July 2019. Horticultural Plant Journal, 5 (4): 170–182.

Horticultural Plant Journal

Available online at www.sciencedirect.com
The journal's homepage: http://www.keaipublishing.com/en/journals/horticultural-plant-journal

Agronomy, Nutritional Value, and Medicinal Application of Faba Bean (*Vicia faba* L.)

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Received 18 November 2018; Received in revised form 27 January 2019; Accepted 21 March 2019

Available online 19 April 2019

A B S T R A C T

Faba bean (*Vicia faba* L.) is a cool season grain legume crop with the potential to be grown as multi-purpose crop in areas with short growing season. Faba bean is grown in many regions in the world due to its high nutritional value, medicinal effect, and effective biological nitrogen fixation. Diverse ecosystem benefits are expected from integrating faba bean in cropping systems. This paper specifically reviews the published work covering agronomic practices, nutritional values, medicinal benefits, and faba bean's capacity for nitrogen fixation.

Keywords: Biomass; Faba bean; L-Dopa; Nitrogen fixation; Nutrient

1. Faba bean overview

Faba bean is a cool-season grain legume crop originated in the Middle East in the pre-historic times and traditionally used as a main source of protein for human and animal nutrition (Multari et al., 2015a,b). The genus Vicia is in the family Fabaceae, which is enormous in number of species with worldwide distribution. Current estimates are of 16,000–19,000 species in approximately 750 genera in this family (Chakraverty et al., 2013). The Fabaceae is second only to the grasses (Poaceae) in terms of economic importance. Various species of Fabaceae are currently growing in temperate areas, humid tropics, arid regions, highlands, savannas, and lowlands, and there are even a few aquatic legumes (Wrigley et al., 2015).

In optimum growing conditions, germination of faba bean seeds takes 10–14 days (Etemadi et al., 2015). However, it will take much longer in dry condition or when soil temperature is cold. On average, faba bean plant grows one node per week. Because faba bean stems are relatively strong and grow upright, the plant can grow 90–130 cm tall, mainly depending on the genotype. At the 8–10 node growth stage, when the plant is around 30 cm tall, faba bean produces its first flowers, usually in the month of June in the Northeastern USA. Flowers and pods appear about 20 cm above the ground. Roughly 25% of the flowers will produce pods, which usually contain three to six seeds (Etemadi et al., 2015). Therefore, proper management practices including irrigation, soil fertility, and time of planting can significantly reduce the number of aborted flowers, thus improve final seed/pod yield.

Generally, seed germination of most legumes is sensitive to low soil temperature. However, faba bean is one of the few cool-season grain legumes and its germination can tolerate cold soil temperature better than most grain legumes. Attempts to select for improved seed germination at the soil temperatures below 15 °C have shown some degree of success

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Peer review under responsibility of Chinese Society for Horticultural Science (CSHS) and Institute of Vegetables and Flowers (IVF), Chinese Academy of Agricultural Sciences (CAAS)

https://doi.org/10.1016/j.hpj.2019.04.004

(Singh and Jauhar, 2005). Better germination rate has been reported in large-seeded cultivars than in small-seeded beans at 12.5 °C (Kang et al., 2008).

Due to the superior nutritional values including protein, carbohydrates, B group vitamins, and minerals (Crépon et al., 2010), faba bean is considered as one of the most important pulse crops in the world. In recent years, cultivation of faba bean has received large attention in USA, Canada and Europe (Etemadi et al., 2014a, 2015, 2018a). As a cool-season legume, faba bean can be included in various cropping systems in shorter-growing season regions such as Northeastern USA. However, currently only two varieties of faba bean are available to the growers in the Northeastern USA. The current available varieties demonstrated some drawbacks such as high seed cost due to the large seed size and relatively low pod yield (Etemadi et al., 2017).

Faba bean is used not only as staple food but also integrated into various crop rotation systems to minimize the occurrence of cereal cyst nematode (*Heterdera avenae*) and soil-borne pathogens (Landry et al., 2016). Faba bean is partially a self-pollinating plant, however flowers attract various pollinators, specifically honey bees. Current reports indicated that honey bees and other natural pollinators can increase the pollination incident and thus grain yield in faba bean (Musallam et al., 2004; Marzinzig et al., 2018).

Faba bean has been identified for its efficient N fixation capacities which is the highest among the cool season legumes (Mekkei, 2014). Reports indicated that faba bean can fix 50–330 kg $N{\cdot}hm^{-2}$ (Galloway et al., 2004; Etemadi et al., 2018d) depending on cultivation management and environmental conditions (Hu and Schmidhalter, 2005). Legumes have a substantial role in maintaining soil fertility, not only through biological N fixation but also by solubilizing insoluble phosphorus (P) in soil, improving the soil physical environment, and increasing soil microbial activity (Rashid et al., 2016). In legumes, the development of effective root nodules with the high capacity for symbiotic N fixation involves a complex series of interactions between the host plant and the symbiotic bacteria (Guinel, 2009). Genetic variation for N fixation has been identified in faba bean (Graham and Vance, 2000). Other factors such as nodule efficiency and earliness and duration of nodulation may also play important role (Martinez-Romero, 2003). It is well known that legumes generally respond to existing N concentration in the soil (Graham, 2008). In soils with relatively high N, legumes prefer using soil N rather than to engage in symbiosis with rhizobia (Divito and Sadras, 2014). However, minimal application of N may stimulate N fixation by improving early plant growth until N fixation provides adequate N for plant growth and development (Huang et al., 2017; Abdul Rahman et al., 2018). On the other hand, fertilizer application rates exceeding the minimal "starter-N" generally suppress nodulation and N fixation (Kinkema et al., 2006).

