Pigeon pea (*Cajanus cajan* L.) based intercropping system: A review

ABSTRACT

Pigeon pea (*Cajanus cajan* L.) is a tropical and subtropical leguminous crop it is rich in protein and has high nutrient content and India is the largest producer. Pigeon pea is grown in a sole cropping system as well as with intercropping system it is majorly intercropped with legumes, cereal, and oilseed crops. Intercropping depends upon the interaction of crop species and their management. Intercropping is done between different types of cereals, pulses, and oilseed crops. Some successful cereal and pulse intercropping systems like (mung bean + maize) where, a larger equivalent yield is obtained by seeding maize following four rows of mung beans than by closer spacing. Wheat is mostly intercropped with chickpea, mustard and barley but in irrigated conditions when wheat intercropped with mustard proved more profitable than wheat intercropped with chickpea. In the Mediterranean nation, common vetch (*Vicia sativa*) is popularly grown with cereals. When maize and cowpea were intercropped in southern Africa, the quantity of nitrogen, phosphate, and potassium in the soil was enhanced. Maize and beans are popular in eastern Africa. However, there are many challenges while adopting intercropping for the survival of the plant. In intercropping of pigeon pea when two or more than crops are sown, they show a synergetic effect, and when it is treated with the biofertilizers like *Rhizobium*, arbuscular mycorrhizal fungi (AMF), phosphate-solubilizing microorganisms (PSM) and plant growth-promoting rhizobacteria (PGPR), it enhances the growth of the plant, fixes atmospheric nitrogen in the soil, availability of phosphorus to the plant increases the uptake of other micro-nutrient to the plant and plant beneficial microbes. When dual inoculation of *Rhizobium* and AMF is done, chlorophyll content increases in the plant.

***Keywords:** Intercropping, Synergetic Effect, Rhizobium, arbuscular mycorrhizal fungi, phosphate-solubilizing microorganisms.*

1. INTRODUCTION

Pigeon pea (*Cajanus cajan* L.) is a leguminous crop of great agricultural and economic importance worldwide [1]. Also known as "arhar" or "tur," it is cultivated in diverse agro-climatic regions, especially in tropical and subtropical areas [2]. Pigeon pea serves as a major source of protein, energy, and essential nutrients for millions of people, particularly in developing countries [3]. Pigeon pea seeds are rich in protein 20-22%. It is also high in nutritive value [4]. Pigeon pea is a hardy and drought-tolerant crop and it holds an important place in Rainfed agriculture. Globally it is cultivated in Kenya, Uganda, Malawi, China, Myanmar, and Nepal [5]. World production of pigeon pea is estimated at 4.49 million tonnes and in India, pigeon pea is mostly cultivated in Maharashtra and it is estimated at 7,00,000 tons. India's total production of pigeon pea is 63% [6]. Pigeon pea is consumed as food in the form of dal, and sambar, a staple food of India. Pigeon pea contains essential amino acids: methionine and lysine [7]. Pigeon pea possesses a particular form of a nitrogen-fixing bacterium called the rhizosphere, which releases growth-promoting chemicals including indole acetic acid, gibberellins and Cytokinin that aid in growing root biomass. Pigeon pea also improves soil conditions and fixes atmospheric nitrogen [8, 9]. Pigeon pea is grown with a different type of intercropping system from cereal and oilseed crops which shows the synergetic effect on the plant and enhances the productivity of the soil [10]. Pigeon pea is planted as an intercrop, which helps efficiently use available resources, resulting in increased productivity and profit [11]. The fundamental benefit of intercropping is that the component crops can use growth resources differently and more efficiently than if they were grown individually [12].

2. INTERCROPPING

The agricultural practices of ancient times are known to have produced crop mixes that were nourished by humans for a very long time in many parts of the world [13]. Since the Indus era (2600–1900 BC), mixed cropping, multi-cropping, or intercropping has been practiced [14]. The intercropping system was well known in Greece since about 300 BC. Theophrastus, one of the finest early Greek philosophers and natural scientists, observed that wheat, barley, and several pulses could be sown at different periods during the growing season and were frequently combined with vines and olives, demonstrating awareness of the practice of intercropping [15]. Intercropping is the practice of growing more than one crop in a field at the same time and place [16]. All Environmental resources are used in the intercropping method to increase crop yield per unit area and per unit time [17].

