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Agronomic Management of Faba Bean (*Vicia faba* L.): A Review

Babli Rani Deb[1,a], Swapan Kumar Paul[1,b,*]

[1]*Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh*
[*]*Corresponding author*

A R T I C L E I N F O

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A B S T R A C T

The faba bean (*Vicia faba* L.) is a winter crop that can be cultivated as a versatile crop. It's yield and quality being strongly influenced by environmental and agronomic factors, nutritional content, medicinal properties, and ability to fix nitrogen biologically. Therefore, to maximize advantages of faba bean cultivation, choosing the appropriate varieties, planting times, techniques, plant density, depth of sowing, and ensuring proper crop nutrients and irrigation is essential. For successful faba bean production in subtropical climates, it's important to assess the performance of different varieties under these specific conditions. Planting dates and soil temperature are crucial for germination, growth, and yield. At the same time, the crop's performance is also influenced by sowing methods, plant density, sowing depth, and water and fertilizer management. Integrating faba beans into cropping systems is expected to offer various ecological benefits. This paper reviews the existing literature on the agronomic practices of faba beans.

[a] bdeb385@gmail.com http://orcid.org/0009-0000-1208-9514 | [b] skpaul@bau.edu.bd http://orcid.org/0000-0002-0163-3251

Introduction

The faba bean (*Vicia faba* L.) is a widely consumed pulse that is a significant basis of protein to both human and animal nutrition. (Cazzato et al., 2012) and as a major supply of nitrogen for the biosphere (Rubiales, 2010). It is originated in the Middle East in the prehistoric era (Multari et al., 2015; Yadav et al., 2017). The genus *Vicia* belongs to the family *Fabaceae*, which contains a wide range of species and is distributed around the world. Approximately 750 genera include 16,000–19,000 species in this family, based on current estimates (Chakraverty et al., 2013). Over sixty countries across the globe, including Australia, South and North America, West and South Asia, East and North Africa, and Southern Europe, are growing it (Merga et al., 2019; Paul and Gupta, 2021: Roy et al., 2022; Meital et al., 2023). After chickpeas, dry-beans, and dry-peas, faba beans are the fourth-most significant pulse grain worldly cultivated, which are used as animal and human feed (Gasim et al., 2015). Because it may be consumed both raw and prepared, it can also be utilized year-round. The crop enhances the quality of the soil by biological nitrogen-fixation (Rubiales and Mikic, 2015). Soil fertility is increased when faba beans are incorporated into agricultural systems (Karkanis et al., 2018). It has been reported that 50–330 kg nitrogen hm^{-2} can be fixed by faba beans depending on climatic situations and cultivation management (Galloway et al., 2004). In recent cropping, it has been largely disregarded as an effective part of crop-cycle, which is vital for reducing the environmental impact of chemical fertilizers. As a result of its diverse applications, high nutritious rate, and capability to flourish in a wide range of agroclimatic environments, the faba bean is a strong fit for sustainable cropping in many underutilized zones. These factors have led to increased international attention for the crop in recent years (Gasim et al., 2015). The faba bean, which is cultivated in the centre and northern regions of Bangladesh, is regarded as an underutilized pulse crop (Paul et al., 2022) and regionally familiar as *Kalimotor, Baklakalai, or Bhograkalai* (Sheikh et al., 2020; Bhomik et al., 2022). This crop usually planted in the winter after the harvest of T. *aman* rice and sown directly as a relay crop in low-lying areas with little to no tillage (Biswas, 1988). Still, there is no available data on its cultivation area or production in Bangladesh. Pulse crops in general are grown on 0.37 million hectares in Bangladesh, producing 0.39 million tons, with faba bean contributing only a small fraction to this total (BBS, 2017). For the people of Bangladesh, pulses are a significant protein source. Faba beans, in particular, are a unique type of legume crop because they are high in minerals, dietary fibre, complex carbohydrates, lecithin, choline, and secondary metabolites like phenolics (Paul and Gupta, 2022). According to Ramirez-Moreno et al. (2015), L-dopa can be found in faba beans, which is known to be pharmacologically active when managing Perkinson disease patients and to improve motor function in humans by raising plasma levels of the drug. Faba beans are well-liked globally as a result of their high in essential nutrients and numerous uses. While it is fed to humans in developing countries, it is mainly fed to hogs, steeds, chickens, and pigeons in advanced country (Singh and Bhatt, 2012a). It is typically served as a human dal (soup) in Bangladesh. It can be eaten fresh, canned, dried, or green (Gasim and Link, 2007). A crop with multiple uses, faba beans can be produced in several climate zones (Singh et al., 2013). The yield of faba beans and their nutritional value are affected by agronomic methods such as timely sowing, managing nutrients and water (Huthily et al., 2020). So, suitable management techniques like water management, soil health, and planting time can greatly lessen the quantity of flowers that fail, increasing the amount of seeds or pods produced in the end.

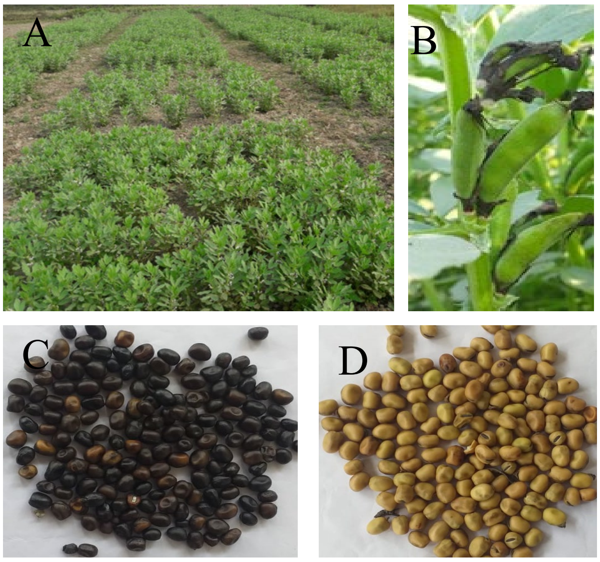

Figure 1. Field of faba bean (A), green pods (B), black seeds (C) and brown seeds (D)

Most legumes are generally sensitive to low soil temperature during seed germination. But unlike most grain legumes, faba beans are one of the few cool-season varieties whose germination can withstand chilly soil temperatures. The goal of improving seed germination in soil that is colder than 15 °C has been partially achieved by selection (Singh and Jauhar, 2005). Due to its remarkable nutritional attributes, such as elevated carbohydrate, protein, B vitamin, and mineral content (Crepon et al., 2010), the faba bean is regarded globally a important pulse crop. The faba bean has various uses, is highly nutritious, and can adjust to a wide range of edaphic and agro-climatic environment, making it an excellent choice for environmentally friendly farming in numerous peripheral areas (Nadal et al., 2003). The crop has drawn more and more attention from around the world in recent years. Therefore, this manuscript focused on agronomical techniques for improving faba bean quality and productivity.