Variation in time to reach specific phenotypic stage is related to the sensitivity of the genotypes to variations in the photo-thermal regimes, thus affecting days to maturity, adaptation to the environment, and crop's yield in diverse growing conditions (Aghaalikhani et al., 2012). Different types of faba bean, including spring, winter, and Mediterranean, exhibit various phenological characteristics; therefore, induction and maintenance of flowering differ among these classes (Patrick and Stoddard, 2010).

Table 1 Seed size of some faba bean varieties

Cultivar	Seed size/($g{\cdot}seed^{-1}$)	Seeding rate/($kg{\cdot}hm^{-2}$)
Aquadulce	2.65	165
Bell Bean	0.51	32
D'Aquadulce	3.92	244
Delle Cascine	3.35	208
Early violletto	2.80	174
Early white	2.53	157
Sweet Lorane	0.68	42
Windsor	3.11	193

Note: Etemadi et al. (2017).

2. Agronomic practices

Traditional agronomic practices in faba bean include certain steps for best incorporating the crop into farming systems to improve soil quality, enhance water use, manage crop residues, and improve the environment through better fertilizer management. Some of the most important agronomic practices in faba bean cultivation are described below.

2.1. *Seed size*

Faba bean is generally considered as a large-seed crop, however its seed size varies greatly among varieties and cultivars (Table 1). Within each cultivar, the seed size also varies greatly depending on pod location. Faba bean seeds are classified as large (>1.0 $g{\cdot}seed^{-1}$), medium (0.5–1.0 $g{\cdot}seed^{-1}$) and small (<0.5 $g{\cdot}seed^{-1}$) (Etemadi et al., 2015). Traditionally at the farm level, the desired population density is determined by the seeding rate, which is primarily determined by the number of seeds per unit weight (kg) (Gezahegn et al., 2016). Plant breeders have recognized the importance of larger seeds in production of food crops and have been breeding for the trait for years. The general conception is that large seeds have more food reserves thus germinate faster, have better vigor and higher yield than smaller seeds within the same cultivar (Harker et al., 2015; Patel et al., 2016). However, the use of smaller seeds can significantly reduce the production costs by lowering the number of seeds needed per unit area (Etemadi et al., 2017). For example, for cultivars presented in Table 1 (Etemadi et al., 2017) the seeding rate varies from 32 to 244 $kg{\cdot}hm^{-2}$ which dramatically influences the seed cost. Seed cost is especially important when faba bean is grown as cover crop or as dual-purpose cash and cover crop. When used as cover crop, it is highly recommended to select small seeded varieties.

2.2. *Seed treatment*

Rhizobia can live in the soil for several years; however, the most efficient N-fixing bacteria may not be among the ones that survive. Although rhizobium bacteria remain alive for 3–5 years in soils, it is recommended to inoculate the seeds every year for achieving maximum N fixation. Faba bean seeds should be inoculated with *R. leguminosarum* cv. viciae (Abd-Alla et al., 2014). Inoculants should be kept dry and fresh and stored properly (Rodelas et al., 1999). Seeds should be inoculated just before planting (Etemadi et al., 2015) so that large numbers of rhizobia will be ready to start the infection process as soon as the roots emerge.

These rhizobia can infect the roots quickly and start the process of nodulation (Makoudi et al., 2018).

2.3. Seeding rate

For most legumes, the choice of population is an important agronomic practice that not only affects their final yield but also influences the amount of biologically N fixation. When used as cover crop, a legume needs to produce at least 4 000–4 500 kg·hm^{-2} of biomass to provide sufficient available N to meet the N demand of succeeding crop (Parr et al., 2011).

The optimum plant population of faba bean for maximum pod and grain yield as well as N fixation is not well documented. A wide range of densities of faba bean is commonly used, from 45 000–60 000 plants·hm^{-2}, depending on the cultivar (seed size) and the region.

Like other grain crops, the response of faba bean to increasing population density is parabolic. However, due to high seed cost the economic population density should be considered for recommendation to the growers. Regardless of seed size, faba bean yield reaches its maximum yield at different plant populations depending on the size of the seed; the smaller the seed, the higher the plant population is needed to reach the yield peak at around 60 000 plants·hm^{-2}. It must be noted that faba bean tends to produce more lateral branches when grown at below optimum populations. The lateral branches often are not as productive as the main stem, therefore, seeding rates should be adjusted for lowering the number of lateral branches and limit them to 2–3 per plant in order to maximize the yield (L'opez-Bellido et al., 2005). There is a correlation between high seeding rate and high humidity within the canopy. Given the fact that faba bean is more sensitive to diseases in high humidity, high populations should be evaluated not only for higher yields but also susceptibility to diseases. Also, when possible, west-east planting pattern is preferable for faster drying by sunlight.