2.1 Advantages of intercropping

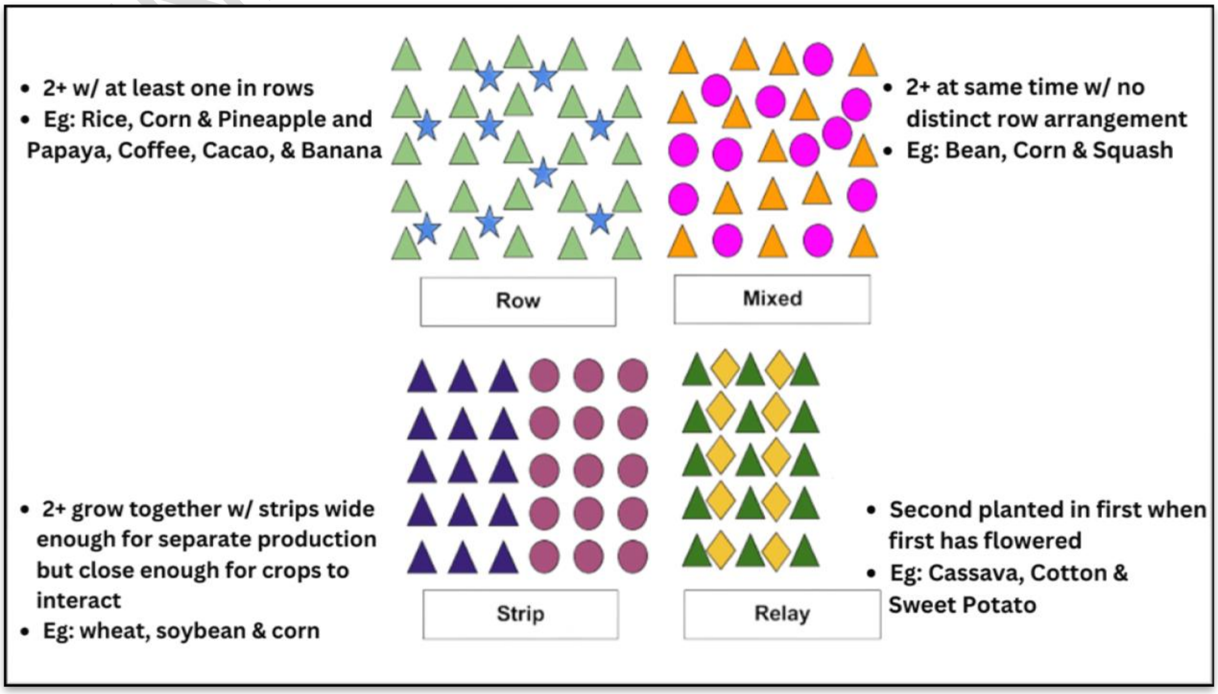
1. To prevent total crop failure due to abnormal weather or pest epidemics [18].
2. To increase overall productivity per unit of land area [19, 20]
3. To make sensible and judicious use of resources including land, labor, and inputs [21,22].
4. The farmer's domestic requirements must be satisfied [21].

2.2 Types of inter-cropping

1. Row intercropping: Growing two or more crops simultaneously when one or more are planted in regular rows and another crop or crops may be grown simultaneously in a row or randomly with the first crop [23, 24].

2. Mixed intercropping: It is the simultaneous cultivation of two or more crops without clearly defined row arrangements. In a pasture-based system, this variety may be appropriate for intercropping grass and legumes [24].

3. Strip-intercropping: The practice of growing more than two crops at once in separate, ergonomically friendly strips that are wide enough for independent cultivation while narrow enough for crop interaction [25].
4. Relay intercropping: The simultaneous cultivation of two or more crops during a certain stage of each crop's life cycle is known as relay intercropping. The second crop is planted



after the first crop has reached its reproductive stage or is almost ripe but before it is ready for harvest [25].

Fig 1: the types of inter-cropping. (**Source:** https://ecosystemsunited.com/2017/01/24/an-introduction-to-intercropping)

3. COMPANION CROPS IN PIGEON PEA INTERCROPPING

3.1. Crops commonly intercropped with pigeon pea

Pigeon pea is often intercropped with a variety of crops, depending on the local agricultural practices and specific agro-climatic conditions [24]. Some common companion crops in pigeon pea intercropping systems include:

Cereals: Sorghum, millet, maize, and pearl millet are commonly intercropped with pigeon pea. Cereal crops provide vertical structure, shade, and support to pigeon pea plants, and their root systems complement each other well [26].