Species Diversity

Species diversity can play a crucial role in enhancing the yield of faba beans by improving pest and disease management, soil health, pollination, microclimate regulation, and overall resilience. Yield and agronomic traits of faba bean varies greatly among different cultivated species due to environmental conditions and their interactions, as well as genetic factors. Comparable to other crops, selecting a cultivar or variety involves finding a stability between adjustability to a particular environment, disease resistance, farming goals, and suitability of a product (Zandvakili et al., 2018). Faba bean varieties differ widely in terms of seed size and color. Small-seeded types, known as tick beans (*Vicia faba* L. subsp. minor), are typically used for animal feed and smother crop. In contrast, medium and large-seeded, referred to as broad beans (*V. faba* subsp. major Harz), are usually used as both green and dry beans (Crépon et al., 2010). The species exhibits considerable genetic diversity, often described through phenotypic traits such as seed size, weight, shape, and color (Cilesiz et al., 2023). According to Karkanis et al. (2018), Depending on seed size, faba bean genotypes are typically divided into three main botanical varieties: (a) Large seeds- *Vicia faba* var. *major* (b) Medium seeds- *Vicia faba* var. *equine* (c) Small seeds- *Vicia faba* var. *minor*, (d) *Vicia faba* sp. *paucijuga*. However, faba bean genotypes are also classified based on frost tolerance, agro-climatic zone, sowing time (spring and winter types), and capability to adjust to aquatic or terrestrial (i.e., drought-prone) conditions.

Soil and Climate

Faba beans grow optimally in fine-textured soils but are versatile enough to thrive in various soil types (Jensen et al., 2010). Though, it can withstand a wide pH extent of 6–9 and sandy-loam soils, particularly in humid areas, faba beans prefer clay-lime, chalky, permeable, medium-textured soils with a neutral pH. Legumes need neutral to alkaline soil to maximize N-fixation by nodules bacteria. However, faba beans can also adapt to more acidic soil conditions (Singh et al., 2013). Growing seasons should be as cool as possible; 18 to 27°C (65–85°F) is the ideal temperature range for productivity (Duke, 1981). According to Gasim and Link (2007), faba beans grow best in a cool season with moderate annual rainfall of 650 to 1000 mm. Although they are thought to withstand frost, they are vulnerable to drought and water logging (Subash and Priya, 2012). The maturation duration varies (90 to 220 days) based on the climate and cultivars (Bond et al., 1985). Most legumes are vulnerable to low soil temperatures during seed germination. Nevertheless, faba beans are unique among cool-season grain legumes in that their germination can withstand lower soil temperatures than that of most other grain legumes. There has been some progress in selecting better seed germination in soil that is colder than 15 °C (Singh and Jauhar, 2005). Large-seeded cultivars have been observed to have a higher germination rate at 12.5 °C than small-seeded beans (Kang et al., 2008). During blossoming, it cannot withstand high temperatures. Some faba bean cultivars seem to be day length-neutral, however, germplasm exchanges between latitudes show that many require lengthy days to flower and mature (Singh et al., 2013).

Table 1. Pod and Seed Characteristics of the Botanical Groups of *Vicia faba* L. (Fouad et al*.,* 2013, Duc et al*.,* 2015a, Etemadi et al*.,* 2019).

Botanical Group	Seed Shape	Seed Weight	Pod Characteristics	Uses
Major	Very plate	>1g	Small to large (from 2 to 10 seeds)	Dry and green beans
Equina	Plate	0.45–1.1 g	Plate, thick, non-dehiscent pods Medium size, 3–5 seeds	Dry and green beans
Minor	Cylindrical to rounded form	0.2–0.5 g	Small with 3–4seeds	Animal feeding and cover cropping
Paucijuga	Rounded to an elliptical form	0.2-0.3g	Very small, dehiscent or non-dehiscent types	Nitrogen fixing cover crop

Table 2. Impact of seed size on the biological yield, harvest index, and seed output of local faba beans.

Treatments	Seed yield (kg/ha)		Biological yield (kg/ha)		Harvest index (%)	
Seed size	1997/98	1996/97	1997/98	1996/97	1997/98	1996/97
Very small	4298	4298	7856	2326	55.3	48.4
Small	4479	4479	8982	2879	50.2	52.1
Medium	4118	4118	8842	3232	47.3	38.3
Large	4513	4513	9528	3675	48.1	25.6
LSD (0.05)	NS	NS	738	524	3	10

(LSD, least significant difference (P = 0.05); NS, not significant) (Source: Al-Rifaee et al., 2004)

Seeding Rate

The population selection of most legumes is a crucial agronomic decision that impacts both the amount of biologically fixed nitrogen (N) and the plant's ultimate output. According to Parr et al. (2011), a legume utilized as a cover crop must yield a minimum of 4,000–4,500 kg hm $^{-2}$ of biomass in order to supply enough readily accessible nitrogen to meet the crop's subsequent nitrogen requirements. It is unclear what the ideal faba bean plant population is for both N fixation and maximum pod and grain yield. Depending on the variety (size of seed) and the area, faba bean densities ranging from 45 000 to 60 000 plants hm $^{-2}$ are frequently utilized (Parr et al., 2011).

Seed Size

The faba bean is typically a large-seeded pulse, but different cultivars and types can differ significantly in seed size. Even within the same cultivar, seed size can differ significantly based on the pod's position. Seeds are categorized into four size groups by weight: large (>1500 mg seed^{-1}), medium (1001-1500 mg seed^{-1}), small (700-1000 mg seed^{-1}), and very small (<700 mg seed^{-1}) (Al-Rifaee et al., 2004). Traditionally the farmers are use the seeding rate based on seed quantity per kilogramme, to establish the target population density (Gezahegn et al., 2016). Plant breeders have long emphasized the significance of larger seeds for crop yield, as they are believed to have more food reserves, which can lead to faster germination, better vigor, and higher yields compared to smaller seeds of the similar cultivars (Harker et al., 2015; Patel et al., 2016). Tomaszewski et al. (1978) observed that larger seeds produced more fresh matter and seeds in faba bean crops. However, Al-Rifaee et al. (2004) found that plants from very small and small seeds emerged more quickly, flowered earlier, podded sooner, matured faster, and had the higher harvest index, which definitely impacted seed yield. In contrast, larger seeds were more susceptible to unfavourable circumstances like low temperatures and dryness. Thus, using smaller seeds is recommended to achieve high yields, decline seeding rates, and improve resilience to environmental stresses like low moisture and temperature (Al-Rifaee et al., 2004). Additionally, smaller seeds can decrease production costs by reducing the seed quantity required for a area (Etemadi et al., 2017).