2.4. Variety

Like other crops, variety or cultivar selection requires achieving a balance between adaptability to a specific environment, disease tolerance, purpose of cultivation, and marketability (Zandvakili et al., 2018). Faba bean varieties vary significantly in seed size and color. Small-seeded types (*Vicia faba* L. subsp. *minor*) also called faba bean or tick bean are commonly used for feeding animals and cover cropping. Medium and large size seed types (*V. faba* subsp. *major* Harz) are called broad bean and commonly used as dry and green beans (Crépon et al., 2010). Although modern cultivars dominate in Australia, Europe and Canada, traditional landraces are grown widely in many countries and a mix of traditional and modern varieties are grown in other countries. Germplasm with best adaptation in Southern Australia originated from the Mediterranean Basin and was the basis for the commercial varieties Fiord and Fiesta (Gnanasambandam et al., 2012). In 2014, three cultivars of high-yielding faba bean were released in Sudan which can tolerate temperatures up to 35 °C including 'Hudeiba93', 'Basabeer' and 'Ed-Damer'. These cultivars have increased faba bean yields in Sudan by 40% and currently are dominating the farmers' fields in the country. The cultivars released in Egypt in 2011, 'Nubaria 3′ are drought tolerant (ICARDA, 2018). In New England, the variety Windsor is currently the dominant cultivar available to the growers (Etemadi et al., 2017). Thus, evaluating more varieties for high potential yield and suitable morphological characteristics can provide valuable information to the researchers and faba bean growers. In addition, introducing faba bean with smaller seed size may result in adoption of faba bean as an efficient N-fixing cover crop.

2.5. Ideal soil conditions

Faba bean grows best on fine-textured soils but tolerates nearly any soil type (Jensen et al., 2010). The ideal soil pH for growing faba bean is $\geq$ 7 (Köpke and Nemecek, 2010). In areas with relatively high precipitation such as Northeastern US, the soils tend to be acidic (New England Vegetable Guide, 2018). Therefore, liming is required for faba bean cultivation when soil pH level is below 6. Although sandy loams are suitable for growing faba bean but more frequent irrigation will then be required. Faba bean has relatively shallow roots, thus the crop may suffer from drought stress in soils that dry quickly. Faba bean seems to be tolerant to short period of water-logging (Tekalign et al., 2016).

2.6. Soil fertility

2.6.1. Nitrogen

In general, legumes are known as self-sustaining crops regarding N. However, the efficiency and magnitude of biologically fixed N varies greatly among the legumes. Legume species that meet 50%–90% of their total N requirements from symbiotic N fixation are considered effective N fixer (N'Dayegamiye et al., 2015). Faba bean and soybean with 75% and 68%, respectively are ranked as high capacity legumes for N fixation (Hoffmann et al., 2007; Peoples et al., 2009).

Arguably, the most important contribution of faba bean to agricultural ecosystems is the substantial amount of atmospheric N that can be fixed by the hosting legume and its associated rhizobia. Depending on the growing conditions, faba bean can fix up to 200 kg N·hm^{-2} (Hoffmann et al., 2007; Horst et al., 2007; Etemadi et al., 2018d). However, the amount of biologically N fixation by legumes is influenced by many factors. Variations in soil pH, water and nutrient availability, and soil temperature, are among factors greatly influence the growth, survival, and metabolic activity of biological N fixation (Mohammadi et al., 2012). Legume plants generally respond to existing N in the soil and often reject symbiosis with rhizobia when enough N is available in the soil (Sinclair and Nogueira, 2018). This effect of plant available soil N is greatest during early vegetative growth, where N fixation by faba bean is low (Vance et al., 1988; Kinkema et al., 2006).

There has been some controversy about the requirement for sowing grain legumes with low levels of "starter N" to overcome N-limitations during early growth stages, however in general positive yield response is seldomly observed when the soil contains >20–30 kg N·hm^{-2} in the plow layer (Roman et al., 2004). Interestingly, faba bean differs from many other legumes and maintains its N-fixing capabilities, even if soils are relatively rich in N (Peoples et al., 2009; Kőpke and Nemecek, 2010). Since the host legume provides carbohydrates to the rhizobia, optimum photosynthesis is required to support maximum derivation of

Table 2 Recommendation for phosphorus fertilizer for faba bean

Nitrogen/(kg·hm^{-2})		Phosphorus P_2O_5/(kg·hm^{-2})				Potassium K_2O/(kg·hm^{-2})			
Soil test result		Very low	Low	Optimum	> Optimum	Very low	Low	Optimum	> Optimum
Recomm. rate	50	100	75	0–50	0	100	75	0–50	0

Note: New England Vegetable Guide, 2018.

atmospheric N to meet N requirement of the legume host plant. It is well documented that the magnitude of agronomic services from legume cover crops are largely dependent on the amount of biomass they can produce at harvest (Finney et al., 2016; Mirsky et al., 2017). Early planting is considered as one major factor that influences legume biomass yield (Komainda et al., 2016; Etemadi et al., 2018d) especially when faba bean is used for cover cropping purpose.

2.6.2. *Phosphorous*

Phosphorous (P) plays important roles in nodulation and biological N fixation, photosynthesis, and nutritional values of legumes including faba bean (Haling et al., 2016; Makoudi et al., 2018). Phosphorus application often results in increased yield and biomass of faba beans in P-limited soils (Daoui et al., 2012), indicating that P fertilizer is essential for grain production in faba beans (Nebiyu et al., 2016). Also, it has been shown that the induction of plant histidine acid phytase HAP gene depends on P sufficiency in faba bean and significant induction of phytase activities in nodules has been reported under P deficiency (Nasto et al., 2017; Makoudi et al., 2018). Makoudi et al. (2018) concluded that under P deficiency condition, more P is allocated to the nodules of faba bean than shoot, presumably to maintain atmospheric N fixation which requires significant amount of energy. Under P deficiency legume reduce their N fixation in exchange for a greater preference for soil available N uptake by roots (Magadlela et al., 2014; Valentine et al., 2017). Although faba bean yield may be compromised by low availability of soil P, it has been demonstrated that faba bean has the capacity of mobilizing soil P by secretion of acids from its rhizosphere (Zhang et al., 2016). When soil P level is high, faba bean can still benefit from application of starter P fertilizer (Selles et al., 2011; Rosolem et al., 2014; Gelfand and Robertson, 2015) (Table 2).

