Online Journal of Biological Sciences

Review

Vegetable Beans: Comprehensive Insights into Diversity, Production, Nutritional Benefits, Sustainable Cultivation and Future Prospects

Sayed Shahidul Islam, Shanta Adhikary, Mahabuba Mostafa and Md. Motaher Hossain

Department of Plant Pathology, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh

Article history
Received: 31-01-2024
Revised: 21-02-2024
Accepted: 27-02-2024

Corresponding Author:
Md. Motaher Hossain
Department of Plant Pathology,
Bangabandhu Sheikh Mujibur
Rahman Agricultural University,
Gazipur, Bangladesh
Email: hossainmm@bsmrau.edu.bd

Abstract: Vegetable beans, members of the *Fabaceae* family, have a rich historical significance as a source of plant-based proteins and nutrients. They have been cultivated worldwide for centuries, enriching the nutritional landscape and constituting a crucial component of human nutrition. The wide array of beans, including common bean, lima bean, tepary bean, mung bean, yard long bean, moth bean, adzuki bean, garbanzo bean, broad bean, soybean, velvet bean, carob bean, sword bean and jack bean, offers a plethora of health benefits, including the prevention of chronic diseases. However, the production and utilization of these vegetable beans face significant challenges, such as poor soil fertility, pest infestation and diseases. In response, innovative approaches like molecular breeding, precision agriculture and UAV-based phenotyping have been explored. These methods aim to mitigate the reliance on chemical treatments and promote sustainable farming practices. Furthermore, a range of disease control strategies, encompassing biological, chemical and cultural controls, have been adopted to combat the challenges posed by pests and diseases. This study offers a comprehensive review of vegetable beans, covering various aspects such as their nutritional composition, global production and consumption trends, advancements in cultivation techniques and strategies for managing diseases. Drawing upon a meticulous analysis of pertinent literature and scholarly resources, this review serves as a valuable resource for researchers and growers alike who are interested in optimizing vegetable bean production through sustainable agricultural practices.

Keywords: Production, Consumption, Nutritional Profile, Health benefits, Constraints, Breeding, Biological Control

Introduction

Vegetables are a broad category of plant or plant-derived products essential to human nutrition and health (Ryder, 2011). Vegetables are second only to cereals in terms of carbohydrate content and they are rich in dietary fiber and have a high-water content of 70-95%. Additionally, certain vegetables are excellent sources of phosphorus, iron, calcium, potassium, vitamins and antioxidants. Among these, beans and legume vegetables are commonly consumed worldwide. Regarding botany, one of the three biggest groups of flowering plants is the *Fabaceae* family (previously known as *Leguminosae*), which includes beans (Jin *et al*., 2019). These annual plants have flat blooms that grow into seeds of different sizes, shapes and colors inside a single elongated pod. They also have herbaceous stems with trifoliate leaves. The *Fabaceae* family has a wide range of plant sizes, from big tropical trees to small wild vetches found in temperate regions. According to more modern nomenclature, the family is divided into three sub-families, with the subfamilies *Papilionoideae*, tribe *Phaseoleae and* subtribe *Phaseolinae* accounting for around two-thirds of all species (Gepts, 2001). Vegetable beans have a wide range of culinary applications; the fresh pods and green seeds are frequently cooked or used in curries. Mature seeds can be sun-dried and kept as vegetables, while ripe seeds are used for pulses (Sultana, 2001). In the

Science Publications

manufacturing chain, proper seed storage is crucial since improper storage temperatures, packing and time spent in storage can all cause seed degradation. Because transparent seeds are more prone to breakage, they may have the "hard-to-cook" effect, which lowers their market value and acceptability by consumers (Ganascini *et al*., 2019).

Vegetable beans are widely accepted in society, particularly among low-income populations in developing nations, as they provide an affordable supply of plant-based proteins and meat substitutes. In addition to protein, beans offer nutritional fiber, carbohydrates, minerals and vitamins, which help these populations' chronic protein deficiencies (Kutoš *et al*., 2003; Hayat *et al*., 2014; Kamboj and Nanda, 2018). A diet rich in beans has several physiological advantages, including managing and preventing metabolic disorders such as diabetes mellitus, coronary heart disease and colon cancer. Moreover, vegetable beans, such as common beans and chickpeas, have various uses across industries (Fig. 1). Chickpeas, for instance, contain compounds beneficial for skin health and are employed in cosmetics. In agriculture, beans aid soil fertility as nitrogen-fixing plants, serve as natural barriers and provide high-protein feed for animals like cows (Alfaro-Diaz *et al*., 2023; Affrifah *et al*., 2023; Schmidt *et al*., 2023).

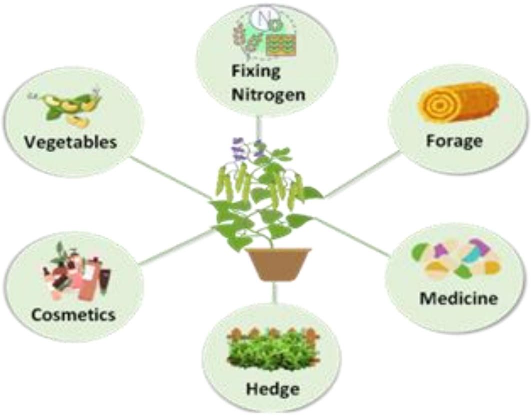

Fig. 1: Diversified uses of vegetable bean

Several obstacles must be overcome to produce and use beans, including choosing the suitable cultivar, cropping conditions and susceptibility to viral, bacterial and fungal diseases. Breeding programs have recently concentrated on improving resistance to heat, drought, diseases and low soil fertility to strengthen biotic and abiotic stress tolerance. Beans have been studied from various perspectives, but comprehensive reviews are lacking regarding their diversity, production, nutritional benefits, sustainable cultivation and prospects. Therefore, this review aims to explore the significance of vegetable beans in human nutrition, covering aspects of production, nutrition, breeding and challenges. The present analysis offers valuable insights for researchers and growers seeking to improve bean production and nutritional value, serving as a contemporary source of information.

Diversity of Cultivated Beans

In the face of prevalent global challenges, including food insecurity, extreme weather and rising living costs, beans emerge as a straightforward and viable solution. With 600 million people expected to be undernourished by 2030 and 9.2% of the world's population suffering from hunger, eating various beans can significantly increase access to vital proteins, fiber, carbs, vitamins and minerals globally (Newnham, 2023). Cultivated on a global scale, various types of beans, such as common bean, lima beans, tepary bean, mung bean, yard-long bean, moth bean, adzuki beans, garbanzo beans, broad beans, soybean, velvet bean, carob bean, sword bean and jack beans contribute to this nutritional diversity. Members of the legume family, such as pole, snap, string and bush beans, are only a few of the many variants of the common bean (*Phaseolus vulgaris*). These versatile beans, known by different names in various countries, have been a dietary staple for centuries and were domesticated around 8000 years ago in South America and central Mexico, resulting in distinct genetic pools covering Mesoamerican and Andean regions (Britannica, 2020; Rodriguez *et al*., 2016). Annually cultivated for their young green pods, runner beans (*Phaseolus coccineus L.*) are a climbing perennial. Found in Central and South America, Africa, the USA and Europe, this bean offers culinary diversity and adaptability (Kalloo and Bergh, 2012). Lima beans (*Phaseolus lunatus*), also called butter beans, sieva beans, or Madagascar beans, are grown for their tasty seeds. The Andean and Mesoamerican lima bean originated from two separate domestication processes, expanding their distribution across neotropical lowlands and the western Andes (Serrano-Serrano *et al*., 2012). *Vigna*, a genus in the legume family, includes well-known cultivated species like mung bean (*Vigna radiata*) and adzuki bean (*Vigna angularis*). Adzuki beans, native to East Asia, are widely grown in various countries, while mung beans find popularity in Asia, the Caribbean and parts of Africa (Parwez *et al*., 2022; Petruzzello, 2023). Fava beans, or broad beans (*Vicia faba L.*), are native to tropical and temperate parts of the world. Grown for its succulent immature seeds, this legume contributes to nutritional diversity in regions spanning North and South America, Europe, Africa and China (Allen, 2013). Pigeon pea (*Cajanus cajan*), originating in the northern Indian subcontinent over 4000 years BCE, has spread to East Africa, Southeast Asia, Latin America, West Africa and the Caribbean. Pigeon peas, an important source of vital nutrients, are an integral part of the diets of small and marginal farmers who grow for subsistence farming (Khoury *et al*., 2015). The practice of cultivating a diverse selection of beans not only satisfies nutritional requirements but also showcases the adaptability of these legumes to varying climates. This may ultimately aid in global food security during these challenging times of climate change and population growth.

Production and Consumption of Beans

Bean vegetables are prevalent across regions where they are extensively grown and eaten. Their popularity is notable in various areas, spanning Europe, East Africa, South Africa, West Africa, West Asia/Middle East, North America, South America, Central America and the Caribbean, East Asia and South Asia. In the year 2019, regional bean production figures were as follows- Asia accounted for 14,369,312 metric tons, Africa produced 7,052,612 metric tons, America contributed 7,039,866 metric tons, Europe produced 367,412 metric tons and Oceania yielded 73,470 metric tons, where Myanmar emerged as the leading bean-producing country, with a production of approximately 5.85 million metric tons followed by India producing around 5.31 million metric tons. Brazil and China trailed behind the top two, producing roughly 2.9 and 1.2 million metric tons. Other notable producers included Tanzania, Uganda, the USA, Mexico, Kenya and Burundi. However, their production figures were considerably lower (Fig. 2). The combined global cultivated area for beans in the same year was 33.1 million hectares, resulting in a total production of 28.9 metric tons (FAO, 2024). African countries emerged as significant consumers of bean vegetables and bean products, with Rwanda, Uganda and Tanzania leading the pack. These nations recorded per capita consumption rates of 34.80 kg (76.56 lbs.), 24.80 kg (54.56 lbs.) and 15.30 kg (33.66 lbs.), respectively (Siddiq *et al.*, 2022). In contrast, certain industrialized economies, such as the United States and Europe, showed lower per capita bean consumption than other nations worldwide (FAO, 2024). These statistics underscore the global appeal of bean vegetables as a vital dietary component, with varying consumption patterns across continents and nations.