Seed Treatment and Sowing

Rhizobia are able to survive for a period of years in the soil, but they may not contain the best N-fixing bacteria. For optimal nitrogen fixation, inoculation of seeds is advised annually, even though rhizobium bacteria can persist in soil for three to five years. Abd-Alla et al. (2014) suggest that faba bean seeds ought to be injected with *R. leguminosarum* cv. *viciae*. Rodelas et al. (1999) emphasize the importance of proper storage of inoculants, keeping them dry and fresh. To maximize the availability of rhizobia for initiating the process of infection as soon as roots show up, seeds need to be infected soon before planting (Etemaidi et al., 2015). These rhizobia have a fast ability to infect roots and trigger nodulation. Direct seeding is the usual method for faba beans. Etemadi et al. (2019) suggest that in places with shorter growing seasons, transplanting might be a more effective method of ensuring early sowing than direct seeding. Moving seedlings may also provide the following additional advantages: double cropping, earlier harvest, early flowering, increased yield, and improved survival rate as well as preventing incident disorders like chocolate spots (Lee et al., 2018, Etemadi et al., 2019). Faba beans take 20 to 25 days to sprout, and it's important to keep the seeds moist until the seedlings are well established. Due to the hard, dry seed's slower water absorption and germination compared to regular beans, planting depth is crucial. To prevent the seed from drying out, planting depth should be between 6 and 10 cm (Singh et al., 2013).

Sowing Time and Spacing

The faba bean productivity is greatly influenced by spacing, which also affects plant growth, resource utilization, and total productivity. Proper spacing allows plants to develop stronger root systems, which are crucial for nutrient uptake and stability. In contrast, overcrowding can result in shallow or tangled roots, limiting nutrient absorption. Plant density, which is regulated by spacing, and yield may not always have a direct relationship. There is an optimal plant density that maximizes yield per unit area. Too few plants (wide spacing) can reduce total yield, while too many plants (narrow spacing) can cause competition and lower yield plant^{-1}. Field trials were carried out by Sharaan et al. (2004) using four cultivars of faba beans (G.2, G.429, G.843, and Misr 1) planted at three distinct dates (October 15, November 5, and November 25) and at three intra-row spacings (15, 20, and 25 cm). The study aimed to find the best sowing date and spacing combination for high yields and quality, considering both environmental and genetic factors. Delay in planting from October 15 to November 25 resulted in a 16.14% increase in seed and pod counts during the first season. During the two seasons, there was a drop in both the number of seeds plant^{-1} and the seed yield faddan^{-1}, by 6.88% and 24.84% and 28.85% and 15.84%, respectively. For the first and second seasons, the intermediate and earliest sowing dates yielded the largest seed weight plant^{-1}, respectively. The greatest harvest index was achieved in both seasons by sowing on November 5.Reducing intra-row spacing from 25 to 15 cm decreased seeds pod^{-1} (by 9.66% in the first season and 6.64% in the second), seeds plant^{-1} (by 31.08% in the first season and 6.01% in the second), and seed weight plant^{-1} (by 34.40% in the first season and 10.67% in the second). Increased plant density in the first season, however, led to a 14.29% increase in seed yield faddan^{-1}. Sheikh et al. (2020) conducted tests on four different plant spacings: and found that 30 cm × 20 cm spacing produced the highest seeds 1.23 t ha^{-1} followed by 30 cm × 15 cm (.14 t ha^{-1}) (Figure 2). The highest values of crude fat (3.16%) and ash (4.79%) were similarly obtained with a spacing of 30 cm × 20 cm. On the other hand, 30 cm × 25 cm had the highest fibre content (15.49%) and the highest crude protein (33.62%). Furthermore, with the 30 cm × 20 cm spacing, the maximum stover output of 1.86 t ha^{-1} was observed (Figure 3).

Irrigation

Faba beans generally require about 400-600 mm of water throughout the growing season, with the highest demand during the development of pods and flowering. The irrigation schedule should be adjusted based on soil type, climate, and growth stage to ensure optimal plant health and yield. According to Khan et al. (2010), faba beans are very responsive to water scarcity than other grain legumes. Although water shortage significantly limits crop yields, faba beans can still somewhat adapt to low water availability. This ability is particularly important in countries with low rainfall, such as Ethiopia, Sudan, Egypt, and Palestine, where faba beans are a major crop (Multari et al., 2015). According to Ouda et al. (2010), water stress during the early podding stage can reduce yield around 50%.The ideal annual rainfall for faba beans ranges from 650 to 1000 mm, and it should be evenly distributed. In standing water, faba beans do not grow well. Therefore, a consistent water supply is essential for optimal yield. The most crucial period for moisture is 9 to 12 weeks after the crop has been established (Torres et al., 2012; Singh et al., 2013). Drought stress, which increases transpiration, negatively affects both the yield and seed quality of faba bean. Paul et al. (2021) observed that faba bean produced higher seed yield (1.49 t ha^{-1}) when irrigated twice at early branching and pod formation stages while the control produced the lowest values (Figure 4).

Fertilizer management:

Leguminous crops need a sufficient amount of available nutrients for optimum growth and yield. Choudhary (2014) stated that the yield of faba beans can be greatly increased by adding 100 quintals of Farm Yard Manure (FYM) or compost, 15-20 kg of N, 40-50 kg of P_2O_5, and 30-40 kg of K_2O per hectare during the final ploughing. The macronutrients that are important for the faba bean crop's maximum growth and productivity are provided by this balanced approach to nutrient management. Choudhary, 2014). The application of N-P_2O_5-K_2O-S @ 10-40-40-10 kg ha^{-1}, respectively resulted in a greater seed production (1.70 t ha^{-1}), according to Paul et al. (2021), while the control produced the lowest values (Figure 5).