2.6.3. *Potassium*

Potassium (K) is an essential nutrient and is involved in plant metabolism by activating many enzymes and plays important role in water management of plants (Zörb et al., 2014). Faba bean often responds positively to K application, especially in dry growing seasons (Barłóg et al., 2018). Availability of adequate K to faba bean plants has a positive effect on N fixation (Römheld and Kirkby, 2010; Gucci et al., 2019). Increased biomass and grain yield production have been reported when K fertilizer was applied to faba bean (Mona et al., 2011; Grzebisz et al., 2013). It is shown that the symbiotic system in faba bean is less tolerant to limiting K supply than the plant itself, but when nodulation occurs, the assimilation of N from the symbiotic source will not be selectively affected by K as opposed to N assimilation from fertilizer (Sangakkara et al., 1996). Furthermore, application of organic fertilizers such as poultry manure (Abdelhamid et al., 2004) and/or combination of mineral and organic fertilizers resulted in the same faba bean productivity as full mineral fertilization (Gucci et al., 2019).

2.6.4. *Magnesium*

Magnesium (Mg) deficiency can reduce faba bean yield (Hariadi and Shabala, 2004). Availability of Mg to plants is affected by various factors including soil moisture deficit or high level of other cations in soil (Cakmak and Marschner, 1992). Although the influence of Mg on biological fixation of atmospheric N in faba bean is not well documented, Peng et al. (2018) reported that application of Mg improved nodule growth and formation of large nodules in soybean. Reports indicated that there is a relationship between Mg supply and the efficiency of N use since the stabilization of RNA depends on Mg with its major function for the activation of glutamine synthetase (Grzebisz et al., 2010). Magnesium application often results in higher concentration of chlorophyll and subsequently higher photosynthesis rate which improves pod yield (Neuhaus et al., 2014).

2.6.5. *Sulfur*

There is a growing evidence that application of sulfur (S) to various crops resulted in their yield improvement due to reduction in industrial emissions and the associated decrease in deposition of S in soils (Scherer, 2009; Pötzsch et al., 2018). Other reasons for S deficiency in soils could be cultivation of high yielding varieties and use of S-free fertilizers. Sulfur is essential for legume-rhizobium symbiotic system, thus application of S fertilizer to the deficient soils may result in increased number and weight of the nodules, total dry matter, grain yield and total amount of N fixed by faba bean especially in soils with low organic matter (Scherer, 2008; Cazzato et al., 2012). In general, legume crops require higher amount of S compared with cereals due to their higher amount of proteins and S-containing amino acids including methionine and cysteine in their seeds (Barłóg et al., 2018). Pötzsch et al. (2018) reported that concentration of S in faba bean shoots was like those of peas but lower than soybean and the absorbed S was mainly accumulated in the seeds of faba bean. Although the benefit of S application in improving faba bean yield may have been due to various reasons, in general positive yield responses have been reported when faba bean was fertilized with S (Cazzato et al., 2012; Barłóg et al., 2018).

2.6.6. *Molybdenum*

Nitrogen fixation in faba bean is strongly associated with the Molybdenum (Mo) status of the shoot tissue (Van Zwieten et al., 2015). The availability of Mo in acidic soils is limited mainly due to sorption to Fe and Al-oxides (Smith et al., 1997). Therefore, application of lime to the acidic soils can significantly enhanced Mo availability in soils and higher Mo content in faba bean seeds (Van Zwieten et al., 2015).

3. Date of planting

In temperate regions faba bean is grown either as winter crop or as spring crop where temperature and day-length are significantly different than winter conditions in Mediterranean-type environments (Luna-Orea et al., 1996). In long growing season conditions, plants often compensate for low plant populations density by producing larger number of lateral branches (Mirshekari et al., 2012; Etemadi et al., 2015). Therefore, the crop cycle i.e. autumn–winter sowing versus spring sowing, greatly influence the length of the vegetative period, thus the final dry matter. The biomass and grain yield benefits from early planted legumes have been documented (Keneni and Imtiaz, 2012; Etemadi et al., 2018d). In general, delay in faba bean sowing resulted in seed yield reduction (L'opez-Bellido et al., 2005). In New England, delay in spring planting of faba bean results in coincidence of flowering stage with high temperatures in summer which not only increase the number of aborted flowers and pods, but also intensifies the incident of chocolate spot bacteria disease (Etemadi et al., 2015).