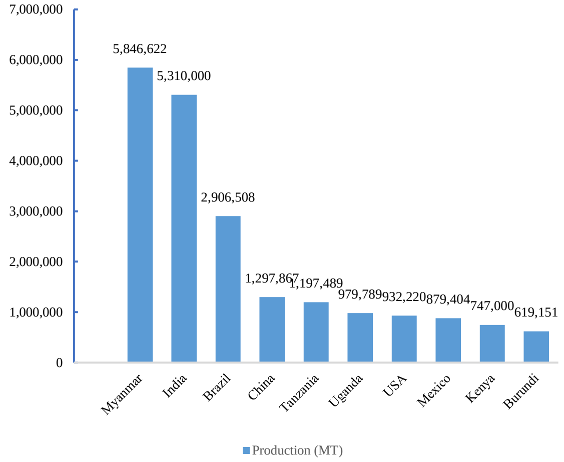

Fig. 2: Some leading bean-producing countries and their production (source: FAO, 2024)

Nutritional Profile and Health Benefits

Vegetable beans offer a rich array of essential nutrients, including vitamin A, thiamin, vitamin C, riboflavin, niacin and various minerals such as magnesium, iron, calcium, phosphorus, sulfur, potassium, sodium and zinc (Ahmed *et al.*, 2015; Buruchara *et al.*, 2011). Additionally, beans provide carbohydrates, proteins and essential elements (Table 1), making them a highly nutritious food source (Sultana, 2001). Both green pods and developed unripe seeds of vegetable beans are not only delicious but also serves as an excellent protein source. Vegetable beans are rich in antifungal proteins and have a low glycemic index, making them a great choice for various dietary needs (Wortman *et al.*, 2004; Ye *et al.*, 2000). The protein content in green pods is approximately 4.5%, while it rises significantly to 25% in dry seeds. Moreover, consuming beans has numerous health benefits (Bennink and Rondini, 2003). These benefits include lower cholesterol levels and preventive and curative properties against advanced diseases like cancer. Specific species of *Phaseolus* beans contain

Table 1: Nutritional composition of different bean vegetables together

No	Compound	Amount	Unit
1	Water	11.55	g
2	Energy	340.5	kcal
3	Energy 1	424	KJ
4	Protein	18.42	g
5	Lipid (fat)	1.30	g
6	Carbohydrate	61.74	g
7	Fiber, dietary	15.38	g
8	Sugars	2.55	g
9	Calcium	115.2	mg
10	Iron	5.57	mg
11	Magnesium	165	mg
12	Phosphorus	394	mg
13	Potassium	1365	mg
14	Sodium	8.5	mg
15	Zinc	3.09	mg
16	Vitamin C1[1]	15.27	mg
17	Thiamin	0.62	mg
18	Riboflavin	0.17	mg
19	Niacin	1.63	mg
20	Vitamin B-6	0.40	mg
21	Folate, DFE[2]	431.75	µg
22	Vitamin A	3.88	mg
23	Vitamin E[3]	0.16	mg
24	Vitamin K[4]	4.24	µg

[1]total ascorbic acid, [2]dietary folate equivalents, [3]α-tocopherol, [4]phylloquinone (source: Siddiq *et al.*, 2022; Khan *et al.*, 2020)

antifungal peptides that have been shown to inhibit the activity of reverse transcriptase (Anderson *et al*., 1999; Bennink, 2002; Wang and Ng, 2006; Ngai and Ng, 2004), potentially delaying the onset of symptoms in HIV-infected patients (Wong *et al*., 2006; Ngai and Ng, 2004). Furthermore, the amount of tyrosinase enzyme may increase to 25% in dry seeds, which may be beneficial for people with hypertension (Ahmed *et al*., 2015). Further research indicates that incorporating bean vegetables, bean products, or legumes into the diet can prevent colorectal cancer, cardiovascular diseases, metabolic syndrome and obesity (Perera *et al*., 2020). This highlights the substantial health advantages associated with the regular consumption of vegetable beans, promoting their inclusion in balanced and nutritious diets.

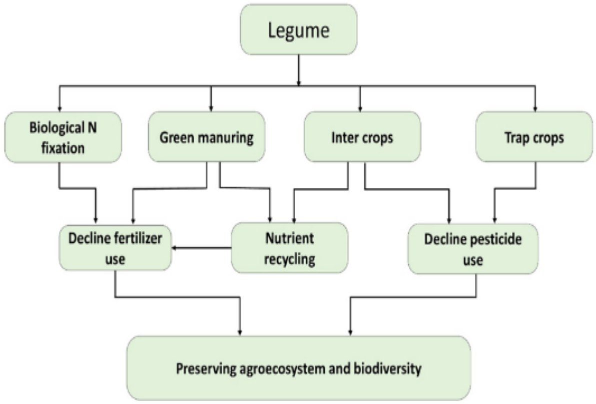

Fig. 3: The role of legumes in sustainable agriculture

Legumes for Sustainable Agriculture

Sustainable agriculture aims to increase crop yield and revenue for small-scale farmers by improving agricultural methods and technology (Livondo *et al*., 2015). Extension agents are essential in advising farmers and telling them about new agricultural legume technology and practices (Davis, 2008; Aker, 2011; Anderson and Feder, 2007; Bell, 2015). Legumes are the cornerstone of sustainable agriculture since they represent the three pillars of a healthy earth, healthy humans and healthy animals. Food security and environmental quality become critical issues as the world's population grows and production costs rise. Because legumes and *Rhizobium* bacteria may coexist, legumes help Biological Nitrogen Fixation, which is essential to agricultural cropping systems. This process enhances soil fertility and reduces the need for energy and nitrogen fertilizers, resulting in cost savings and mitigating nitrogen leaching. Additionally, legumes improve soil physical conditions and promote biodiversity (Courty *et al*., 2015; Peix *et al*., 2015). Legumes, commonly grown on marginal lands, serve various roles, such as intercrops, trap crops, green manure and alley crops, aiding nutrient cycling in agriculture. Their nitrogen-fixing ability, leaf shedding and nutrient release positively impact subsequent crop yields (Das and Ghosh, 2012). Incorporating legumes enhances sustainability and productivity in farming, offering long-term environmental and economic benefits. Thus, legumes can promote sustainable agriculture by fixing nitrogen, serving as intercrops, trap and green manure crops, reducing dependence on synthetic fertilizers and pesticides, promoting nutrient recycling and minimizing chemical usage in the field (Fig. 3). Moreover, legumes contribute to preserving agroecosystem integrity and biodiversity by improving soil health and providing habitats for beneficial organisms. Overall, legumes foster diverse ecosystems in agricultural landscapes, ensuring enduring sustainability and resilience.

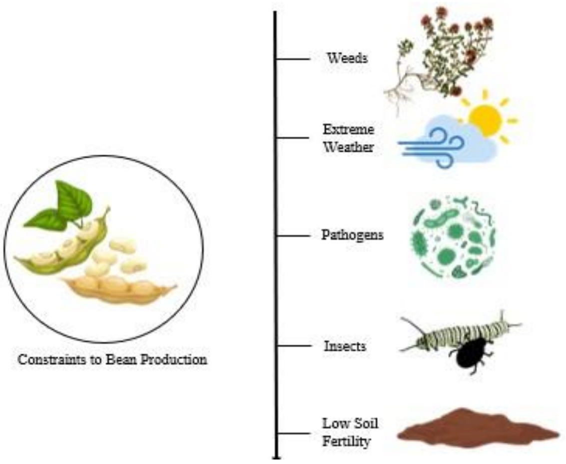

Fig. 4: Biotic and abiotic constraints to bean production

Constraints to Bean Production

Vegetable beans are a crucial legume food consumed worldwide and play a vital role, especially for lower-income individuals and marginal farmers. However, several biological, edaphic and climatic challenges hinder bean production. The main difficulties impacting vegetable bean production include diseases, insect pests, extreme weather, weed infestations and inadequate soil fertility (Fig. 4). Diseases significantly threaten various vegetable bean crops. Pathogens with pathogenic traits and varying virulence attack vegetable beans, with their prevalence and importance depending on locality, cropping season, year and cultivar. Common diseases affecting bean production include *Cercospora* leaf spot, Ascochyta leaf spot, anthracnose, Halo blight, Web blight, common bacterial blight, bean rust, bean common mosaic virus and others (Table 2). These diseases are major culprits responsible for production losses, especially in tropical regions, where many vegetable bean-producing countries are situated. Additionally, pathogens like bean golden mosaic virus, web blight and *Ascochyta* blight play economically important roles but are limited to specific environmental conditions in growing regions (Fig. 5). In recent years, web blight has emerged as a new disease in Bangladesh (Kader *et al*., 2022). Some pathogens, such as root rots, are widespread but have relatively lower economic significance. Insect pests are another formidable challenge affecting vegetable bean production, causing significant economic damage both preharvest and postharvest. Such pests include bean flies, bean pod weevils, bruchids and leafhoppers and are widely distributed in tropical bean-producing countries (Schwartz and Corrales, 1989). Weeds represent a persistent problem for farmers throughout the history of agricultural production and may lead to reduced yields and substantial economic losses (Buhler *et al*., 1998). Common examples of economically significant and widespread weeds in vegetable bean fields include bathua (*Chenopodium album L*.), smooth crabgrass (*Digitaria ischaemum*), bish katali (*Polygonum persicaria L.*), large crabgrass (*Digitaria sanguinalis L*.), wild mustard (*Sinapis arvensis* L.) and wild radish (*Raphanus raphanistrum*) (Khan *et al*., 2020). Soil fertility poses a significant constraint to vegetable bean production. Nutrient deficiencies, soil toxicities (Schwartz and Corrales, 1989), imbalanced fertilizer use, inadequate crop rotation, limited micronutrient application and insufficient utilization of organic matter can lead to decreased soil fertility, negatively impacting bean yields (Margaret *et al*., 2013; Khan *et al*., 2020).

Climate change is likely to alter the occurrence and severity of disease, insect and weed infestations. The climatic changes are also expected to result in greater precipitation in equatorial places, namely the Northern Andes and the East African highlands (Yadav *et al*., 2011). The excessive amount of rainfall is anticipated to worsen problems associated with several types of fungal diseases, including those that reside in the soil and impact the health of leaves, such as angular leaf spot and anthracnose (Beebe *et al*., 2011). Moreover, the simultaneous occurrence of abundant rainfall and moderate to high temperatures is expected to increase the occurrence of web blight and angular leaf spots at elevations between 50 and 1400 m above sea level (Frahm *et al*., 2004). Abiotic stresses such as drought and heat may also significantly limit vegetable bean yield. Addressing these constraints is crucial for sustaining and improving vegetable bean production, ensuring food security and supporting agricultural livelihoods worldwide.