Legumes: leguminous crops like chickpea, cowpea, and mung bean are often grown alongside pigeon pea. Legumes have similar nitrogen-fixing capabilities, which collectively contribute to enhanced soil fertility [27].

Oilseeds: Groundnut (peanut) is frequently intercropped with pigeon pea. Oilseeds provide additional economic benefits and contribute to the overall yield [28].

Vegetables: Various vegetables like okra, tomato, and bottle gourd are compatible with pigeon pea intercropping. These vegetables occupy different niches in the field and can be harvested earlier than pigeon pea, allowing for efficient land use and income diversification [29].

Spices and Herbs: Spices such as coriander, fenugreek, and mint, as well as herbs like basil, can be integrated into pigeon pea intercropping systems, adding aromatic and culinary value while promoting biodiversity [30].

3.2. Synergistic relationships and complementary growth patterns

The choice of companion crops in pigeon pea intercropping is based on their ability to complement each other's growth patterns and resource utilization. For example:

Nitrogen Fixation: Pigeon pea and other leguminous companions have the ability to fix atmospheric nitrogen through their root nodules. This process benefits the entire intercropping system, as the fixed nitrogen becomes available to all plants, supporting their growth [31].

Canopy Structure: Crops with varying canopy structures are often selected to optimize sunlight interception and utilization. Tall-growing companion crops, like maize or sorghum, can provide support and shade to the taller pigeon pea plants, reducing competition for sunlight and improving light distribution [32].

Root Architecture: Different crops have different root depths and patterns, which allows them to access nutrients from different soil layers. This minimizes competition for nutrients and enhances overall nutrient uptake efficiency in the intercropping system [33].

Pest and Disease Management: Some companion crops exhibit natural pest-repellent properties, reducing pest pressure on pigeon pea. Additionally, diverse intercropping systems disrupt pest and disease cycles, preventing widespread infestations [34].

3.3. Yield and productivity implications of different companion crops

The selection of companion crops can significantly influence the overall yield and productivity of the pigeon pea-based intercropping system [35]. The yield implications depend on various factors, such as crop selection, planting density, and management practices. Some key points to consider include:

Complementary Yields: Intercropping pigeon pea with complementary crops can lead to increased total yields per unit area. The combined harvest of pigeon pea and the companion crop contributes to overall productivity [36].

Crop Diversification: Intercropping diversifies income streams and reduces the risk of total crop failure. If one crop fails due to adverse conditions, the other companion crops may still produce a yield, providing a safety net for farmers [37].

Competitive Yields: In some cases, the yields of individual crops in an intercropping system may be lower than in monoculture due to resource competition. However, the overall productivity can be enhanced due to efficient resource utilization and reduced pest pressure [38].

Management Considerations: Proper crop management, including the choice of planting density, intercropping patterns, and nutrient management, plays a crucial role in optimizing yields and productivity in intercropping systems [39].

4. INTERCROPPING WITH PULSES

In the current state of agriculture, growing only grains or cereals as the only crop is not very lucrative. There is a pressing need to include pulses in the system for producing cereals to meet the wide range of consumer demand and the constantly expanding population [40]. The main objective of intercropping is to ensure better and sustainable output, even if the cereal + legumes intercropping system is widely advertised as insurance against crop failure for monocultures in rainfed environments [41]. Cereals often use nutrients from the upper soil layers and are nutrient-exhaustive crops [42]. Legumes have the potential to fix atmospheric nitrogen in the soil, increasing soil fertility and using fewer of the limited soil resources [43]. In both developed and developing countries, cereal+ legumes intercropping plays an important part in subsistence agriculture and supplies a variety of food crops, especially in regions with insufficient irrigation infrastructure [44]. Intercropping legumes and cereals help in weed control and increases soil fertility, both of which increase crop output [45]. The intercropping of cereals with legumes, like soybean (*Glycine max* L.), groundnut (*Arachis hypogaea* L.), and others with cereals like rice (*Oryza sativa* L.), maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), and pearl millet (*Pennisetum typhoides*), among others, offers excellent potential for reducing the negative effects of moisture stress in plants [46].

4.1. Consequently, the following guidelines should be followed for the successful intercropping of cereal and legumes.

I. The peak nutritional requirements of the component crops should not coincide [47].
II. The component crops should not compete with one another too much for light. There is rivalry within and between species for these resources because all plants utilize sources, such as light, water, nutrients, etc. The legume depends on this

source when the nonlegume or cereal component crop in an intercropping system is primarily dependent on biologically fixed N and is fiercely competitive for absorbing soil inorganic N [48].