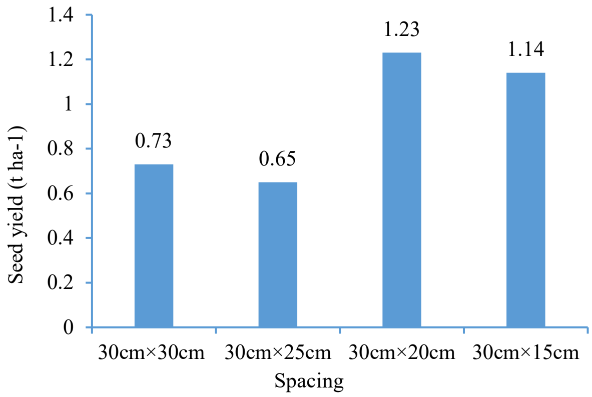

Figure 2. Impact of spacing on seed yield of faba bean (Reproduced from Sheikh et al., 2020)

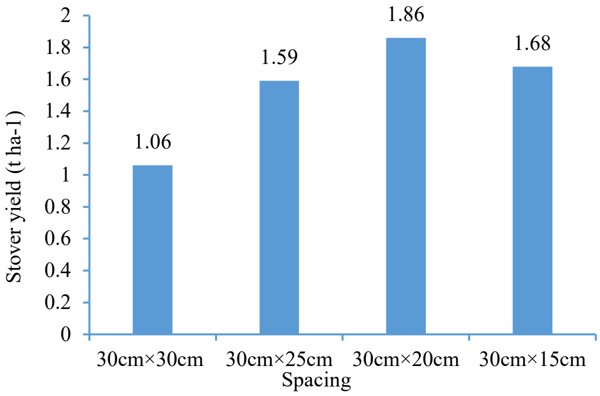

Figure 3. Impact of spacing on stover yield of faba bean (Reproduced from Sheikh et al., 2020)

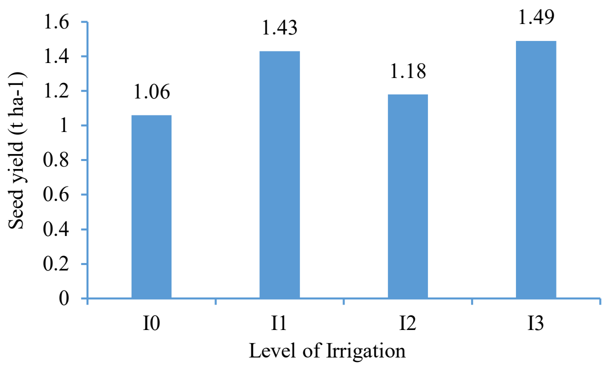

Figure 4. Impact of Irrigation on seed yield of faba bean (Reproduced from Paul et al., 2021). Here, I_0= no irrigation, I_1= one irrigation at early branching stage, I_2= one irrigation at pod formation stage and I_3= two irrigations at early branching and pod formation stages.

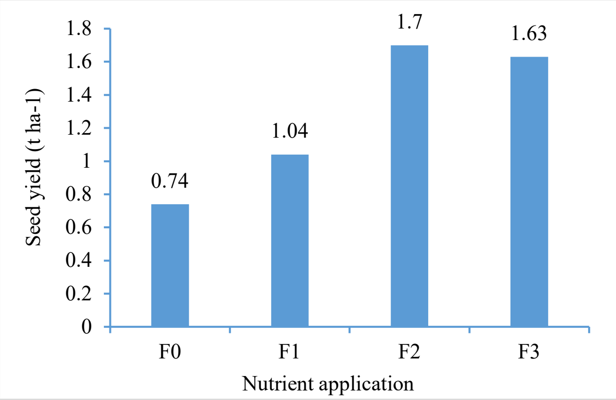

Figure 5. Impact of nutrient application on seed yield (Reproduced from Paul et al., 2021). Here, F_0 = 0-0-0-0, F_1 = 5-20-20-5, F_2 = 10-40-40-10 and F3 =15-60-60-15 @ N-P_2O_5-K_2O-S kg ha^{-1}, respectively.

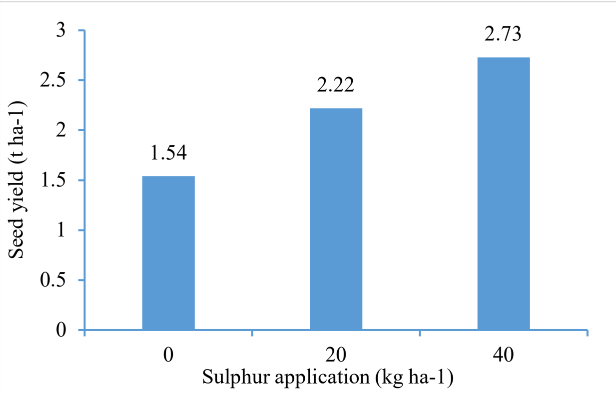

Figure 6. Impact of sulphur on seed yield of faba beans (Reproduced from Miah et al., 2023)

Legume crops often respond well to phosphorus fertilization, especially in soils where phosphorus is limited. Phosphorus is an essential nutrient element for legume crops (Kumar et al., 2019). For faba beans, phosphorus fertilizer applications typically ranges 20 - 30 kg P ha^{-1} (FAO, 2000). Increasing the rate of phosphorus fertilization to 45-46.5 kg P_2O_5 ha^{-1} has been shown to significantly boost faba bean yield and its contributing characteristics (El-Habbasha et al., 2007). Furthermore, Yasmin et al. (2020) found that applying 40 kg P ha^{-1} led to the greatest numbers for the branches plant^{-1}, pods plant^{-1}, 1000-seed weight, seed and stover yield, and protein percent in seeds (Figure 7).

Sulphur has unique physiological and biochemical functions, making it an essential component of the legume-rhizobium system. Following nitrogen, phosphorus, and potassium, it is frequently recognised as the fourth primary nutrient (Marschner 1995). According to Cazzato et al. (2012) and Głowacka et al. (2019), sulphur fertilization has an influence on grain yield, seed quality, and N-fixation. According to Miah et al. (2023) the highest results for branches plant^{-1}, pods plant^{-1}, 1000-seed weight, seed and stover yields were obtained by applying 40 kg S ha^{-1} (Figure 6).