Table 2: Important diseases of beans, their host, causal agents and geographical distribution

Sl. No	Disease	Major Host	Causal organism	Symptoms	Distribution	References
1	Halo blight	Kidney bean, lima bean, runner bean, yellow-eyed bean	*Pseudomonas syringae* pv. *phaseolicola*	Initially, it manifests as a small waterlogged lesion that gradually takes on a yellowish-green hue and develops a surrounding halo	Commonly found in regions with elevations ranging from moderate to high. Preferred by temperatures ranging from 16-20°C as well as damp and overcast weather conditions	
2	Bean anthracnose	Common bean, country bean, soybean	*Colletotrichum lindemuthianum*	The diseased pods develop black-red sunken cankers or patches	Most common in rainy areas. Destructive at cool to moderate temperatures and excessive humidity	Buruchara *et al*. (2010) Chupp (1954)
3	Ascochyta leaf spot	Faba bean, French bean, garbanzo bean	*Ascochyta phaseolorum*	Irregularly shaped brown or purple blotches on leaves or pods	The disease is prevalent across Africa, where conditions are especially cold and humid	Williams (1987)
4	Web blight	Country bean, common bean, soybean, winged bean	*Rhizoctonia solani*	Water soaking symptoms, followed by browning or necrotic circular lesions	Hot and humid regions of Madagascar, D.R. Congo and Ethiopia are affected	Li-Juan *et al*. (1993) McKenzie and Grahame (2010)
5	Powdery mildew	Common bean, lima bean, broad bean, cluster bean	*Erysiphe poligoni*	Initially, appears as necrotic, irregular, chlorotic lesions, which are succeeded by the characteristic white, powdered appearance	Disease develops in environments characterized by elevated temperatures (20-24°C), reduced humidity and shadiness	East-West Seed (2023)
6	White mold	Common bean, kidney bean, lima bean, mung bean	*Sclerotinia sclerotiorum*	Appears as a greyish-green water-soaked lesion and finally shows white/cotton mold. Black sclerotia formed	Widespread and occurs at intermediate altitudes with cool and moist conditions but seasonally important	

Table 2: Continue

				on infected tissue	
7	Leaf rust	Common bean, French bean, soybean	*Uromyces appendiculatus*	Pustules of red-brown powdery spores on the lower side of the leaves	Wherever beans are grown, rust occurs. It is distributed in cool to moderate temperatures with moist conditions
8	Bean root rots	Faba bean, common bean, lima bean	*Sclerotium rolfsii*, *Pythium* spp. *Rhizoctonia solani*, *Fusarium solani* f. sp. *phaseoli*	Plants wilt and die, roots decay and leaves turn yellow and fall	Widespread in tropics and are favoured under stress conditions, such as low soil fertility, warm to high temperature, high relative humidity, drought and acid soils
9	Charcoal rot or ashy stem blight	Common bean, lima bean, soybean	*Macrophomina phaseolina*	Symptoms usually appear during or after flowering. But seedlings can also be impacted. Emerging seedling hypocotyls may develop brown lesions	Distributed throughout the tropics and subtropics areas. More destructive with sudden rainfall and high temperatures
10	Fusarium wilt or Fusarium yellows	Common bean, mung bean, soybean	*Fusarium oxysporum* f. sp. *phaseoli*	Yellowing of lower leaves, which may gradually spread to the upper leaves. Discolouration of xylem and phloem above and below the soil line.	Distributed widely throughout Africa but not equally across various countries. Favorable conditions include low relative humidity, high temperature during drought and wounded plants
11	Sudden Death Syndrome (SDS)	Soybean	*Fusarium virguliforme* (Synonym*: F. solani*)	Interveinal chlorosis and necrosis are typical for SDS	SDS is among the most devastating soil-borne diseases in the USA. When this disease occurs in the presence of soybean cyst nematode, disease symptoms occur earlier and are more severe
12	Cercospora leaf spot	Common bean, country bean, French bean, mung bean, soybean, lima bean	*Cercospora* spp.	The spots initially appear as little brown specks, then grow into brown circular spots with grey centers. The affected center tissue becomes thin and brittle and often drops out, leaving a shot-hole appearance	Found throughout the hot and wet regions where the bean is grown. Favorable conditions are warm to high temperature (21-30-35) and high relative humidity
13	Common Bacterial Blight (CBB)	Common bean, runner bean, country bean, lima bean, mung bean, soybean	*Xanthomonas campestris* pv. *phaseoli*	Commonly water soak areas on leaves that turn into necrotic lesions. During severe infections, the leaves of the plant may fall off and the plant may become floppy and droopy	Widespread throughout tropical regions. Warm to extreme temperatures and high relative humidity are favourable conditions
14	Bean Common Mosaic Virus (BCMV) and Bean Yellow Mosaic Virus (BYMV)	Country bean, French bean, soybean, Common bean	Virus	Mosaic patterns on leaves between light and dark green are typical signs of both diseases. Foliage loss and inhibition of growth in plants	The two most significant viral infections affecting bean plants in Africa and Asia

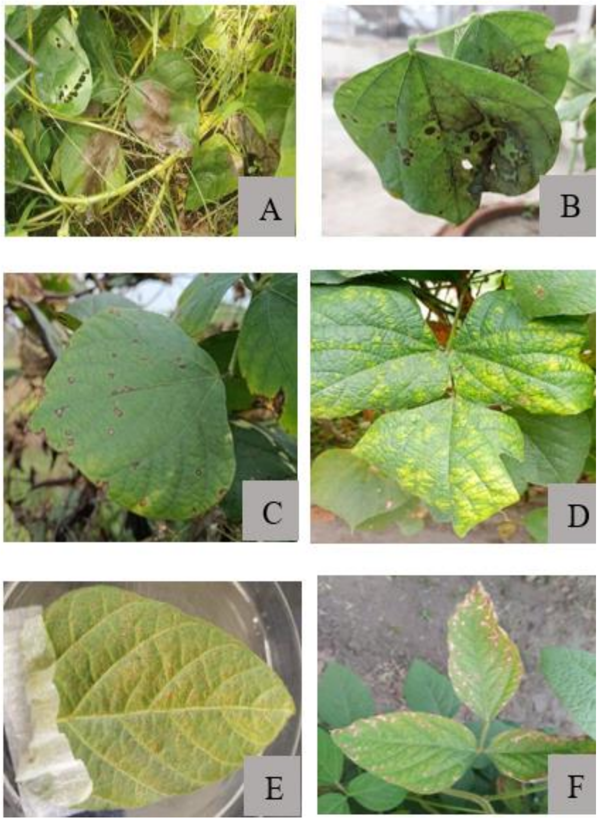

Fig. 5: Diseases of bean. (A) Web blight of mung bean; (B) Web blight of country bean; (C) *Cercospora* leaf spot of country bean; (D) Bean Common Mosaic Virus (BCMV), (E) Soybean rust; (F) Sudden death of soybean

A comprehensive study conducted by Hall and Nasser (1996) reveals the presence of various infectious diseases in vegetable beans, categorized into different groups based on the causative agents. In total, 50 infectious diseases have been identified in vegetable beans, each with distinct characteristics and implications for crop health. Fungal pathogens contribute to the largest proportion of infectious diseases in vegetable beans, with 29 identified. These fungi can cause significant damage to crops, impacting yield and quality. Viral infections pose another significant threat to vegetable bean production, with 14 viral diseases detected in the crop. These viruses can spread rapidly and have varying severity on the plants. Bacterial pathogens are responsible for four infectious diseases in vegetable beans. While relatively fewer in number compared to fungi and viruses, these bacteria can still have detrimental effects on crop health. Nematodes, microscopic worm-like organisms, contribute to two infectious diseases in vegetable beans. Despite their small size, nematodes can cause considerable damage to the root systems of plants. One infectious disease in vegetable beans is attributed to a Mycoplasma-Like Organism (MLO). These organisms exhibit characteristics similar to mycoplasmas, bacteria without a cell wall. Understanding the types and prevalence of infectious diseases in vegetable beans is essential for implementing effective management strategies to protect crop health and ensure sustainable production.

Disease Management in Bean Cultivation

Disease management in bean cultivation is vital for sustaining crop health and productivity. It ensures the prevention and control of harmful pathogens that can impact bean plants, safeguarding yields and quality. Effective disease management practices contribute to sustainable agriculture, reducing the reliance on chemical interventions and promoting long-term soil health. By addressing potential threats early, farmers can minimize economic losses and maintain a stable and resilient bean production system. Overall, prioritizing disease management is integral to successful and sustainable bean cultivation.

Table 3: Effective fungicides used as a seed dressing and protective treatment for controlling bean diseases

No	Trade name	Rate of doses
Seed treatment/seed dressing		
1	Benomyl or thiophanate methyl	5.2 g/kg of seed
2	Cerasan	0.5 g/100 g of seed
3	Thiram	0.5 g/100 g of seed
4	Ziram	0.5 g/100 g of seed
Protective fungicide/systemic fungicide		
5	Azoxystrobin	1 mL/L of water
6	Benomyl	0.55 g/L of water
7	Carbendazim	0.5 kg/ha
8	Copper oxychloride	3 g/L of water
9	Captafol	3.5 kg/ha
10	Chlorothalonil	2 g/L of water
11	Dithane M45	2.20 kg/ha
12	Dicloran	2 g/L of water
13	Fentin hydroxide	1.2 g/L of water
14	Mancozeb	2 g/L of water
15	Maneb	3.5 g/L of water
16	Tryfloxystrobin	0.5 mL/L of water
17	Zineb	3.5 g/L of water

(source: Schwartz and Corrales, 1989; PTAC, 2020)

Chemical Control

Chemical control is a vital method employed to combat and restrict the proliferation of pathogens that transmit diseases to plants. Chemical methods are particularly useful for large agricultural areas due to their rapid, effective action and immediate results. The ease of application and operation makes chemical control a practical choice for many farmers in agrarian practices

(Budge and Whipps, 2001; Matheron and Porchas, 2004). Common fungicides for controlling various bean diseases protect crop health and ensure optimal yields (Table 3). One widely used group of fungicides is the triazoles, which include chemicals like tebuconazole and propiconazole. Triazoles exhibit efficacy against various fungal infections, including those responsible for diseases such as anthracnose and rust in beans. Another important class is the strobilurins, represented by fungicides such as azoxystrobin and pyraclostrobin. Strobilurins are known for their broad-spectrum activity and systemic nature, making them effective against foliar diseases like rust and angular leaf spot. Additionally, benzimidazoles, like thiophanate-methyl, are commonly employed for their preventive and curative properties against various fungal infections in beans. Copper-based fungicides, such as copper hydroxide or copper oxychloride, are popular for managing diseases like common bacterial blight. Integrated disease management often involves a combination of these fungicides with other control measures, emphasizing a holistic approach to mitigate the development of resistance and promote sustainable bean cultivation practices. It is essential for farmers to carefully select and rotate fungicides, considering factors like disease prevalence, local conditions and potential impacts on non-target organisms, to ensure effective disease control and minimize environmental risks. Although farmers can effectively manage plant diseases and optimize agricultural productivity by using chemical control, it is important to balance chemical use with sustainable and eco-friendly practices to ensure the long-term health and resilience of agricultural ecosystems.