4. Method of planting

Traditionally faba bean is seeded directly into the soil. However, to ensure early sowing in shorter-season areas, faba bean may benefit from transplanting compared with direct seeding (Etemadi et al., 2015). In shorter-growing season region such as Northeastern US, transplanting faba bean provides the opportunity for double cropping and avoids incident of some diseases such as chocolate spot (*Botrytis fabae*) (Etemadi et al., 2018e). Moreover, in such areas, weather conditions including wet soil in early spring may not allow early planting, thus transplanting faba bean can be considered as an alternative method to direct seeding. Transplanting seedlings also offers some other potential benefits including higher yield, better survival rate, early flowering, and earlier harvest (Lee et al., 2018). Transplanting faba bean requires an indoor sowing in late March and transplanting into the main field when seedlings are approximately 15 cm tall. Research indicated that the optimum temperature for growing faba bean in the greenhouse is 15 °C and seedlings will be ready for transplanting within 12–15 days (Etemadi et al., 2015). Pro-mix media in a 3.2 cm cell size tray is enough for this short growing period in the greenhouse.

In the field condition, faba bean seeds should be planted about 2.5 cm deep and the distance between plants on planting rows is 15 or 23 cm, depending on row spacing. This planting arrangement provides approximately 48 000–60 000 plants·hm^{-2} (Etemadi et al., 2015).

5. Diseases

5.1. *Chocolate spot (Botrytis fabae)*

Chocolate spot is one of the most important economic disease that damages the foliage, limits photosynthetic activity and faba bean production (Torres et al., 2004). Long periods of high humidity and high temperature promote the switch from a non-aggressive phase to an aggressive phase of the disease (Terefe et al., 2015). The aggressive phase of the disease is favored also by low levels of K and P in the soil and high plant population density, which leads to more humid conditions within the plant canopy. Symptoms for non-aggressive chocolate spot include small red-brown lesions on leaves of the plant and sometimes on stems and pods (Haile et al., 2016). Prevention is the most effective management strategy. Early planting is recommended to avoid high humidity and high temperatures in late spring and early summer (Kora et al., 2017). Appropriate plant spacing to encourage air circulation within the canopy is also an effective management tool. Foliar fungicide application throughout the season can be effective (Hawthorne, 2004).

5.2. *Leaf blight (Xanthomonas campestris, syn. Xanthomonas axonopodis)*

Leaf blight is another bacterial disease that can be introduced by contaminated seeds and over-wintering of bacteria in crop residues (Belete and Bastas, 2017). This disease is favored by warm temperatures and wet, humid conditions.

Water-soaked spots on leaves which enlarge and become necrotic. Spots may be surrounded by a zone of yellow discoloration, and lesions can coalesce and give the plant a burnt appearance (Buruchara et al., 2010). Dead leaves remain attached to the plant and circular, sunken, red-brown lesions may be present on pods. The lesions on pod may leak during humid conditions. Use of clean seeds (Tar'an et al., 2001; Gillard et al., 2009), resistant varieties, seed treatment with an appropriate antibiotic prior to planting and spraying plants with an appropriate protective, copper-based fungicide before appearance of symptoms are used as effective methods of treatments (Schwartz et al., 2005; OMAFRA, 2009; Buruchara et al., 2010).

5.3. *Bacterial brown spot (Pseudomonas syringae)*

The bacteria overwinter in crop residues and are more severe when the foliage is wet for a long period. Small, dark-brown necrotic spots on leaves may be surrounded by an area of yellow tissues. Water-soaked spots on pods turn brown and necrotic, and pods may twist and distort in the area of infection (Schwartz et al., 2005). Use of clean seeds, proper crop rotation, and the removal of crop residues from the field after harvest are considered as preventive measures (Harveson and Schwartz, 2007).

5.4. *Powdery mildew (Erysiphe cichoracearum)*

This fungus overwinters on plant residues or alternate hosts. Disease emergence is favored by warm, dry weather with cool nights that result in dew formation. Yellow spots on upper surface of leaves, and powdery gray-white areas coalesce to cover entire plant. If the plant is infected heavily, it may appear light blue or gray in color (Trabanco et al., 2012). Use of resistant varieties and when possible use of overhead irrigation that washes the fungus from leaves and reduces its viability are preventive practices. Also, recommended is early planting to avoid high air temperature and humidity. Application of S-based pesticides may be required to control heavy infestations (Van Emden et al., 1988).

5.5. *Fusarium root rot (Fusarium solani)*

Damage caused by the emergence of the fungal disease is worsened by warm, compacted soils, limited soil moisture, and poor soil fertility. The disease is noted by stunted plant growth and yellowing, necrotic basal leaves, brown, red, or black streaks on roots that coalesce as they mature. Lesions may spread above the soil line (Abdel-Kader et al., 2011).

6. Insects

Black bean aphid (*Aphis fabae*) can cause severe damage to faba bean (Webster et al., 2010). When using seedlings, check for aphids before transplanting. Reflective mulches such as silver-colored plastic can deter aphids from feeding on plants by limiting landing of the pest. Sturdy plants can be sprayed with a strong jet of water to knock aphids from leaves. Insecticides are required generally only to treat aphids if the infestation is very high since plants generally tolerate low or medium leaf infestation. Insecticidal soaps or oils such as neem or canola are usually the best insecticides for control (Birch, 1985).