III. The component crops should be complementary to one another in order to maximize the utilization of growing resources in both time and area. The N-use complementarity is the most significant relationship between grains and legumes [47-49].

IV. For intercropping to be successful with the least amount of competition, component crops' maturities should differ by at least 30 days [28].

4.2. Some popular intercropping systems in legumes and cereals

Cereal and legume intercropping systems are fairly widespread in India:

I. *Zea mays* L., also known as maize, is often farmed in India throughout both the wet (summer) and dry (winter) seasons. Between the rows of maize, pulses like mung beans (*Vigna radiata* L.) and urd beans (*Vigna mungo* L.) are sown. Sowing maize after four rows of mung bean or urd bean produces a larger equivalent yield than tighter spacing because maize develops quicker in the wet season [50]. However, with winter-sown maize, the maize crop planted after each row of vegetable pea (*Pisum sativum* L.) had a greater maize equivalent yield compared to solitary maize, maize plus lentil (*Lens culinaris* Medikus), or maize + bean (*Pisum sativum* L.). Furthermore, north-south planting was determined to be the optimum way to limit the shading impacts of maize on legumes [51].

II. The subtropical dry plains of India are a major producer of pearl millet, and a number of grain legumes, including green gram, black gram, cowpea, and groundnut, can be cultivated as intercrops with high equivalent yields [52].

III. Chickpea (*Cicer arietinum* L.) was frequently grown with wheat (*Triticum aestivum* L.), barley (Hordeum vulgare L.), and other crops in rainfed environments. Wheat intercropping with mustard (*Brassica juncea* L.), however, was more lucrative under irrigation conditions than wheat intercropping with chickpeas. A good row ratio, in addition to the selection of appropriate kinds, is vital for maximum profit. However, intercropping pulses with wheat is not always lucrative because of the closer spacing [53].

IV. In Mediterranean rainfed areas, cereal and legume intercropping is rather common. A common intercropping crop in Mediterranean nations is common vetch (*Vicia sativa*), an annual legume with a climbing habit and high protein content [54].

V. Across a traditional intercropping system, field peas, and spring barley are produced in Europe. In intercropping systems with weed infestation and soils with low nitrogen availability, pea + barley intercropping showed potential for protein increase [55].

VI. Maize + bean intercropping systems are very prevalent in Eastern Africa, and maize + cowpea/groundnut intercropping systems are prevalent in Southern Africa [56]. Maize + cowpea intercropping has been shown to increase soil N, phosphorus (P), and potassium (K) contents in this region as compared to maize monocrops [57].

5. CHALLENGES AND LIMITATIONS

1. Competition for Resources and Growth Constraints:

Intercropping systems involve growing multiple crops together, which can lead to competition for essential resources such as sunlight, water, and nutrients [58]. Pigeon pea and companion crops may have varying growth rates and resource requirements, leading to imbalances and reduced yields for some crops. Careful management and selection of compatible crops are necessary to minimize resource competition and maximize overall productivity [59].

2. Potential Allelopathic Effects:

Certain crops, including pigeon pea, release natural chemicals into the soil that can inhibit the growth of neighboring plants [60]. While allelopathy can help suppress weeds and pests, it may also affect the growth of companion crops. Understanding and managing allelopathic interactions are crucial to avoid negative impacts on crop performance in intercropping systems [61].

3. Weed Management:

Weed control can be challenging in intercropping systems, as different crops may have varying susceptibilities to weeds. Pigeon pea itself is relatively weed-competitive [62], but companion crops might not be as effective in suppressing weeds. Integrated weed management practices, such as timely weeding, mulching, and using cover crops, are essential to minimize weed competition and ensure successful intercropping [63].

4. Market and Logistical:

Intercropping systems often result in diverse crop yields, making post-harvest handling and marketing more complex [25]. Market demands might not always align with the intercropped crops, leading to challenges in selling and distributing the harvested produce. Farmers may face difficulties in finding suitable buyers or processing facilities for their diverse crops, potentially affecting profitability and market access [64].