Biological Control

Non-chemical control measures are crucial in pursuing better, safer pest management practices with minimal environmental impacts (Isman, 2006; Pickett and Bugg, 1998; Ruberson *et al*., 1998). Biological control stands out among these strategies as a host-specific and long-term solution for plant diseases (Rebek *et al*., 2012). While biological control shows promise, its history in combating diseases has faced limitations, mainly due to laboratory-based experimentation (*in vitro*). *Trichoderma* is a widely utilized biological control agent, followed by *Rhizobium*, arbuscular mycorrhiza and various bacterial agents for experimental purposes (Bi *et al*., 2007; Harrison, 1999). However, these agents are yet to be introduced to farmers and made available in the market. Researchers are currently focusing on biocontrol agents due to their eco-friendliness and safety. Various antagonistic biocontrol agents, including *Bacillus* spp., *Pseudomonas* spp., *Burkholderia* spp. *and Trichoderma* spp., effectively combat diseases caused by pathogens such as *Erwinia* spp., *Agrobacterium radiobacter*, *Phytophthora* spp., *Fusarium* spp., *Rhizoctonia solani and Pythium* spp. (Compant *et al*., 2005; Pérez-García *et al*., 2011). At the farmer level, these microbial agents have shown beneficial potentials that support sustainable agriculture while reducing environmental costs (O'Brien, 2017; Barratt *et al*., 2018). Implementing biocontrol agents has been observed to reduce pesticide usage by approximately 50% in different countries (Macfadyen *et al*., 2014). Biocontrol agents work through competition for resources and the production of antagonistic chemicals that are toxic to pathogens (Shafique *et al*., 2016). They can also induce plant resistance against pathogens and other disease-causing agents. *Trichoderma harzianum*, *Pseudomonas fluorescence* and *Bacillus subtilis have* shown high efficacy in combating plant diseases (Shafique *et al*., 2016; Loganathan *et al*., 2010). Tephrosia leaf extract, fermented cattle dung and urine, neem seed kernel extract/suspension and aqueous extracts of chilies, tobacco leaves and garlic, either individually or in combinations, have also shown promise as biopesticides. Commercial products like neem extract (powder and oils) and *Bacillus thuringiensis* are also available in the market (Buruchara *et al*., 2010). Sustainable and environmentally friendly pest management can be achieved by prioritizing biological control techniques and incorporating them into farming practices. This will help farmers as well as the environment.

Regulatory and Cultural Measures

While farmers commonly use chemical control methods due to their effectiveness and efficiency, certain cultural practices are also employed to manage diseases. The quarantine method prevents the long-distance transmission of plant pathogens across countries, states and regions. This involves carefully inspecting and controlling plant materials, containers, packing materials, seeds and soil that could potentially carry disease-causing agents (Crooks, 2005). Some practices focus on preventing the spread and establishment of pathogens and promoting healthy plant growth. Crop rotation, intercropping and mixed cropping can gradually reduce the amount of pathogen impurity. *Tricho* compost, an example of organic amendments, has the ability to enhance soil conditions and establish a biocidal environment that effectively inhibits soilborne pathogens (Paret *et al*., 2010). When applied to the soil, *Tricho* compost generates heat under wet conditions, effectively controlling pathogens. Cultivating the same crop promotes disease persistence, making diverse cropping systems more favorable (Mihajlović *et al*., 2017; Goss *et al*., 2009). To prevent the spread of infections, it is important to remove and dispose of plant debris, diseased plant parts and contaminated tools and equipment through soil sanitation. Additionally, it is helpful to control the growth of weeds and other plants that can host diseases to aid in disease prevention (Baysal-Gurel *et al*., 2018). Grafting offers an alternative solution of chemical control, where the desired plant is joined to a rootstock that exhibits resistance to bean diseases (Core, 2005; Rivard and Louws, 2006). Furthermore, cultural techniques such as soil solarization, biofumigants, anaerobic soil disinfestation, soil steam sterilization and soilless culture are globally implemented for the purpose of disease control. By implementing these cultural practices, farmers can maintain a healthier agroecosystem, minimize disease spread and reduce the reliance on chemical control methods, contributing to sustainable agriculture practices.

Host Resistance

Plant host resistance refers to the heritable defense mechanisms of vegetables and beans against specific pests or diseases. Vegetable beans with host resistance exhibit reduced susceptibility to diseases like bacterial, fungal, or viral infections. One prominent example of this resistance is seen in the context of rust, a severe disease caused by *Uromyces appendiculatus* (Pers.) Unger. Rust has a significant negative impact on common bean production (*Phaseolus vulgaris L.*) worldwide. The resistance to bean rust is primarily governed by 14 major dominant genes originating from the Andean and Mesoamerican gene pools (Souza *et al*., 2013). Deployment of these genes in elite bean cultivars may resist the rust disease. *Fusarium* root rot (FRR), induced by *Fusarium solani*, presents a notable challenge to common bean production worldwide. Screening for FRR resistance is complex due to variations in the environment and the biology of the pathogen. By employing multiple isolates of *F. solani*, a greenhouse screening assay has identified resistant varieties within the Andean and Middle American diversity panels (Zitnick-Anderson *et al*., 2020). Resistance to anthracnose in French beans is determined by monogenic independent genes denoted by the Co symbol, with additional reports of quantitative resistance loci (Kelly and Vallejo, 2004; Oblessuc *et al*., 2014; González *et al*., 2015). For common beans, resistance to angular leaf spot primarily relies on single dominant genes, though recent research suggests a more quantitative aspect (Gonçalves-Vidigal *et al*., 2011) involving Quantitative Trait Loci (QTLs) (GonzÃ¡lez *et al*., 2015, 2013; Oblessuc *et al*., 2013; 2012; Keller *et al*., 2015). Silicon (Si) has been acknowledged for enhancing resistance against Cercospora leaf spot in soybeans by bolstering host defenses, such as increased concentrations of soluble phenolics, lignin and phytoalexins. Si also enhances the activity of defense enzymes and gene transcription levels (Nascimento *et al*., 2014; Fortunato *et al*., 2012). Common Bacterial Blight (CBB), caused by *Xanthomonas axonopodis* pv. *phaseoli* and *X. axonopodis* pv. *phaseoli* var. *fuscans* poses a significant challenge to common bean production in Ethiopia. Evaluation of diverse accessions has identified genotypes with lower severity values on leaves, pods and Areas Under the Disease Progress Curve (AUDPC), offering valuable genetic resources for future CBB resistance breeding programs (Tumsa *et al*., 2020). *Sclerotinia sclerotiorum* induces *Sclerotinia* stem rot in soybeans and resistance to this necrotrophic fungal pathogen is linked to early jasmonate accumulation, increased scavenging ability and reprogramming of the phenylpropanoid pathway (Ranjan *et al*., 2019; Hossain *et al*., 2023). Host resistance is not limited to pathogens, but also extends to protection against pests. Spodoptera frugiperda damages bean crops and certain cultivars exhibit resistance through antixenosis and antibiosis mechanisms (Alves de Paiva et *al*., 2018). Mung bean accessions resist major insect pests, including cowpea aphids, thrips, whiteflies, bruchids and spotted pod borers (Nair *et al*., 2019). *Glycine soja*, a wild relative of soybean, offers advantageous traits, including resistance to soybean aphids (Hesler *et al*., 2022). Additionally, host resistance can improve resistance to environmental conditions such as drought or extremely high temperatures. Abiotic stress in soybeans stimulates the production of 1-Aminocyclopropane-1-Carboxylate (ACC) and ethylene, which enhances stress resistance but may also affect soybean yield when present in excessive amounts (Nahar *et al*., 2016).

Integrated Disease Management

Integrated disease management utilizes multiple disease control measures to manage diseases effectively. Using natural products for managing illnesses, such as botanical plant extracts and microbial antagonists, is environmentally benign and safe for people and other organisms. Fungicides are also effective in disease control, although expensive and improper use should be avoided. Farmers should try using all available control strategies before adopting chemical control (Suprapta, 2012). It is important to apply proper cultural and agronomic practices to manage diseases effectively. Biological control plays a vital role in Integrated Disease Management (IDM) systems, with seed priming serving as a key method for evaluating novel bacterial strains as antagonists (Fitzsimons and Miller, 2010; Ansari and Mahmood, 2017; Bhuiyan *et al*., 2018; Kandikattu *et al*., 2017; Lau and Lennon, 2011; Van Der Heijden *et al*., 2006). Seed priming with rhizosphere-dwelling microorganisms (PGPRs) induces systemic resistance against fungal, bacterial and viral pathogens in various plant species and positively influences plant growth and yield. Utilizing bioagents and botanicals and minimizing the use of organic pesticides once diseases are present reduces the chemical burden on the environment and stimulates soil microbial activity, directly and indirectly affecting plant communities' production, variety and composition. In cases where diseases persist, resistant cultivars become a viable option (Fitzsimons and Miller, 2010; Ansari and Mahmood, 2017; Bhuiyan *et al*., 2018; Kandikattu *et al*., 2017; Lau and Lennon, 2011; Van Der Heijden *et al*., 2006). Integrated soil management plays a crucial role in IDM, particularly for controlling soil-borne pathogens. However, it can be challenging to identify and integrate alternative practices, especially in commercial plantations. While fungicides and resistance inducer PGPR have shown efficacy *in vitro* and greenhouse conditions, field validation is necessary to assess their short-term disease response and impact on soil, rhizosphere organism communities and plant microbiomes. This approach requires broad testing across different contexts, taking into account the bean vegetable diseases' status, cultivar diversity and cropping systems in relevant areas.