Biofertilizer application

A biofertilizer, also known as a biological fertilizer, is a substance that contains live or dormant microorganisms. These microorganisms either colonize the rhizosphere or reside within plants to promote growth directly or indirectly by supplying essential nutrients (Fasusi et al., 2021; Timofeeva et al.,2023). Biofertilizers improve soil fertility by including the microorganisms like *Anabaena*, *Nostoc*, *Rhizobia*, *Burkholderia*, *Clostridium* and *Tolypothrix*. These microorganisms settle in the rhizosphere or plant tissues when treated to seeds, surfaces of crops, or soil. They aid in the growth of the plant by transforming essential nutrients, like phosphorus and nitrogen, into forms that are soluble through procedures like phosphate solubilisation and nitrogen fixation (Rokhzadi et al., 2004; Ramasamy et al., 2020). Incorporating biofertilizers into faba bean cultivation enhances growth, yield, and quality by optimizing nutrient availability, improving soil health, and reducing the environmental impact of farming practices (Sheikh et al. 2020; Ding et al. 2021; Bhardwaj et al. 2024). El-Yazid et al. (2007), observed that beneficial microorganisms in biofertilizers also promote growth of plants and provide defense against infections and pests. According to Sheikh et al. (2020) the use of biofertilizer improved seed quality and yield when compared to a control group. While Rhizobium inoculum 120 g kg^{-1} seeds provided the highest levels of crude protein (33.54%) and crude fat (2.82%), Rhizobium inoculum 80 g kg^{-1} seed application produced the highest levels of seed yield (1.04 t ha^{-1}), stover yield (1.75 t ha^{-1}), ash (4.88%), and fibre (15.28%). According to Badr et al. (2013) In order to fix nitrogen, faba beans symbiotically partner with Rhizobium bacteria, more especially *Rhizobium leguminosarum* Frank bv. *viciae*. To achieve the maximum amount of nitrogen fixation, which is usually between 60 and 250 kg ha^{-1} year^{-1}, farmers are normally encouraged to inoculate their seed with the appropriate culture (Torres et al., 2012). When compared to the non-inoculation control, faba bean cultivars treated with VA-mycorrhizal demonstrated increases in seed yield ha^{-1} of 20.7% and 23.2% (Figure 8). According to Bhomik et al. (2022), brown seeded faba bean with rhizobial strain FM-1a had the highest number of nodules plant^{-1} (85.67), nodules dry weight ha^{-1} (8.27 mg), dry weight ha^{-1} (198 g), number of pods ha^{-1} (47.33), 100-seed weight (23.48 g), seed (2.66 t ha^{-1}) and stover (3.26 t ha^{-1}) yields compared to other strains and controls.

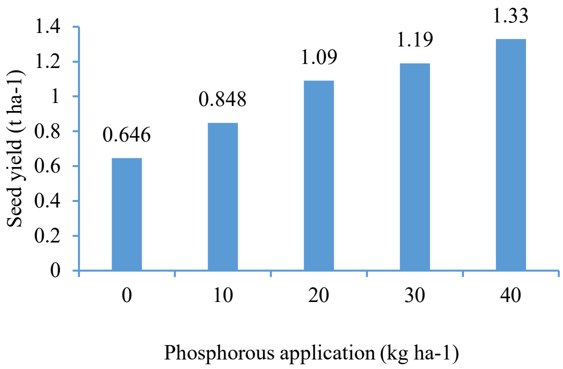

Figure 7. Impact of sulphur on seed yield of faba beans (Reproduced from Miah et al., 2023)

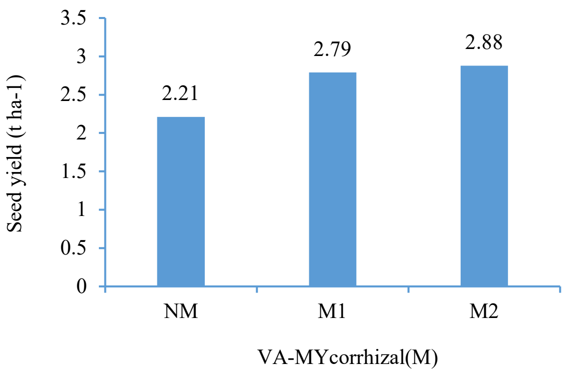

Figure 8. Impact of VA-MYcorrhizal (M) inoculation on seed yield of faba bean (Reproduced from Badr et al., 2013). Here, (a) inoculation with strain of VA-mycorrhizal fungi *Glomus* macrocarpium (M_1) *Glomus manihitis* (M_2) and (b) without inoculation (NM).

Crop rotation

Crop rotation, an essential practice for boosting the yield through successive production of agronomic crops, which provide sustainability of faba bean production by improving soil fertility, managing pests and diseases, controlling weeds, and enhancing overall soil health. These benefits lead to higher and more consistent yields. Establishing an effective crop rotation strategy is crucial for ensuring long-term productivity in faba bean farming through soil biological and physical properties improvement (Aschi et al., 2017) and also offers a range of ecological benefits by including faba bean into a cropping system (Köpke and Nemecek, 2010). Traditionally a legume into a crop rotation system were incorporated due to their ability to supply nitrogen for subsequent crops (Ntatsi et al., 2018). It is a effective approach for organic farming, where nitrogen supply are heavily depends on the sources that are not derived from fossil fuels. Growing economic and environmental concerns regarding synthetic nitrogen fertilizers have revived interest in the role of legumes within crop rotations. Although the exact nitrogen-fixing capacity of faba beans is still being studied, they are acknowledged as a reliable nitrogen source. As such, faba beans can be integrated into rotational systems as a cash, cover, or multi-purpose agronomic crop. Additional advantages of faba bean incorporated in a rotational system are: role as break crop (Abera et al., 2015), resources for beneficial and pollinator insects (Etemadi et al., 2015), boosting soil microbes (Wahbi et al., 2016), reducing soil-borne pathogen (Jensen et al., 2010), and provide L-DOPA (L-3, 4-dihydroxyphenylalanine) sources.

Mulching

Mulching is a highly beneficial practice for faba bean cultivation, offering advantages such as moisture conservation, temperature regulation, weed suppression, soil health improvement, and disease prevention. These benefits contribute to improved plant growth, higher yields, and more sustainable farming practices. Implementing mulching (artificial and natural) can be a valuable strategy for improving the yield and resilience of faba bean. Artificial mulching refers to the practice of covering soil around the plants with organic or inorganic materials that can provide several purposes. Natural mulching helps in retaining soil moisture by reducing evaporation. As the soil crust breaks down, it creates a loose, porous layer on the surface that traps moisture and reduces water loss. Both are highly beneficial practice for faba bean cultivation, offering advantages such as soil moisture conservation through evaporation reduction, temperature regulation, weed suppression, soil health improvement, minimizing fertilizer leaching and disease prevention which improves crop resilience and final yield. The benefits of using mulching materials in cultivation also include early harvesting through early flowering and increasing flower number (Lee et al., 2018).