5. Knowledge and Adoption Barriers:

Intercropping requires specific knowledge and skills in crop management, pest control, and agronomic practices [65]. Small-scale farmers, particularly those with limited access to information and resources, may hesitate to adopt intercropping due to uncertainty about its benefits and management complexities. Promoting awareness and providing training on intercropping techniques are essential to encourage wider adoption [66].

6. Insect Pest and Disease Management:

While intercropping can reduce the risk of insect pest outbreaks, it may also create microenvironments that favor certain insect pests and diseases [67]. The presence of multiple crop species can complicate pest identification and control measures. Integrated pest management (IPM) strategies that consider the specific intercropping system are necessary to prevent and manage pest and disease pressures effectively [68].

7. Resource Intensive Initial Establishment:

Establishing a successful intercropping system may require additional labor and resources, especially during the initial stages [69]. For instance, preparing the land for multiple crops, acquiring seeds or seedlings of companion crops, and adopting new management practices can pose initial challenges for farmers [70].

8. Monitoring and management complexity

Intercropping systems may demand more attentive monitoring and management compared to monoculture systems [61]. Proper timing of planting, nutrient application, and irrigation must be carefully coordinated for different crops. Regular monitoring is necessary to address any imbalances and ensure optimal growth conditions [71]. While pigeon pea-based intercropping systems offer numerous benefits, they also present certain challenges and limitations. Effective weed and pest management, careful resource allocation, and addressing market and logistical concerns are crucial for the successful implementation of intercropping [72]. With proper planning and knowledge sharing, farmers can overcome these challenges and harness the potential of pigeon pea-based intercropping to achieve sustainable agricultural practices and improved livelihoods [73].

6. PIGEONPEA- CEREAL LEGUME OR OIL SEED BASED INTERCROPPING SYSTEM

6.1. Pigeon pea and cereal intercropping:

Pigeon pea is frequently interplanted with grains like sorghum, pearl millet, or maize [74]. In this method, cereal crops that mature in 100–120 days are grown, with crop/variety selection depending on the farmer's desire and local adaptation. Two rows of cereal and one row of pigeon peas are traditionally grown together. Pigeon pea plants are subject to intense competition for nutrients, moisture, light, and space in this situation. Pigeon pea plants' main attribute that contributes to production, the number of branches, rapidly declines, leading to a large drop in output. Pigeon pea is interplanted with Setaria, finger millet, and rainfed rice in addition to the main crops. However, these combinations only cover a small amount of ground [75].

6.2. Pigeon pea and legume intercropping:

Pigeon pea is intercropped with early-maturing legumes including groundnut, cowpea, green gram, black gram, and soybean. In India's Central and South Zones, intercropping pigeon pea with green gram, black gram, and field bean has been observed. However, in the frontline experiments (35 ha), combining pigeon pea and soybean in a 2:4 ratio increased grain yield by 27.7% and net return by 40.5% in comparison to a sole crop. Pigeon pea and soybean are the highest-paying crop comigration in high-input agriculture. In this setup, both crops have considerably less competition and have great yields. Pigeon pea and groundnut are another common intercrop combo. This kind of crop production is employed in areas that receive rain and have light soils ideal for growing groundnuts. Six to eight groundnut rows are frequently placed between the two rows of spreading-type pigeon peas. Harvested pigeon pea products include green pods (used for vegetables), dried pods (used for grains), and stems (used for essential household fuel) [75].

6.3. Pigeon pea and oilseed intercropping:

This technique is becoming increasingly important as the need for vegetable oils and protein grows. Pigeon pea and sesame were frequently intercropped in oilseed crops. Farmers value both component crops under this arrangement [76]. Intercropping of pigeon pea and sesame is common in dry areas of central India and Myanmar. On alfisols soil in India's Vindhyan range, it was discovered that pigeon pea/sesame intercropping is highly profitable [77].

Table 1. Pigeon is grown with different types of crops like

Intercropping of pigeon pea		
Cereal combination	**Legume combination**	**Oilseed combination**

Pigeon pea + sorghum Pigeon pea+ millet Pigeon pea +maize Pigeon pea+ upland rice	Pigeon pea+ soybean Pigeon pea+ mung bean Pigeon pea+ black gram Pigeon pea+ cowpea Pigeon pea+ groundnut	Pigeon pea+ sesame Pigeon pea + sunflower

Table 2. Effect of different pigeon pea-based intercropping systems on the cost of cultivation, gross return, Net return, and B: C ratio.