Innovations and Improvements in Bean Cultivation

Innovations and improvements in bean cultivation are crucial for ensuring efficient, productive and resilient farming practices. Crop health monitoring and weed removal play pivotal roles in this regard, as frequent attacks by pests and pathogens can lead to diseases, which can adversely impact the crop's quality and quantity. To tackle this difficulty, a comprehensive precision agriculture setup has been suggested, which combines Internet of Things (IoT) devices, image processing techniques, Machine Learning/Deep Learning (ML/DL), gene pyramiding, marker-assisted selection and CRISPR/Cas9 gene editing systems (Fig. 6). This system can be useful in delivering controlled water sprinkling along with real-time detection of healthy and damaged bean leaves and environmental data (Devi *et al*., 2023). Unmanned Aerial Vehicles (UAVs) have revolutionized large-scale phenotyping in plant breeding, particularly for dry bean genotypes. Singh *et al*. (2023) emphasize the transformative impact of UAV-based High-Throughput Phenotyping (HTP) in assessing complex traits efficiently. Aerial imaging systems offer a valuable tool for evaluating numerous dry bean genotypes, providing insights into plant characteristics. Controlled Environment Agriculture (CEA) is another notable advancement, especially for protein-rich crops like soybeans. Greenhouses and vertical farms have demonstrated the potential to enhance essential amino-acid production and improve crop nutritional content. CEA enables optimized production, enhanced crop protection, reduced land usage and potential manipulation of crop physiological mechanisms, contingent on thoroughly understanding crop environmental responses (Graamans, 2022). While conventional breeding methods have improved bean varieties, the pace of genetic progress in yield enhancement has been relatively sluggish. Das *et al*. (2017) suggested the adoption of advanced molecular marker technologies to accelerate cultivar development. Marker-Assisted Selection (MAS) enables the efficient transfer of favorable Quantitative Trait Loci (QTLs) into active breeding populations, facilitating gene stacking and the simultaneous transfer of multiple traits (Das *et al*., 2017; Miklas *et al*., 2006; Tryphone *et al*., 2013). The groundbreaking CRISPR/Cas9 gene-editing tool has also been utilized to manipulate genes in common beans, particularly targeting RFO biosynthetic genes. As exemplified by De Koning *et al*. (2021); De Koning *et al*. (2023), this technology enables precise gene knockout, presenting opportunities for trait enhancement in crops. The application of CRISPR/Cas9 extends beyond common beans; Yao *et al*. (2023) demonstrated its use in modifying soybean genes related to oil content, flowering patterns, seed characteristics, plant height and nodulation.

Fig. 6: Innovations and improvement techniques in bean cultivation

Future Prospects and Research Directions

It is crucial to improve bean farming, nutrition and disease management through cooperative research, innovation and other types of interdisciplinary cooperation in order to address global issues, including food security, sustainability and health. The requirement for increased yields, greater nutritional quality and increased resistance to the effects of changing climates and new diseases and pests has given rise to a number of prospective areas in which to concentrate research efforts. It is essential to develop bean varieties that can adapt to changing climatic conditions, particularly those resistant to drought, heat and pests (Beebe *et al*., 2013). Enhancing crop yields and ensuring a steady supply of this essential food source could be achieved through research into developing more resilient beans to climate change's effects. The fight against malnutrition and nutritional deficiencies can benefit from biofortification activities. By raising the quantities of protein, iron, zinc and other micronutrients in legumes, innovations in bean breeding may increase their nutritional value (De Moura and Stoffella, 2011). Extensive research is necessary for formulating integrated pest and disease control strategies that can pave the way to reducing the number of chemical inputs and sustainably encouraging bean cultivation (Dita *et al*., 2018). Research on biological controls, cultural practices and resistant cultivars are all part of this approach. Agroecological farming approaches can help improve soil health, biodiversity and the general sustainability of bean-growing systems (Kremen and Miles, 2012). These practices can be promoted by creating awareness among academics, farmers and policymakers. Bean production can benefit from optimizing resource allocation, improvements in yield prediction and streamlining management procedures, all of which are made possible by advances in remote sensing, data analytics and precision agriculture (Bhatt, 2019). Collaboration between researchers and stakeholders can result in innovations in post-harvest technologies, storage and processing methods that increase shelf life, decrease losses and preserve nutritional quality (Mohapatra and Sutar, 2018). Advances in post-harvest technology, storage and processing processes can be developed due to collaboration between researchers and stakeholders. These innovations can increase shelf life, reduce losses and maintain nutritional quality (McCollum *et al*., 2013). Accelerating advances in bean farming, nutrition and disease management can be accomplished through collaborative platforms. These platforms should facilitate the sharing of research findings, best practices and indigenous knowledge. In conclusion, the future of vegetable bean cultivation, nutrition and disease management rests in interdisciplinary, institution-wide and regional collaboration. By concentrating on climatic resilience, nutritional enhancement, integrated pest and disease management, agroecological approaches, technological adoption, post-harvest management and knowledge exchange, researchers and stakeholders may help create a more sustainable and nutrient-dense global food chain.

Conclusion

Vegetable beans contribute significantly to nutritional and food security across diverse climates. As the world grapples with hunger and undernourishment, the consumption of beans emerges as a practical and accessible solution. The paper highlights the global production and consumption patterns of beans, emphasizing their popularity in various regions and nations. Furthermore, the nutritional profile and health benefits of vegetable beans underscore their potential to prevent diseases, making them an invaluable component of a balanced diet. The role of beans in sustainable agriculture is crucial, particularly due to their ability to perform Biological Nitrogen Fixation, which positively impacts soil fertility and biodiversity. However, there are several challenges that need to be addressed when it comes to bean production, including issues related to soil fertility, pests and diseases. To overcome these challenges, various disease management strategies, including chemical and biological control, regulatory measures, cultural practices and the importance of host resistance, have been discussed. Collaboration between researchers, stakeholders and policymakers is crucial to developing climate-resilient bean varieties, enhancing nutritional content and adopting integrated pest and disease management strategies. Emphasis is placed on agroecological practices, technology adoption and post-harvest management to optimize resource allocation and streamline management procedures. By fostering interdisciplinary collaboration and knowledge sharing, the global community can work towards a more sustainable and nutritious food system, ensuring the continued importance of beans in meeting the world's evolving needs.

Acknowledgment

The authors thank the reviewers for their contribution to the peer evaluation of this study.

Funding Information

The authors have received financial support from the Research Management Committee (RMC) of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh, for providing support for writing this manuscript.

Author’s Contributions

Sayed Shahidul Islam: Drafted, research implementation and data collection.

Shanta Adhikary: Research planned, data collected, drafted and data analyzed.

Mahabuba Mostafa: Research planned, data interpreted and reviewed.

Md. Motaher Hossain: Concepted, fund acquisition, Research designed and drafted reviewed.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues are involved.

References

Ahmed, M. T., Miah, M. R. U., Amin, M. R., & Hossain, M. M. (2015). Evaluation of some plant materials against pod borer infestation in country bean with reference to flower production. *Annals of Bangladesh Agriculture*, *18*, 71-78. https://bsmrau.edu.bd/journal/wpcontent/uploads/sites/320/2018/07/acticle_8_17.pdf

Aker, J. C. (2011). Dial "A" for agriculture: A review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, *42*(6), 631-647. https://doi.org/10.1111/j.1574-0862.2011.00545.x

Ansari, R. A., & Mahmood, I. (2017). Optimization of organic and bio-organic fertilizers on soil properties and growth of pigeon pea. *Scientia Horticulturae*, *226*, 1-9. https://doi.org/10.1016/j.scienta.2017.07.033

Allen, L. (2013). Legumes. Encyclopedia of Human Nutrition, Caballero, B., Allen, L., Prentice, A. (3rd Ed.), *Elsevier Academic Press*, *San Diego*, *CA*, 74-79. https://search.worldcat.org/title/Encyclopedia-of-human-nutrition/oclc/828743402

Anderson, J., R., & Feder, G. (2007). "Handbook of Agricultural Economics." 2343-2378. https://doi.org/10.1016/S1574-0072(06)03044-1

Anderson, J. W., Smith, B. M., & Washnock, C. S. (1999). Cardiovascular and renal benefits of dry bean and soybean intake. *The American Journal of Clinical Nutrition*, *70*(3), 464S-474S. https://doi.org/10.1093/Ajcn/70.3.464s

Alves de Paiva, L., de Carvalho Resende, W., Teixeira Silva, C. L., de Sousa Almeida, A. C., Ribeiro da Cunha, P. C., & Gonçalves de Jesus, F. (2018). Resistance of common bean (*Phaseolus vulgaris*) cultivars to Spodoptera frugiperda (*Lepidoptera*: *Noctuidae*). *Revista Colombiana de Entomología*, *44*(1), 12-18. https://doi.org/10.25100/socolen.v44i1.6531

Affrifah, N. S., Uebersax, M. A., & Amin, S. (2023). Nutritional significance, value-added applications and consumer perceptions of food legumes: A review. *Legume Science*, *5*(4), e192. https://doi.org/10.1002/leg3.192

Alfaro-Diaz, A., Escobedo, A., Luna-Vital, D. A., Castillo-Herrera, G., & Mojica, L. (2023). Common beans as a source of food ingredients: Techno-functional and biological potential. *Comprehensive Reviews in Food Science and Food Safety*, *22*(4), 2910-2944. https://doi.org/10.1111/1541-4337.13166

Barratt, B. I. P., Moran, V. C., Bigler, F., & Van Lenteren, J. C. (2018). The status of biological control and recommendations for improving uptake for the future. *BioControl*, *63*, 155-167. https://doi.org/10.1007/s10526-017-9831-y

Baysal-Gurel, F., & Kabir, N. (2018). Comparative performance of fungicides and biocontrol products in suppression of *Rhizoctonia* root rot in viburnum. *J. Plant Pathol. Microbiol*, *9*(9). https://doi.org/10.4172/2157-7471.1000451

Beebe, S., Ramirez, J., Jarvis, A., Rao, I. M., Mosquera, G., Bueno, J. M., & Blair, M. W. (2011). Genetic improvement of common beans and the challenges of climate change. *Crop Adaptation to Climate Change*, 356-369. https://doi.org/10.1002/9780470960929.ch25

Beebe, S., Rao, I., Blair, M., & Acosta, J. (2013). Phenotyping common beans for adaptation to drought. *Frontiers in Physiology*, *4*, 28034. https://doi.org/10.3389/fphys.2013.00035