7. Biomass, seed, and pod yield

Faba bean is an important source of plant protein for human and animal consumption and is harvested as fresh pods with immature seeds or dried seeds (Crepon et al., 2010; Singh et al., 2013). General conception is that the larger seeds may have more food reserves thus germinate faster and out-yield smaller seeds within the same variety/cultivar. In faba bean, the induction of flowering, retention of flowers and development of seeds are all critical processes determining the final yield (Patrick and Stoddard, 2010; Etemadi et al., 2018e). It has been suggested that higher biomass accumulation is required to obtain higher seed yield (Mortimer et al., 2012). A high positive correlation between seed yield and biomass production has been reported for faba bean (Kubure et al., 2016). However, faba bean as a cool-season grain legume is sensitive to high temperature, low moisture availability, and days to flowering (L'opez-Bellido et al., 2005), therefore earlier maturity may be beneficial for producing optimum yield. For example, Etemadi et al. (2018e) reported that in shorter-season conditions, cultivars of faba bean such as Aquadulce with less GDD requirement out-yielded the late maturity faba bean cultivars. They concluded that the number of days to reach maximum CGR is highly correlated with the seed yield. Seed yield is a function of biomass production and partitioned assimilates into the seeds (Ricciardi et al., 2001; Tilman et al., 2002).

In most legumes, dry matter accumulation reaches a maximum around the start of seed filling. In faba bean, root, petiole, stem, and pod weight then remain constant. However, a report noted that as seed weight increased, leaf weight decreased by about 45% (Singh and Schwartz, 2010). Total DM accumulation in faba bean is quite variable, but Croser et al. (2003) reported that field beans accumulated two-thirds of their overall DM before the end of flowering. In other legumes, soybean accumulates 30%–67% before flowering, and lentils accumulated 16%–30% before flower initiation with most of the DM being produced after anthesis (Ayaz et al., 2004). Ayaz et al. (2004) with pinto beans (*Phaseolus vulgaris* L.) in Canterbury, New Zealand, found seed yield was correlated highly with total DM with a stable harvest index. They considered that high total DM yield was probably a prerequisite for high pinto bean seed yield as was found in chickpea (*Cicer arietinum* L.) by Russo (2003). By comparison, with DM accumulation in soybean (*Glycine max* Merr.), indeterminate plants produced more vegetative growth during flowering and pod set than determinate plants (Eckert et al., 2011).

The yield component approach has been used extensively to study the physiology of seed yield of legumes and other crops (Greven et al., 2004). The relationship among yield components has been described as compensatory or mutually interdependent (Mohamdi et al., 2002). Consequently, a significant change in one yield component may not necessarily affect the final seed yield. Nevertheless, highest seed yields are often obtained when all the yield components are maximized (Gomez-Paniagua and Wallace, 1992; Mirshekari et al., 2013).

Because of considerable variations in faba bean seed size (Etemadi et al., 2017), lack of recommended population density, and whether the seed is being harvested for fresh or dried purpose, results of seed yields are considerably different. For example, Coelho (1987) reported dramatic differences in seed yield of faba bean (4 750–10 950 $kg{\cdot}hm^{-2}$) in various population densities. Fresh pod yield of eight faba bean varieties reported by Etemadi et al. (2015) varied from 2 052 to 17 038 $kg{\cdot}hm^{-2}$.

8. Faba bean in cropping systems

Crop rotation has been represented as agro-ecosystem diversification "in time" whereas intercropping systems have been practiced providing diversity "in space" (Tosti and Guiducci, 2010). Diverse ecosystem benefits are expected from integrating faba bean in cropping systems (Köpke and Nemecek, 2010). Traditionally, legumes are used in cropping systems due to their contribution to the N need of proceeding crops (Zandvakili et al., 2012; Jahanzad et al., 2014; Ntatsi et al., 2018). This is even more practiced in organic operations which are heavily relying on non-fossil-based N. In recent years, some economic measures including soil health as well as environment concerns due to the application of commercial N fertilizer resulted in reassessment of the use of legumes in various cropping systems. The capacity of faba bean in biologically fixing N has not been conclusively determined. However, faba bean has been grouped as a highly efficient source of N. Thus, whether as cash crop, cover crop, or dual-purpose cash/cover crop, faba bean can be used in rotational systems with other non-legume crops. Other benefits from using faba bean in cropping systems include (i) break crop in a rotational program (Abera et al., 2015; Landry et al., 2015), (ii) feed source for pollinators and beneficial insects (Etemadi et al., 2015), (iii) enhanced soil microbial activity (Van der Putten et al., 2013; Wahbi et al., 2016), (iv) control of soil-borne diseases (Jensen et al., 2010), and (v) a rich source of L-DOPA (L-3,4-dihydroxyphenylalanine) (Etemadi et al., 2014b, 2018b, 2018c).

Traditionally faba bean is used in rotational program with cereals (Ashraf et al., 2004). The benefits of faba bean to the proceeding cereal include N contribution (Etemadi et al., 2018d; Kaci et al., 2018), enhanced soil biological characteristics (Bünemann et al., 2004; Aschi et al., 2017), and break crop to control plant diseases. When faba bean is grown primarily for its N contribution, the maximum benefit is obtained when the succeeding crop has relatively long growth period to make most efficient use of

N mineralization occurs later in growing season (Jensen et al., 2010). A Canadian five-cycle rotation-study comparing a faba bean-barley-wheat and a barley-barley-wheat rotation showed that faba bean enhanced the average yield in the subsequent barley and wheat crops by 21% and 12%, respectively which was equivalent to providing the cereals with around 120 kg N·hm^{-2} (Xinyou and Van, 2005). The residues of shoot and the root of faba bean generally have a low C/N ratio therefore, N mineralization often takes place very fast (Shi, 2013). This fast release of N may not be well synchronized with the N uptake of the succeeding crop, thus may result in increased risk of N loss to the environment (Jensen et al., 2010), more so in conventional tillage system (Etemadi et al., 2018d). Improving the synchrony of N release from faba bean residues can enhance the N uptake/utilization efficiency of the succeeding crop, thus reducing potential environmental hazards. Intercropping faba bean with cereals such as barley, wheat and maize can be productive due to their complementarity in the use of N resources and other nutrients (Tosti and Guiducci, 2010). Etemadi et al. (2018d) reported that in no-till system, 50% N release from faba bean residues delayed by approximately one month, compared with conventional tillage system.