Weed Management

Weed competition is most critical when the crop is young or actively growing. During this stage, it is essential to remove weeds, as this is the brief period in the crop's development when weeding yields the highest economic benefits, the most intense competition in faba beans with weeds occurs within the first 20-30 days after sowing. This emphasizes the importance of timely weed management in faba bean productivity. Frenda et al. (2013) noticed that weed infestation is a significant obstacle to the production of faba bean, which can cut yield by up to 50%. To achieve a high yield, weeds must be removed as soon as possible, ideally between 25 and 75 days after sowing (Tawaha and Turk, 2001).

A weed-free environment in faba bean throughout the growth period till 60 DAS can resulted in increasing of plant height, branching, pod and seed numbers, seed weight and finally yield (Miah et al., 2023). Weed management methods that have been practiced in faba bean field are prevention, cultural control, chemical control and integrated management. An integrated weed management strategy in include ploughing, sowing improved variety, fertilizer application, pre-emergence herbicide spray and/or manual weeding in such sequential order with proper timing of the activities (Table 3).

Table 3. Integrated management of weeds in faba bean (Source: Hundessa et al., 2022)

Season	Weed control methods
Off-season	• clearing farm land by cutting weeds before seed setting and removing them from the field • cleaning farm tools and machineries before entering and starting operation in the crop field
Before planting	• twice ploughing
At planting	• sowing improved variety weed free seed at recommended rate, time, pattern and spacing • application of recommended NPS
Before emergence	• Pendimethalin or S-metolachor application at 1 L ha^{-1} rate in 200 L ha^{-1} water
After emergence	• manual assisted hoeing and hand weeding activities on 30 to 35 and 50 to 55 DAS • removal of weeds left from the control practices

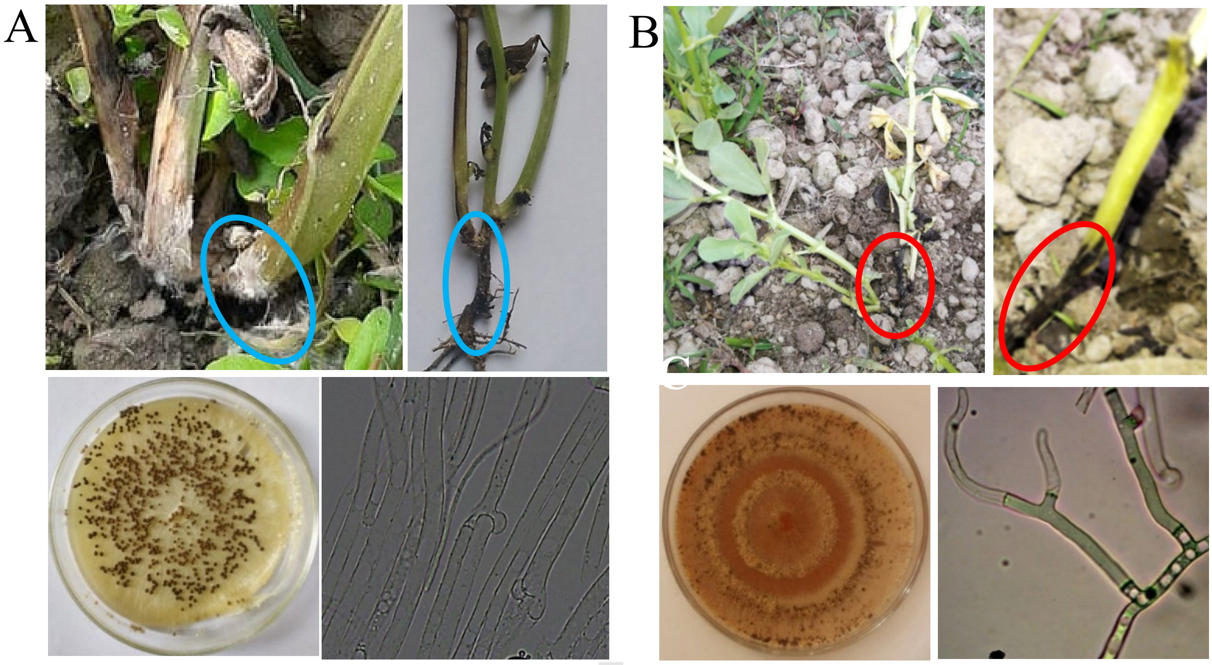

Figure 9. A. Collar rot disease of faba beans caused by Sclerotium rolfsii (Paul et al., 2023) B. Collar and root rot disease caused by Rhizoctonia solani (Paul et al., 2022) observed in Bangladesh field.

Diseases and their management

Faba beans is susceptible to several diseases that can significantly impact their yield and quality. Particularly in humid weather, faba bean crops are mostly vulnerable to fungal infections. The three primary diseases affecting faba bean crops worldwide are rust, chocolate spot, and ascochyta blight (Torres et al., 2006; Stoddard et al., 2010). However, root rot of fababean is a major problem in china, Bangladesh, Egypt, Ethiopiea and some other tropical countries (Abdel-Razik et al. 2012; Yu et al. 2023; Paul et al. 22, 23). Many pathogens, such as Fusarium spp., *Rhizoctonia* spp., *Sclerotium rolfsii*, *Pythium* spp., *Phoma* spp., and *Aphanomyces* spp., can cause the root rot disease of faba beans (Heyman et al. 2013; Rubiales and Khazaei, 2022; Paul et al. 22, 23). In china, root rot and wilt disease associated with *Fusarium* spp., *Rhizoctonia solani*, and *Pythium debaryanum* are a major challenge are the major concern to yield losses of 5%–30% and even up to 100% due to advantageous environmental situations (Dong et al., 2014; Zhang et al., 2018). Additionally, Yu et al. (2023) documented that a large amount of root and stem rot disease were identified with 10% to 30% of plants dying and up to 40% in fields with severe infection (Yu et al., 2023). In Bangladesh, collar rot (Figure 9A), caused by *Sclerotium rolfsii*, has been reported with an incidence ranging from 11% to 19%, while collar and root rot (Figure 9B), attributed to *Rhizoctonia solani*, showed an average disease incidence of 7.16% (Paul et al., 2022; Paul et al., 2023). Sahile et al. (2010) and Emeran et al. (2011) have indicated that yield losses from rust and chocolate spot infections can vary significantly, from 22% to 42% and 36% to 68%, respectively. Synthetic fungicides are commonly used for managing faba bean diseases, alongside practices such as crop rotation and residue removal from fields after harvest (Harveson and Schwartz, 2007). Biofungicides are also employed as a biorational approach to disease management (El-Mougy and Abdel-Kader. 2008; Sahile et al. 2011). An overview of prevalent diseases affecting faba beans and their corresponding management strategies is provided in Table 4.