Bell, M. (2015). ICT-Powering behavior change for a brighter agricultural future. *Washington DC: USAID/Modernizing Extension and Advisory Services (MEAS)*. https://meas.illinois.edu/wp-content/uploads/2015/04/Bell-2015-ICT-for-Brighter-Ag-Future-MEAS-Discussion-Paper.pdf

Bennink, M. R. (2002). Consumption of black beans and navy beans (*Phaseolus vulgaris*) reduced azoxymethane-induced colon cancer in rats. *Nutrition and Cancer*, *44*(1), 60-65. https://doi.org/10.1207/s15327914nc441_8

Bennink, M., R., & Rondini, E., A. (2003). Eat beans to improve your health. *American Dry Bean Board*, *Vienna*, *VA*. http://www.americanbean.org/HealthNutrition/Home-MSU%20Study.Htm

Bi, H. H., Song, Y. Y., & Zeng, R. S. (2007). Biochemical and molecular responses of host plants to mycorrhizal infection and their roles in plant defence. *Allelopathy Journal*, *20*(1), 15-28. https://www.researchgate.net/profile/Rensen-Zeng/publication/281665895_Biochemical_and_molecular_responses_of_host_plants_to_mycorrhizal_infection_and_their_roles_in_plant_defence/links/56a8838b08ae997e22bd25e1/Biochemical-and-molecular-responses-of-host-plants-to-mycorrhizal-infection-and-their-roles-in-plant-defence.pdf

Budge, S. P., & Whipps, J. M. (2001). Potential for integrated control of *Sclerotinia sclerotiorum* in glasshouse lettuce using *Coniothyrium minitans* and reduced fungicide application. *Phytopathology*, *91*(2), 221-227. https://doi.org/10.1094/phyto.2001.91.2.221

Buhler, D. D., Netzer, D. A., Riemenschneider, D. E., & Hartzler, R. G. (1998). Weed management in short rotation poplar and herbaceous perennial crops grown for biofuel production. *Biomass and Bioenergy*, *14*(4), 385-394. https://doi.org/10.1016/s0961-9534(97)10075-7

Buruchara, R. A., Mukaruziga, C., & Ampofo, K. O. (2010). Bean disease and pest identification and management. https://cgspace.cgiar.org/server/api/core/bitstreams/735eccaf-866b-443e-af20-8213b406d4c0/content

Buruchara, R., Chirwa, R., Sperling, L., Mukankusi, C., Rubyogo, J. C., Mutonhi, R., & Abang, M. M. (2011). Development and delivery of bean varieties in Africa: The Pan-Africa Bean Research Alliance (PABRA) model. *African Crop Science Journal*, *19*(4), 227-245. https://www.ajol.info/index.php/acsj/article/view/74168

Bhuiyan, S. A., Garlick, K. anderson, J. M., Wickramasinghe, P., & Stirling, G. R. (2018). Biological control of root-knot nematode on sugarcane in soil naturally or artificially infested with *Pasteuria penetrans*. *Australasian Plant Pathology*, *47*, 45-52. https://doi.org/10.1007/s13313-017-0530-z

Bhatt, M. R. (2019). Systematic studies on Orchidaceae of Gujarat (Doctoral dissertation, Maharaja Sayajirao University of Baroda (India). https://www.proquest.com/openview/fffe9d903e76d65942a6cca620cd56d5/1?pq-origsite=gscholar&cbl=51922&diss=y

Britannica, T. (2020). Editors of encyclopaedia. *Argon. Encyclopedia Britannica*. https://www.britannica.com/plant/common-bean

Chupp, C. (1954). A monograph of the fungus genus *Cercospora*. *A Monograph of the Fungus Genus Cercospoia*. https://doi.org/10.1093/aibsbulletin/4.3.11-d

Core, J. (2005). Grafting watermelon onto squash or gourd rootstock makes firmer, healthier fruit. *Agricultural Research*, *53*(7), 8-10. http://www.ars.usda.gov/is/AR/

Compant, S., Duffy, B., Nowak, J., Clément, C., & Barka, E. A. (2005). Use of plant growth-promoting bacteria for biocontrol of plant diseases: Principles, mechanisms of action and future prospects. *Applied and Environmental Microbiology*, *71*(9), 4951-4959. https://doi.org/10.1128/aem.71.9.4951-4959.2005

Courty, P. E., Smith, P., Koegel, S., Redecker, D., & Wipf, D. (2015). Inorganic nitrogen uptake and transport in beneficial plant root-microbe interactions. *Critical Reviews in Plant Sciences*, *34*(1-3), 4-16. https://doi.org/10.1080/07352689.2014.897897

Crooks, J. A. (2005). Lag times and exotic species: The ecology and management of biological invasions in slow-motion1. *Eco Science*, *12*(3), 316-329. https://doi.org/10.2980/i1195-6860-12-3-316.1

Das, A., & Ghosh, P., K. (2012). Role of legumes in sustainable agriculture and food security: An Indian perspective. *Outlook on Agriculture*, *41*(4), 279-284. https://doi.org/10.5367/oa.2012.0109

Das, G., Patra, J. K., & Baek, K. H. (2017). Insight into MAS: A molecular tool for development of stress resistant and quality of rice through gene stacking. *Frontiers in Plant Science*, *8*, 233392. https://doi.org/10.3389/fpls.2017.00985

Davis, K. E. (2008). Extension in Sub-Saharan Africa: Overview and assessment of past and current models and future prospects. *Journal of International Agricultural and Extension Education*, *15*(3). https://doi.org/10.5191/jiaee.2008.15302

De Koning, R., Kiekens, R., Toili, M. E. M., & Angenon, G. (2021). Identification and expression analysis of the genes involved in the raffinose family oligosaccharides pathway of *Phaseolus vulgaris* and *Glycine max*. *Plants*, *10*(7), 1465. https://doi.org/10.3390/plants10071465

De Koning, R., Wils, G. E., Kiekens, R., De Vuyst, L., & Angenon, G. (2023). Impact of drought and salt stress on galactinol and raffinose family oligosaccharides in common bean (*Phaseolus vulgaris*). *AoB Plants*, *15*(4), plad038. https://doi.org/10.1093/aobpla/plad038

De Moura, F., F., & Stoffella, P., J. (2011). Breeding biofortified crops for reducing malnutrition. *Plant Breeding*, *130*(1): 1-10. https://doi.org/10.1111/j.1439-0523.2010.01800.x

Devi, N., Sarma, K. K., & Laskar, S. (2023). Design of an intelligent bean cultivation approach using computer vision, IoT and spatio-temporal deep learning structures. *Ecological Informatics*, *75*, 102044. https://doi.org/10.1016/j.ecoinf.2023.102044

Dita, M., A., M., Barquero, D., Heck, W., C & Madden, L., V. (2018). Integrated disease management of chocolate spot on *faba bean*: Advances made through a multidisciplinary approach. *Plant Disease*, *102*(1): 12-29. https://doi.org/10.1094/pdis-02-17-0172-fe

EWS. (2023). EWS Plant Doctor. *East-West Seed*. Retrieved from. https://plantdoctor.eastwestseed.com/

FAO. (2024). FAOSTAT. *Food and Agriculture Organization*. http://www.fao.org/faostat/en/#data

Frahm, M. A., Rosas, J. C., Mayek-Pérez, N., López-Salinas, E., Acosta-Gallegos, J. A., & Kelly, J. D. (2004). Breeding beans for resistance to terminal drought in the lowland tropics. *Euphytica*, *136*, 223-232. https://doi.org/10.1023/b:euph.0000030671.03694.bb

Fitzsimons, M. S., & Miller, R. M. (2010). The importance of soil microorganisms for maintaining diverse plant communities in tallgrass prairie. *American Journal of Botany*, *97*(12), 1937-1943. https://doi.org/10.3732/ajb.0900237

Fortunato, A. A., Rodrigues, F. Á., & do Nascimento, K. J. T. (2012). Physiological and biochemical aspects of the resistance of banana plants to Fusarium wilt potentiated by silicon. *Phytopathology*, *102*(10), 957-966. https://doi.org/10.1094/phyto-02-12-0037-r

Ganascini, D., Laureth, J. C. U., Mendes, I. S., Tokura, L. K., Sutil, E. L., Villa, B. D., ... & Coelho, S. R. M. (2019). Analysis of the production chain of bean culture in Brazil. *Journal of Agricultural Science*, *11*(7), 256. https://doi.org/10.5539/jas.v11n7p256

Gepts, P. (2001). *Phaseolus vulgaris* (beans). *Encyclopedia of Genetics*, *1444*, 1445. https://doi.org/10.1006/rwgn.2001.1749

Goss, E. M., Carbone, I., & Grünwald, N. J. (2009). Ancient isolation and independent evolution of the three clonal lineages of the exotic sudden oak death pathogen Phytophthora ramorum. *Molecular Ecology*, *18*(6), 1161-1174. https://doi.org/10.1111/j.1365-294x.2009.04089.x.

GonzÃ¡lez, A., M., F., J., Yuste-Lisbona, A., P., RodiÃo, A., M., De Ron, C., Capel, M., García-Alcázar, R., L., & Santalla, M., M. (2015). Uncovering the genetic architecture of *Colletotrichum lindemuthianum* resistance through QTL mapping and epistatic interaction analysis in common bean. *Frontiers in Plant Science*, *6*. https://doi.org/10.3389/fpls.2015.00141

Gonçalves-Vidigal, M. C., Cruz, A. S., Garcia, A., Kami, J., Vidigal Filho, P. S., Sousa, L. L., ... & Pastor-Corrales, M. A. (2011). Linkage mapping of the Phg-1 and Co-1 4 genes for resistance to angular leaf spot and anthracnose in the common bean cultivar and 277. *Theoretical and Applied Genetics*, *122*, 893-903. https://doi.org/10.1007/s00122-010-1496-1.

