diets to a certain extent, for example, to enrich food products with antioxidants or fibres. In the feed sector, the use of the husks is also limited by the anti-nutritional properties, and the tannin content should be carefully monitored before including the husks in an animal's diet. Until now, research on the husks in the non-food sector has focused on the application as a low-cost environmentally friendly sorption agent to remove heavy metals and synthetic dyes from wastewater.

This review paper has shown that the residual materials of faba beans contain valuable components and might be used for a multitude of different applications, be it in the food, feed, or non-feed sector. The material should thus not be disposed of but further valorised in order to exploit the full potential of the biomass. However, especially with regard to food and non-food use, the valorization processes still have to be established. Further research is particularly needed to unleash the potential of husks and pods for different applications.

Abbreviations *AC*: Activated carbon; *CE*: Catechin equivalents; *COD*: Chemical oxygen demand; *DF*: Dietary fibre; *DM*: Dry matter; *FM*: Fresh matter; *GAE*: Gallic acid equivalents; *IDF*: Insoluble dietary fibre; *IVDMD*: In vitro dry matter digestibility; *IVOMD*: In vitro organic matter digestibility; *L-DOPA*: L-3,4-dihydroxyphenylalanin; *LHV*: Lower heating value; *NDF*: Neutral detergent fibre; *ME*: Metabolizable energy; *Qm*: Maximum adsorption capacity; *QE*: Quercetin equivalents; *RE*: Rutin equivalents; *SD*: Standard deviation; *SDF*: Soluble dietary fibre; *SOC*: Soil organic carbon; *TFC*: Total flavonoid content; *TPC*: Total phenolic content; *VOC*: Volatile organic compound; *VS*: Volatile solids

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