Insects

Aphids, beetles, and hoppers are regarded as major pests of faba beans. Though these pests occasionally appear on faba beans, they can rarely reach levels that cause significant economic harm. Aphids and leafhoppers also role as a vector for viruses, with leafhoppers specifically transmitting aster yellows.

Table 4. List of faba beans diseases, their causal agents, symptoms and possible management

Disease name and causal organism	Symptoms	Management
Chocolate spot (*Botrytis fabae*)	Small reddish-brown lesions appear on the plant's leaves and sometimes on the stems and pods. (Haile et al., 2016).	The best management technique is prevention. It is advised to plant early to avoid late spring and early summer's high humidity and heat. Application of *Trichoderma* spp. have also shown effectiveness to control the disease (Sahile et al. 2011; Kora et al., 2017).
Leaf blight (*Xanthomonas campestris syn. Xanthomonas axonopodis*)	Small, expanding necrotic water spots develop on the leaves, with lesions that can merge, giving the plant a scorched appearance. The spots may be surrounded by a yellow discoloration. Round, deep reddish-brown lesions can also appear on the pods, and dead leaves may remain attached. Buruchara et al., 2010)	Effective treatment methods include using clean seeds (Tar'an et al., 2001; Gillard et al., 2009), planting resistant varieties, treating seeds before planting, and spraying plants with a suitable copper-based fungicide as a preventive measure before symptoms appear (Buruchara et al., 2010).
Bacterial brown spot (*Pseudomonas syringae*)	Small, dark-brown necrotic patches are frequently encircled by a yellow tissue patch (Schwartz et al., 2005).	Preventive measures include using clean seeds, implementing crop rotation, and burning or cleaning residues from crop field after harvesting (Harveson and Schwartz, 2007).
Powdery mildew (*Erysiphe cichoracearum*)	Yellow dots appear on the tops of the leaves, and areas of powdery grey-white coating cover the entire plant. Plants that are heavily infected may exhibit slight gray and blue discoloration. (Trabanco et al., 2012).	Using resistant varieties and, overhead irrigation to wash fungus spores from the leaves. Early planting to avoid high temperatures and humidity. Spraying sulfur pesticides is also advised for chemical control. (Van Emden et al., 1988).
Fusarium root rot (*Fusarium solani*)	Stunted growth, yellowing of leaves, necrotic basal leaves, and brown, black or red streaks on mature plant roots. (Abdel-Kader et al., 2011).	Use resistant varieties, proper crop rotation, improve soil drainage and structure. If the disease is severe, apply appropriate soil fungicides (benomyl or carbendazim) before planting. Furthermore, seed priming with biofungicides reduce the disease severity (El-Mougy and Abdel-Kader. 2008)
Collar and root rot (*Rhizoctonia solani*)	Dark brown to black lesions on infected plant roots extending upon collar region (Paul et al., 2022)	Intercropping with garlic, application of Rizolex-T, chitosan and biocontrol agents such as Arbuscular mycorrhizae (AM), yeast significantly decreased the incidence and disease index of root rot diseases El-Mehy et al., 2022; Gazzar et al., 2023).
Collar rot (*Sclerotium rolfsii*)	Water-soaked sunken lesions appeared on the collar region followed by the expansion of rotten areas along with white mycelial mass (Paul et al., 2023).	Implementing crop rotation, and burning or cleaning residues from crop field. Provax (Carboxin 17.5% + Thiram 17.5% FF) shows strongest mycelia growth inhibition.
Rust (*Uromyces viciae-fabae* (Pers.) J. Schröt)	Rust usually occurs late in the growing season during podding, resulting in leaf damage and premature leaf drop (Sillero et al., 2011)	Rust can be successfully controlled by foliar spraying fungicides such as chlorothalonil, thiram, maneb, or mancozeb, and dithiocarbamates (difenoconazole, epoxiconazole, or tebuconazole) (Emeran et al., 2011).

Shoots and buds of faba beans are consumed through Blister beetles and grasshoppers, and localized damage symptom appear on the infected plant. Blister beetles pose a concern when faba beans are cultivated for livestock feed because of the toxin cantharidin. Early in the season, inspect plants for tissue damage caused by cutworms. It's important to note that insecticide seed treatments do not protect against cutworms, but faba bean seedlings can regrow from the growing point at the seed after damage. Additionally, pea leaf weevils (Tkachuk, et al., 2020), and black bean aphid (Webster et al., 2010) causes significant damage to faba beans. Visual inspection before transplanting can reduce the aphid infestation, and a reflective mulch (silver-colored plastic) can prevent aphids to reaching on plants. A mechanical way like strong water jet can dislodge aphids from sturdy plant leaves. Plants can usually tolerate low to medium levels of aphid presence, otherwise insecticides are typically needed for severe infestations. Neem or canola soap, extract or oil are generally applied as the most effective biocontrol. (Birch, 1985). Faba bean's insects are listed in Table 5.

Table 5. Insects found feeding on leaves, stems, flowers and pods of faba beans (Source: Nuessly et al., 2004).

Order	Family	Insect	Plant part
Orthoptera	Acrididae	*Chortophaga australion*	Leaf
	Tettigoniidae	*Microcentrum rhombifolium*	Leaf
Thysanoptera	Thripidae	*Frankliniella bispinosa*	Flower
		Frankliniella insularis	Flower
		Frankliniella kelliae	Flower
Hemiptera	Miridae	*Creontiades rubinervis*	Leaf
	Lygaeidae	*Oncopeltus cayensis*	Stem /pod
		Ozophora trinotata	Leaf
	Pyrrhicoridae	*Dysdercus mimulus*	Pod
	Coreidae	*Acanthocephala femorata*	Pod
		Anasa scorbutica	Pod
		Leptoglossus phyllopus	Pod
		Zicca taeniola	Pod
	Pentatomidae	*Acrosternum hilare*	Pod
		Acrosternum marginatum	Pod
		Edessa bifida	Pod
		Euschistus ictericus	Pod
		Euschistus quatrator	Pod
		Nezara viridula	Pod
		Thyanta perditor	Pod
	Cicadellidae	*Draeculocephala mollipes*	Leaf
		Gypona sp.	Leaf
	Aphidae	*Acyrthosiphon pisum*	Leaf
		Aphis craccivora	Leaf and stem
	Pseudococcidae	*Planococcus citri*	Root and stem
Coleoptera	Scarabaeidae	*Anomala marginata*	Pollen/nectar
		Euphoria sepulcralis	Pollen/nectar
		Trigonopeltastes delta Forster	Pollen/nectar
	Cantharidae	*Chauliognathus marginatus*	Pollen/nectar
	Chrysomelidae	*Diabrotica balteata*	Leaf
		Diabrotica undecimpunctata howardi	Leaf
	Curculionidae	*Diaprepes abbreviatus*	Leaf
Lepidoptera	Arctiidae	*Spilosoma virginica*	Leaf
	Noctuidae	*Feltia subterranea*	Seedling stem
		Spodoptera eridania	Leaf
	Saturniidae	*Automeris io io*	Leaf
	Hesperiidae	*Lerema accius*	Flower
Diptera	Agromyzidae	*Liriomyza trifolii*	Leaf
Hymenoptera	Chrysididae	*Chrysis* sp.	Nectar
	Halictidae	*Agapostemon splendens*	Nectar
		Halictus sp.	Nectar
	Anthophoridae	*Xylocopa micans*	Nectar
	Apidae	*Apis mellifera* L.	Pollen/nectar