Graamans, L. (2022). Protein-rich crops: Growing soybean in vertical farms. *Wageningen University and Research*. https://www.wur.nl/en/research-results/research-institutes/plant-research/greenhouse-horticulture/show-greenhouse/protein-rich-crops-growing-soybean-in-vertical-farms.htm

Hall, R., & Nasser, L. C. (1996). Practice and precept in cultural management of bean diseases. *Canadian Journal of Plant Pathology*, *18*(2), 176-185. https://doi.org/10.1080/07060669609500643

Harrison, M. J. (1999). Molecular and cellular aspects of the arbuscular mycorrhizal symbiosis. *Annual Review of Plant Biology*, *50*(1), 361-389. https://doi.org/10.1146/annurev.arplant.50.1.361

Hayat, I., Ahmad, A., Masud, T., Ahmed, A., & Bashir, S. (2014). Nutritional and health perspectives of beans (*Phaseolus vulgaris* L.): An overview. *Critical Reviews in Food Science and Nutrition*, *54*(5), 580-592. https://doi.org/10.1080/10408398.2011.596639

Hesler, L. S., Tilmon, K. J., Varenhorst, A. J., Conzemius, S. R., Taliercio, E., & Beckendorf, E. A. (2022). Challenges and Prospects of Wild Soybean as a Resistance Source Against Soybean Aphid (*Hemiptera*: *Aphididae*). *Annals of the Entomological Society of America*, *115*(1), 25-38. https://doi.org/10.1093/aesa/saab033

Hossain, M. M., Sultana, F., Li, W., Tran, L.-S. P., & Mostofa, M. G. (2023). *Sclerotinia sclerotiorum* (Lib.) de Bary: Insights into the Pathogenomic Features of a Global Pathogen. *Cells*, *12*, 1063. https://doi.org/10.3390/cells12071063

Isman, M. B. (2006). Botanical insecticides, deterrents and repellents in modern agriculture and an increasingly regulated world. *Annu. Rev. Entomol.*, *51*, 45-66. https://doi.org/10.1146/annurev.ento.51.110104.151146

Jin, D. P., Choi, I. S., & Choi, B. H. (2019). Plastid genome evolution in tribe Desmodieae (*Fabaceae*: *Papilionoideae*). *PloS One*, *14*(6), e0218743. https://doi.org/10.1371/journal.pone.0218743

Kader, M. A., Mubin, M. M. U., Rubayet, M. T., Khan, A. A. & Hossain, M. M. (2022). First report of web blight of *Lablab purpureus* caused by *Rhizoctonia solani* AG-5 in Bangladesh. New Disease Reports, 46, e12129. https://doi.org/10.1002/ndr2.12129

Kalloo, G., & Bergh, B. O. (Eds.). (2012). Genetic improvement of vegetable crops. *Newnes*. ISBN:10- 9780080984667.

Kamboj, R., & Nanda, V. (2018). Proximate composition, nutritional profile and health benefits of legumes-a review. *Legume Research-An International Journal*, *41*(3), 325-332. https://doi.org/10.18805/lr-3748

Khan, A. U., Choudhury, M. A. R., Talucder, M. S. A., Hossain, M. S., Ali, S., Akter, T., & Ehsanullah, M. (2020). Constraints and solutions of country bean (*Lablab purpureus* L.) Production: A review. *Acta Entomology and Zoology*, *1*(2 Part A). https://doi.org/10.33545/27080013.2020.v1.i2a.17

Khoury, C. K., Castañeda-Alvarez, N. P., Achicanoy, H. A., Sosa, C. C., Bernau, V., Kassa, M. T., ... & Struik, P. C. (2015). Crop wild relatives of pigeonpea [*Cajanus cajan* (L.) Mill sp.]: Distributions, ex situ conservation status and potential genetic resources for abiotic stress tolerance. *Biological Conservation*, *184*, 259-270. https://doi.org/10.1016/j.biocon.2015.01.032

Kremen, C., & Miles, A. (2012). Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities and trade-offs. *Ecology and Society*, *17*(4). https://doi.org/10.5751/es-05035-170440

Kutoš, T., Golob, T., Kač, M., & Plestenjak, A. (2003). Dietary fibre content of dry and processed beans. *Food Chemistry*, *80*(2), 231-235. https://doi.org/10.1016/s0308-8146(02)00258-3

Kandikattu, H. K., Rachitha, P., Jayashree, G. V., Krupashree, K., Sukhith, M., Majid, A., ... & Khanum, F. (2017). Anti-inflammatory and anti-oxidant effects of Cardamom (*Elettaria repens* (Sonn.) Baill) and its phytochemical analysis by 4D GCXGC TOF-MS. *Biomedicine and Pharmacotherapy*, *91*, 191-201. https://doi.org/10.1016/j.biopha.2017.04.049

Kelly, J. D., & Vallejo, V. A. (2004). A comprehensive review of the major genes conditioning resistance to anthracnose in common bean. *Hort Science*, *39*(6), 1196-1207. https://doi.org/10.21273/hortsci.39.6.1196

Keller, B., Manzanares, C., Jara, C., Lobaton, J. D., Studer, B., & Raatz, B. (2015). Fine-mapping of a major QTL controlling angular leaf spot resistance in common bean (*Phaseolus vulgaris* L.). *Theoretical and Applied Genetics*, *128*, 813-826. https://doi.org/10.1007/s00122-015-2472-6

Li-Juan, L., Zhao-hai, Y., Zhao-jie, Z., Ming-shi, X., & Han-qing, Y. (1993). *Faba bean* in China: State-of-the-art review. *International Center for Agricultural Research in the Dry Areas (ICARDA). Aleppo, Syria*, 127-128. https://pdf.usaid.gov/pdf_docs/pnabr353.pdf

Livondo, L. J. anderson, K., Macharia, E. W., & Oduor, P. O. (2015). Factors affecting communication channels preference by farmers in access of information on adoption of agricultural technology for striga control: A case of Bungoma County, Kenya. *International Journal of Current Research*, *7*(11), 23057-23062. https://www.journalcra.com/sites/default/files/issue-pdf/11604.pdf

Loganathan, M., Sible, G. V., Maruthasalam, S., Saravanakumar, D., Raguchander, T., Sivakumar, M., & Samiyappan, R. (2010). Trichoderma and chitin mixture based bioformulation for the management of head rot (Sclerotinia sclerotiorum (Lib.) deBary)-root-knot (Meloidogyne incognita Kofoid and White; Chitwood) complex diseases of cabbage. *Archives of Phytopathology and Plant Protection*, *43*(10), 1011-1024. https://doi.org/10.1080/03235400802214885

Lau, J. A., & Lennon, J. T. (2011). Evolutionary ecology of plant-microbe interactions: Soil microbial structure alters selection on plant traits. *New Phytologist*, *192*(1), 215-224. https://doi.org/10.1111/j.1469-8137.2011.03790.x

Macfadyen, S., Hardie, D. C., Fagan, L., Stefanova, K., Perry, K. D., DeGraaf, H. E., ... & Umina, P. A. (2014). Reducing insecticide use in broad-acre grains production: An Australian study. *PloS One*, *9*(2), e89119. https://doi.org/10.1371/journal.pone.0089119

Matheron, M. E., & Porchas, M. (2004). Activity of boscalid, fenhexamid, fluazinam, fludioxonil and vinclozolin on growth of *Sclerotinia minor* and *S. sclerotiorum* and development of lettuce drop. *Plant Disease*, *88*(6), 665-668. https://doi.org/10.1094/pdis.2004.88.6.665

McCollum, D., M., I., Gomez, J., P, & Thompson, A., W. (2013). Collaborative research partnerships in the development of improved varieties for the Andean region. *Food Security*, *5*(3): 341-353. https://doi.org/10.1007/s12571-013-0267-z

McKenzie, E., & Grahame, J. (2010). Pacific Pests, Pathogens and Weeds. apps.lucidcentral.org/pppw_v10/text/web_full/entities/bean_cercospora_leaf_spot_301.htm

Mihajlović, M., Rekanović, E., Hrustić, J., Grahovac, M., & Tanović, B. (2017). Methods for management of soilborne plant pathogens. *Pesticidi I Fitomedicina*, *32*(1), 9-24. https://doi.org/10.2298/PIF1701009M

Miklas, P. N., Kelly, J. D., Beebe, S. E., & Blair, M. W. (2006). Common bean breeding for resistance against biotic and abiotic stresses: From classical to MAS breeding. *Euphytica*, *147*, 105-131. https://doi.org/10.1007/s10681-006-4600-5

Mohapatra, D., S., K., M., & Sutar, N. (2018). Post-harvest management of pulses: A review. *Food and Bioprocess Technology*, *11*(2): 213-242. https://doi.org/10.1007/s11947-017-2007-5

Margaret, N., Tenywa, J. S., Otabbong, E., Mubiru, D. N., & Basamba, T. A. (2013). Development of common bean (*Phaseolus vulgaris* L.) production under low soil phosphorus and drought in Sub-Saharan Africa. https://doi.org/10.5539/jsd.v7n5p128

Ngai, P. H., & Ng, T. B. (2004). Coccinin, an antifungal peptide with antiproliferative and HIV-1 reverse transcriptase inhibitory activities from large scarlet runner beans. *Peptides*, *25*(12), 2063-2068. https://doi.org/10.1016/j.peptides.2004.08.003

Newnham, P. (2023). Opinion: Why beans are key to accelerating a change to our food system. *Devex*. https://www.devex.com/news/opinion-why-beans-are-key-to-accelerating-a-change-to-our-food-system-105709

Nahar, K., Hasanuzzaman, M., & Fujita, M. (2016). Heat stress responses and thermotolerance in soybean. *In Abiotic and Biotic Stresses in Soybean Production*, (pp. 261-284). Academic Press. https://doi.org/10.1016/B978-0-12-801536-0.00012-8

Nair, R. M., Pandey, A. K., War, A. R., Hanumantharao, B., Shwe, T., Alam, A. K. M. M., ... & Rane, J. (2019). Biotic and abiotic constraints in mungbean production-progress in genetic improvement. *Frontiers in Plant Science*, *10*, 462374. https://doi.org/10.3389/fpls.2019.01340

Nascimento, K. J. T., Debona, D., França, S. K. S., Gonçalves, M. G. M., DaMatta, F. M., & Rodrigues, F. Á. (2014). Soybean resistance to *Cercospora sojina* infection is reduced by silicon. *Phytopathology*, *104*(11), 1183-1191. https://doi.org/10.1094/phyto-02-14-0047-r

O'Brien, P. A. (2017). Biological control of plant diseases. *Australasian Plant Pathology*, *46*, 293-304. https://doi.org/10.1007/s13313-017-0481-4

Oblessuc, P. R., Baroni, R. M., da Silva Pereira, G., Chiorato, A. F., Carbonell, S. A. M., Briñez, B., ... & Benchimol-Reis, L. L. (2014). Quantitative analysis of race-specific resistance to *Colletotrichum lindemuthianum* in common bean. *Molecular Breeding*, *34*, 1313-1329. https://doi.org/10.1007/s11032-014-0118-z