9. Dietary nutrients in faba bean

9.1. *Mineral nutrients*

Faba bean is rich in proteins, complex carbohydrates, dietary fiber, choline, lecithin, minerals and secondary metabolites including phenolic compounds (Mohseni and Golshani, 2013; Etemadi et al., 2018c). Also, faba bean seeds are low in fats, cholesterol-free, and low sodium (Adamu et al., 2015). Globally, faba bean is recognized as one of the most important staple legumes for human consumption (López-Pedrouso et al., 2012).

Diversification in the use of beans, e.g., soybean, garden bean, faba bean, can stimulate an increased cultivation and supply of these crops. This is essential to attaining sustainable food security in terms of nutritional quality (Jahanzad et al., 2014). Micronutrient deficiency is recognized as the "hidden hunger" in the world (Zandvakili et al., 2019). Legume seeds are typically rich in micronutrients such as Fe and Zn (Khazaei et al., 2017). Iron and Zn are essential for sustenance and optimal physiological function of all forms of life on the planet (Bailey et al., 2015).

9.2. *Phosphorus and potassium contents*

Among the different edible parts of faba bean, P content is in the order of seed > pod wall > leaf (Etemadi et al., 2018a). Like N mobilization, P in leaves and pods are mobilized into other pods and seeds (Bender et al., 2015). Faba bean varieties differ with regard to nutrient accumulation. For example, Etemadi et al. (2018a) reported a significant variation existed among the faba bean varieties in terms of P content. Unlike N and P, which were more concentrated in the seed part, the highest K concertation were detected in pod wall with 38% and 44% higher than seeds and leaves, respectively (Etemadi et al., 2018a). In Mediterranean diets, pods are edible part and are considered as important nutrient source when consumed with the immature seeds; hence, accumulation of K in pods can be an important dietary source of K (Singh et al., 2013).

9.3. *Nitrogen or protein content*

Nitrogen accumulation in various parts of faba bean is in the order of seed > pod wall > leaf (Etemadi et al., 2018a). Higher accumulation of N in seeds than in other parts is expected since N is mobilized from the leaf and pod wall to the seeds during the seed-filling period (Pazdernik et al., 1997; Bender et al., 2015). However N content in various varieties differ significantly. For example, Etemadi et al. (2018a) compared eight faba bean varieties for their N content and reported that the highest N concentration was measured in Windsor with 3.47%, followed by Delle Cascine with 3.43%, whereas the lowest N concentration in seeds was detected in Early Violletto with 2.71%.

9.4. *Calcium and magnesium contents*

Unlike N, P, and K, with the lowest accumulation in the leaf, Ca mainly accumulates in faba bean leaves. Concentration of Ca in the faba bean leaves was more than three-fold than its concentration in the pod wall and eight-fold in the seed (Etemadi et al., 2018a). Similar to Ca the highest concentration of Mg was in the order of leaf > pod wall > seed. They also concluded that the difference between plant parts regarding Mg accumulation was more pronounced than the difference amongst the varieties. Magnesium content in the leaf was more than two-fold than in the seeds. Calcium is an immobile element while Mg is a mobile nutrient (Zandvakili et al., 2017); however, the similar pattern of partitioning of these nutrients in plant organs may indicate that mobilization of Ca and Mg from vegetative plant parts to seeds and pods is minimal. The high Ca and Mg in the leaf tissue could be important from the nutritional point of view for human diet in areas that leaves are also consumed.

9.5. *Iron, copper, zinc, and manganese contents*

Research showed that the concentration of Fe in different organs of faba bean was significantly different and in the order of leaf > pod > seed. The accumulation of Fe in the leaf component of the plants was 8.7-fold and 3.2-fold higher than in seeds and pod walls, respectively (Etemadi et al., 2018a). However, it is reported that some legumes, like faba bean, can contain high amounts of Fe binding polyphenols that inhibit Fe absorption (Sandberg, 2002). In Etemadi et al. (2018a) report, the highest Fe concentration was detected in Delle Cascine in leaves at 804 mg·kg^{-1} while the lowest Fe concentration was measured in the seeds of Early Violletto with 59 mg·kg^{-1}. Mahmoud et al. (2006) reported a similar result on the accumulation of Fe in the leaves of faba bean. However, in general faba bean seeds could be considered as an important dietary source to alleviate Fe deficiency in humans. Similarly, there is a difference among plant organs in Zn and Mn accumulation. The concentration of these two elements in various parts of faba bean were in the order of seed > leaf > pod wall while Cu distribution was in the order of seed = leaf > pod (Etemadi et al., 2018a). Faba bean leaves can be consumed as a good source of Cu in human diets.

10. Faba bean as a medicinal plant

10.1. L-Dopa as main medicine for Parkinson's

Faba bean accumulates a large amount of *L*-Dopa in its various parts (Etemadi et al., 2015). L-Dopa, a precursor of dopamine currently used as a major ingredient in treating Parkinson's disease and hormonal imbalance (Surwase et al., 2012; Inamdar et al., 2013; Hu et al., 2015; Etemadi et al., 2018b).