(Nuessly et al., 2004)

Harvesting and Yield

Harvesting is important for faba beans because it maximizes yield, preserves quality, ensures proper storage, and has significant economic, environmental, and sustainability implications. Timely and efficient harvesting practices are essential for producing high-quality faba beans that meet market demands and involve to sustainable agronomic practices. The time required for faba beans to extent harvest maturity depends on the variety and environmental conditions, typically ranging from 80 to 120 days after planting. Harvesting should commence when the stems are still slightly green. As the beans mature, the stems become black or dry, and the lower pods start to darken or when most seeds can be easily separated from the hilum. At this stage, the beans usually have a moisture content between 30 and 35%. Generally, a moisture level of 15 to 18% in the seeds at harvest is adequate to reduce the risk of shattering. However, drying too quickly at high temperatures often leads to stress cracks (Singh et al., 2013). Typically, about 70-100 quintals per hectare of green pods can be obtained (Choudhary, 2014). One tonne of raw fava beans produces around 240 kg of protein, 520 kg of starch, 200 kg of fiber, and a small amount of oil (Tsolakis et al., 2019).

Limitations and Future Directions for Faba Bean Cultivation

Faba bean cultivation faces several limitations, including susceptibility to diseases like rust, chocolate spot, and collar rot, which can significantly reduce yield (Torres et al., 2006; Stoddard et al., 2010; Paul et al., 2022, 2023). The reliance on synthetic fungicides raises concerns about environmental impact and the development of resistant pathogen strains. Additionally, abiotic stresses such as drought, poor soil fertility, and extreme temperatures can further limit productivity (Khan et al., 2010). Therefore research should focus on developing disease-resistant and stress-tolerant faba bean varieties through advanced breeding techniques, including marker-assisted selection and CRISPR-Cas technology. Integrating sustainable farming practices, such as biofungicides, crop rotation, and organic soil amendments, can also improve disease management. Moreover, increasing research on faba bean's nutritional value and promoting its use as a protein-rich crop in sustainable food systems could enhance its global significance.

Conclusion

The faba bean is a versatile and highly valued crop, renowned for its nutritious and medicinal properties. Its seeds, pods, and leaves are packed with protein and contain nearly all the essential nutrients required in human diets. Additionally, faba beans are renowned for their high biological nitrogen fixation capabilities among grain legumes. It is appreciated for its nitrogen-fixing ability, which improves soil fertility and minimizes the reliance on synthetic fertilizers. This makes them an excellent choice for crop rotations, particularly in sustainable agricultural systems. With proper management, including the right choice of variety, planting time, and soil management, faba beans can produce high yields. However, the yield can be significantly influenced by environmental factors including soil type, available moisture, and temperature. Effective management of pests and diseases is crucial for maximizing faba bean productivity. Faba beans are a versatile and valuable crop in agronomy, offering numerous benefits to farmers, the environment, and food systems. Ongoing research and development are essential to optimize their production and address challenges such as disease resistance and climate adaptability.

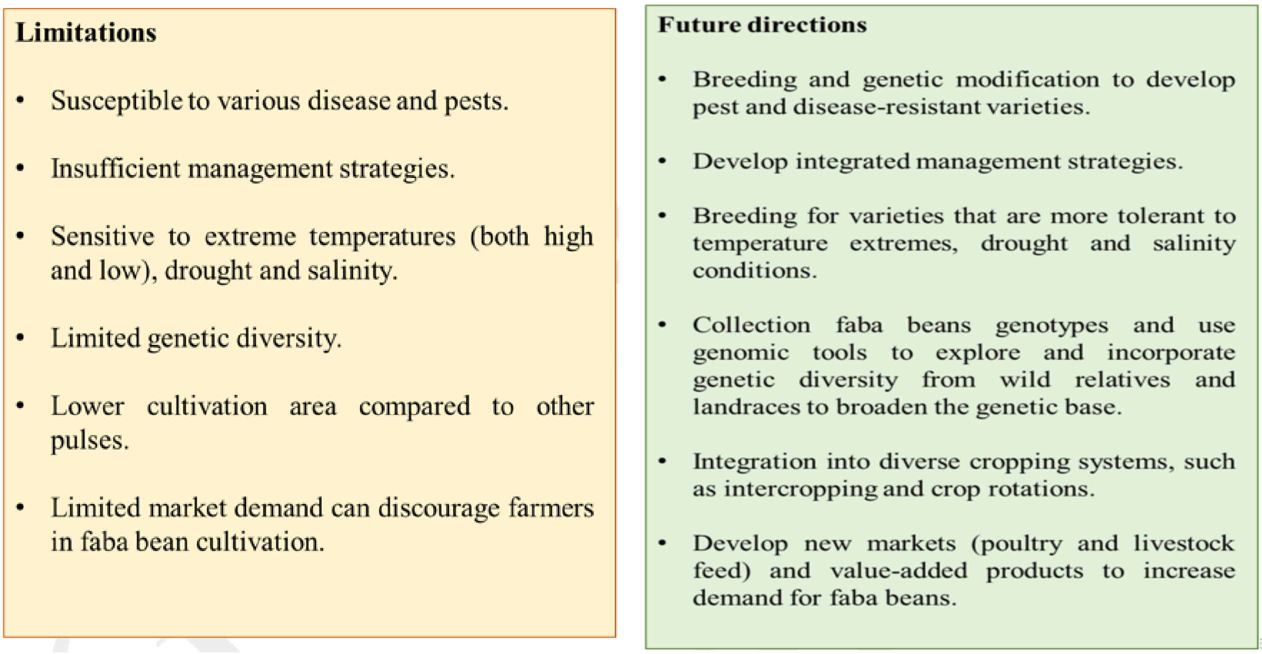

Figure 10. Limitations and future directions for faba bean cultivation

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