Oblessuc, P. R., Baroni, R. M., Garcia, A. A. F., Chioratto, A. F., Carbonell, S. A. M., Camargo, L. E. A., & Benchimol, L. L. (2012). Mapping of angular leaf spot resistance QTL in common bean (*Phaseolus vulgaris* L.) under different environments. *BMC Genetics*, *13*, 1-9. https://doi.org/10.1186/1471-2156-13-50

Oblessuc, P. R., Cardoso Perseguini, J. M. K., Baroni, R. M., Chiorato, A. F., Carbonell, S. A. M., Mondego, J. M. C., ... & Benchimol-Reis, L. L. (2013). Increasing the density of markers around a major QTL controlling resistance to angular leaf spot in common bean. *Theoretical and Applied Genetics*, *126*, 2451-2465. https://doi.org/10.1007/s00122-013-2146-1

Paret, M. L., Cabos, R., Kratky, B. A., & Alvarez, A. M. (2010). Effect of plant essential oils on *Ralstonia solanacearum* race 4 and bacterial wilt of edible ginger. *Plant Disease*, *94*(5), 521-527. https://doi.org/10.1094/pdis-94-5-0521

Parwez, R., Naeem, M., Aftab, T., Ansari, A. A., Gill, S. S., & Gill, R. (2022). Heavy metal toxicity and underlying mechanisms for heavy metal tolerance in medicinal legumes. *In Hazardous and Trace Materials in Soil and Plants*, (pp. 141-177). Academic Press. https://doi.org/10.1016/b978-0-323-91632-5.00024-0

Peix, A., Ramírez-Bahena, M. H., Velázquez, E., & Bedmar, E. J. (2015). Bacterial associations with legumes. *Critical Reviews in Plant Sciences*, *34*(1-3), 17-42. https://doi.org/10.1080/07352689.2014.897899

Perera, T., Russo, C., Takata, Y., & Bobe, G. (2020). Legume consumption patterns in us adults: National Health and Nutrition Examination Survey (NHANES) 2011-2014 and Beans, Lentils, Peas (BLP) 2017 survey. *Nutrients*, *12*(5), 1237. https://doi.org/10.3390/nu12051237

Pérez-García, A., Romero, D., & De Vicente, A. (2011). Plant protection and growth stimulation by microorganisms: Biotechnological applications of Bacilli in agriculture. *Current Opinion in Biotechnology*, *22*(2), 187-193. https://doi.org/10.1016/j.copbio.2010.12.003

PTAC. (2020). Retrieved from Bangladesh Crop Protection Association. *Pesticide Technical Advisory Committee*. bcpabd.com/wp-content/uploads/2021/01/Registered-pesticide-List-of-Bangladesh-upto-2020.pdf

Petruzzello, M. (2023). c | Description, Origin, Uses, Nutrition and Facts. *Encyclopedia Britannica*. https://www.britannica.com/plant/mung-bean

Pickett, C. H., & Bugg, R. L. (Eds). (1998). Enhancing biological control: Habitat management to promote natural enemies of agricultural pests. *Univ of California Press*. ISBN-10: 9780520213623.

Rebek, E. J., Frank, S. D., Royer, T. A., & Bográn, C. E. (2012). Alternatives to chemical control of insect pests. *Insecticides-basic and other applications. Rijeka (Croatia), Shanghai (China): InTech*, 171-196. https://doi.org/10.5772/29887

Rivard, C., & Louws, F. J. (2006). *Grafting for disease resistance in heirloom tomatoes*. NC Cooperative Extension Service. https://www.sare.org/wp-content/uploads/12AGI2011.pdf

Rodriguez, M., Rau, D., Bitocchi, E., Bellucci, E., Biagetti, E., Carboni, A., ... & Attene, G. (2016). Landscape genetics, adaptive diversity and population structure in *Phaseolus vulgaris*. *New Phytologist*, *209*(4), 1781-1794. https://doi.org/10.1111/nph.13713.

Ruberson, J., Nemoto, H., & Hirose, Y. (1998). Pesticides and conservation of natural enemies in pest management. In Conservation biological control (pp. 207-220). *Academic Press*. https://doi.org/10.1016/b978-012078147-8/50057-8

Ryder, E. (2011). World vegetable industry: Production, breeding, trends. *Hortic Rev*, *38*, 299. ISBN-10: 0470872365.

Ranjan, A., Westrick, N. M., Jain, S., Piotrowski, J. S., Ranjan, M., Kessens, R., ... & Kabbage, M. (2019). Resistance against *Sclerotinia sclerotiorum* in soybean involves a reprogramming of the phenylpropanoid pathway and up-regulation of antifungal activity targeting ergosterol biosynthesis. *Plant Biotechnology Journal*, *17*(8), 1567-1581. https://doi.org/10.1111/pbi.13082

Schwartz, H. F., & Corrales, M. A. P. (Eds). (1989). Bean production problems in the tropics. *CIAT*. ISBN-10: 9789589183045.

Serrano-Serrano, M. L. andueza-Noh, R. H., Martínez-Castillo, J., Debouck, D. G., & Chacón S, M. I. (2012). Evolution and domestication of lima bean in Mexico: Evidence from ribosomal DNA. *Crop Science*, *52*(4), 1698-1712. https://doi.org/10.2135/cropsci2011.12.0642

Shafique, H. A., Sultana, V., Ehteshamul-Haque, S., & Athar, M. (2016). Management of soil-borne diseases of organic vegetables. *Journal of Plant Protection Research*, *56*(3). https://doi.org/10.1515/jppr-2016-0043

Siddiq, M., Uebersax, M. A., & Siddiq, F. (2022). Global production, trade, processing and nutritional profile of dry beans and other pulses. *Dry beans and pulses: Production, Processing and Nutrition*, 1-28. https://doi.org/10.1002/9781119776802.ch1

Singh, K. D., Balasubramanian, P., Natarajan, M., Wang, H., & Ravichandran, P. (2023). UAV-based Multispectral Imaging for High-throughput Phenotyping of Dry Bean Breeding Trials. *Authorea Preprints*. https://essopenarchive.org/doi/full/10.22541/essoar.170110651.16979152

Sultana, N. (2001). Genetic variation of morphology and molecular markers and its application to breeding in Lablab bean. *A Ph. D Thesis, Kyshu University, Fukuoka, Japan, 143*. https://shorturl.at/ceR27

Suprapta, D. N. (2012). Potential of microbial antagonists as biocontrol agents against plant fungal pathogens. https://shorturl.at/kxIVX

Souza, T. L. P., Faleiro, F. G., Dessaune, S. N., Paula-Junior, T. J. D., Moreira, M. A., & Barros, E. G. D. (2013). Breeding for common bean (*Phaseolus vulgaris* L.) rust resistance in Brazil. *Tropical Plant Pathology*, *38*, 361-374. https://doi.org/10.1590/s1982-56762013005000027

Schmidt, H. D. O., & Oliveira, V. R. D. (2023). Overview of the incorporation of legumes into new food options: an approach on versatility, nutritional, technological and sensory quality. *Foods*, *12*(13), 2586. https://doi.org/10.3390/foods12132586

Tryphone, G. M., Chilagane, L. A., Protas, D., Kusolwa, P. M., & Nchimbi-Msolla, S. (2013). Marker assisted selection for common bean diseases improvements in Tanzania: Prospects and future needs. *Plant Breeding from Laboratories to Fields. Intech*, *22*, 121-47. https://doi.org/10.5772/52823

Tumsa, K., Shimelis, H., Laing, M., Mukankusi, C., & Mathew, I. (2020). Identification of sources of resistance to common bacterial blight in common bean in Ethiopia. *Journal of Phytopathology*, *168*(11-12), 707-720. https://doi.org/10.1111/jph.12951

Van Der Heijden, M. G., Bakker, R., Verwaal, J., Scheublin, T. R., Rutten, M., Van Logtestijn, R., & Staehelin, C. (2006). Symbiotic bacteria as a determinant of plant community structure and plant productivity in dune grassland. *FEMS Microbiology Ecology*, *56*(2), 178-187. https://doi.org/10.1111/j.1574-6941.2006.00086.x

Wang, H. X., & Ng, T. B. (2006). An antifungal peptide from baby lima bean. *Applied Microbiology and Biotechnology*, *73*, 576-581. https://doi.org/10.1007/s00253-006-0504-5

Williams, M. A. J. (1987). Cercospora zonata. (Descriptions of Fungi and Bacteria). *Descriptions of Fungi and Bacteria*, (94), Sheet-939. https://doi.org/10.1079/dfb/20056400939

Wong, J. H., Zhang, X. Q., Wang, H. X., & Ng, T. B. (2006). A mitogenic defensin from white cloud beans (*Phaseolus vulgaris*). *Peptides*, *27*(9), 2075-2081. https://doi.org/10.1016/j.peptides.2006.03.020

Wortman, S. C., Kirkby, A. R., Eledu, A. C., & Allen, J. D. (2004). Atlas of common bean (*Phasealus vulgaris* L.) production in Africa. Cali, Colombia. *International Centre for Tropical Agriculture, CIAT*. https://doi.org/10.33545/27080013.2020.v1.i2a.17

Yadav, S. S., Redden, R. J., Hatfield, J. L., Lotze-Campen, H., & Hall, A. E. (2011). *Crop adaptation to climate change*. John Wiley and Sons. https://doi.org/10.1002/9780470960929

Yao, D., Zhou, J., Zhang, A., Wang, J., Liu, Y., Wang, L., ... & Qu, X. (2023). Advances in CRISPR/Cas9-based research related to soybean (*Glycine max* (Linn.) Merr) molecular breeding. *Frontiers in Plant Science*, *14*, 1247707. https://doi.org/10.3389/fpls.2023.1247707

Ye, X. Y., Wang, H. X., & Ng, T. B. (2000). Dolichin, a new chitinase-like antifungal protein isolated from field beans (*Dolichos lablab*). *Biochemical and Biophysical Research Communications*, *269*(1), 155-159. https://doi.org/10.1006/bbrc.2000.2115

Zitnick-Anderson, K., Oladzadabbasabadi, A., Jain, S., Modderman, C., Osorno, J. M., McClean, P. E., & Pasche, J. S. (2020). Sources of resistance to *Fusarium solani* and associated genomic regions in common bean diversity panels. *Frontiers in Genetics*, *11*, 533155. https://doi.org/10.3389/fgene.2020.00475