L-Dopa, is an amino acid, naturally isolated from various legumes (Chattopadhyay et al., 1994; Inamdar et al., 2013) and other crops such as banana (*Musa spp*.) (Gautam et al., 2012). *L*-Dopa is synthesized from the amino acid *L*-tyrosine in the mammalian body and brain (Randhir and Shetty, 2004; Miller et al., 2009). Earlier reports (Peaston and Weinkove, 2004; Miller et al., 2009) indicated that *L*-Dopa is an important precursor for the various neurotransmitters like dopamine (Upadhvay et al., 2014), noradrenaline and adrenaline collectively known as catecholamines (Gautam et al., 2012). Commonly parkinson's disease patients are treated with synthesized *L*-Dopa. Synthesized *L*-Dopa is expensive and often related to a variety of side effects including nausea, vomiting, low blood pressure, drowsiness, and restlessness (Patil et al., 2013). Therefore, consuming natural sources of *L*-Dopa to avert potential side effects has been recommended (Singh et al., 2012; Patil et al., 2013).

It is estimated that the annual world demand for *L*-Dopa is about 250 tons with a market value of about $101 billion (Patil et al., 2013). Cultivation of crops that are rich in natural *L*-Dopa to overcome side effects and the high cost of production of synthetic *L*-Dopa thus seems justifiable (Singh et al., 2012; Patil et al., 2013).

10.2. L-Dopa content in faba bean

Faba bean is ranked after velvet bean (*Mucuna Pruriens* L.) in terms of *L*-Dopa content (Soares et al., 2014). The amount of *L*-Dopa in faba bean, however, is dependent on genotypes (Etemadi et al., 2014b), environmental conditions (Multari et al., 2015), growth stage (Geng, 2012), and organs (Etemadi et al., 2014a). Cao (2010) reported a large variation of *L*-Dopa content among faba bean genotypes including in flowers across 197 cultivars, seedlings across 32 cultivars, seeds across 52 cultivars with the green seed coat. Similarly, Hu et al. (2015) reported a significant variation in *L*-Dopa concentration among six faba bean lines that differed in flower color.

Distribution of *L*-Dopa in various parts of faba bean is not uniform, and different organs accumulate *L*-Dopa at different rates (Geng, 2012). However, many earlier reports have focused on *L*-Dopa content in seeds, and less attention has been given to the amount of *L*-Dopa in other parts of the plant. In general, *L*-Dopa concentration in various faba bean organs reaches its peak concentration at early stages of growth (Etemadi et al., 2018b). However, *L*-Dopa yield is a product of concentration and plant biomass (Etemadi et al., 2018b) thus highest *L*-Dopa yield can be obtained at later stages of growth when biomass is maximized.

Availability of N and P to faba bean plants may influence the *L*-Dopa synthesis. Ramakrishna and Ravishankar (2011) reported that deficiencies in N and P directly influenced the accumulation of phenylpropanoids. Although faba bean is a N-fixing plant, the effect of supplemental N fertilization on *L*-Dopa concentration is not well documented. Etemadi et al. (2018c) concluded that N stress had no significant influence on the amount of accumulated *L*-Dopa.

Because fresh faba bean is always not available in all locations, Parkinson patients relying on fresh natural source of *L*-Dopa should have stored relatively large amounts of plants for consumption. Therefore, naturally *L*-Dopa rich plants may be processed by various methods including chopped frozen tissues or dried powdered plant parts. Processing plant parts however, may negatively influence the *L*-Dopa concentration. Earlier reports (Echeverria and Bressani, 2006; Vadivel and Pugalenthi, 2010) indicated that *L*-Dopa in legumes can be destroyed by cooking and soaking in alkaline solutions. Dahouda et al. (2009) concluded that the *L*-Dopa in velvet bean was degraded by cooking but not by roasting. Recently, Etemadi et al. (2018c) studied the influence of various processing methods on *L*-Dopa content of faba bean leaves and seeds. In this study the *L*-Dopa content influenced by different processing methods were in the order of: Fresh material > frozen > oven-dried > air dried (2 days) > air dried (4 days) > air dried (7 days) > boiled.

11. Conclusion

Faba bean is a valuable multi-purpose crop which can be grown for its nutritional and medicinal values. Faba bean seeds, pods, and leaves are rich in protein and almost all elements required for human diets. The biological N fixation by faba bean is considered high among the grain legumes. Integrating faba bean in various cropping systems such as crop rotations and intercropping improves natural soil fertility and reduce the consumption of commercial N fertilizer.

12. Future research

To maximize the ecological benefits from faba bean, efficient nodulations and biological N fixation is required. Therefore, one important area of research should be focused on introduction of elite strains of N-fixing bacteria, especially in regions with lack of faba bean cultivation history. In shorter-season regions, faba bean can be used to extend growing season therefore integrating faba bean into various cropping systems including various forms of intercropping and crop rotations should be explored. Also, introducing genotypes with winter hardiness capacity are useful for areas with harsh winter condition. Since chocolate spot bacteria is a limiting factor in faba bean cultivation, more research should be applied by introducing resistance cultivars. Since we found several benefits from transplanting faba bean in contrast to the conventional direct seeding, the authors believe that transplanting faba bean as an alternative planting method should be explored further.

Acknowledgment

This project was partially funded by the University of Massachusetts Amherst Agricultural Experiment Station and Northeast Sustainable Agriculture and Research Education (SARE) (GNE14-078).

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