Intercropping of Pigeon pea with cereals					
Intercropping	**Cost of cultivation (₹/ha)**	**Gross return (₹/ha)**	**Net return (₹/ha)**	**B:C ratio**	**Source**
Pigeon pea + sorghum	-	37796	30179	4.96	[78]
Pigeon pea + pearl millet	7721	26410	18689	2.42	[79]
Pigeon pea + maize	20444	34737	14293	0.70	[80]
Pigeon pea + upland rice	-	35337	17477	1.98	[81]
Intercropping of pigeon pea with legumes					
Pigeon pea + soybean	-	87135	59194	2.11	[82]
Pigeon pea + mung bean	20293	177464.67	157171	8.74	[83]
Pigeon pea + black gram	17676	45587	27911	1.58	[80]
Pigeon pea + cowpea	-	78884	51490	1.87	[82]
Pigeon pea + groundnut	13359	-	21379	1.60	[84]
Intercropping of pigeon pea with oilseeds					
Pigeon pea + sesame	19655	203140.17	183485	10.33	[83]
Pigeon pea + sunflower	16782	34793	18012	2.10	[85]

7. ROLE OF BIO-FERTILIZER IN PULSE INTERCROPPING SYSTEM

There are thousands of microbial cells per gram of root in the rhizosphere, a tiny patch of soil around plant roots that is home to over 30,000 prokaryotic species. In general, these organisms promote plant production and development [86, 87]. The microbial population in the rhizosphere is known as the microbiome which has a genome greater than that of plants [88]. In terms of sustainable agriculture and biosafety programs, rhizosphere microbial populations have emerged as a suitable substitute for synthetic fertilizers [89]. Plant growth-promoting rhizobacteria (PGPR), nitrogen-fixing cyanobacteria, mycorrhiza, and fungi are all examples of rhizobacteria which are helpful bacteria that prevent plant diseases, stress-tolerant endophytes, and microbes that degrade materials are among the agriculturally important microbial communities [90].

7.1. Nitrogen-fixing microorganism:

N is a vital plant nutrient for optimum pulse productivity [91]. The majority of the soil in India lacks nitrogen, which is a nutrient that is heavily utilized by pulse crops. Nitrogen is lost from the soil more through volatilization, leaching etc [92]. Although nitrogen makes up 78% of the atmosphere, it is fixed by diazotroph bacteria in the soil, which convert atmospheric nitrogen into ammonia when nitrogenase enzyme is present. Symbiotic, associative symbiotic, and free-living N-fixing bacteria are the 3 categories [93].

7.2. Response of Pulses to ***Rhizobium***

According to nodulation studies, a preponderance of legumes farmed in India requires inoculation each season since the majority of cultivated soils for pulses are known members of the *V. unguiculata* group of rhizobia. A higher yield is observed when the seed is inoculated with a *Rhizobium* strain. The studies showed that the yield increases brought on by *Cajanus cajan* L. inoculation ranged from 1.2% to 20.3%, 8 to 47.8%, and 1.8 to 26.4% in 1992, 1993, and 1994, respectively, in various parts of India. Additionally, it appears that different *Rhizobium* strains and types interact to boost grain production [94]. Biological nitrogen fixation **(**BNF) reduces or eliminates the requirement for N fertilization, which helps not just the legumes but also any intercropped or following crop. N-fixing bacteria provide ammonium into the biomass of legume plants in soils with low mineral N concentration, enabling them to develop more quickly than their rival plants. N-fixing bacteria, on the other hand, are often competitively rejected by non-fixing species when N is abundant since. The technique is costly [95] and suggests that a range of physiological and ecological factors, including the plant's nitrogen needs and the environment's C: N stoichiometry, tend to limit BNF in legume systems [96].

7.3. Multiple Microbes to Increase Pigeon pea Productivity

Plant-growth-promoting organisms, such as phosphate solubilizers, *Bacillus, Pseudomonas*, *arbuscular mycorrhizal fungi*, and others, can be inoculated with Rhizobia. to increase agricultural production [97].

7.4. Phosphate-Solubilizing Microorganisms

P is a vital nutrient for crops and is frequently found in the soil in both inorganic and organic forms. Examples of inorganic forms of P include complexes of phytins, phospholipids, and nucleic acids [98]. After being applied to the soil, the phosphorus in superphosphate and other synthetic fertilizers quickly changes from its accessible form into insoluble ones. Therefore, a limiting factor for agricultural plants is always the supply of P. The simultaneous inoculation of *Rhizobium* and phosphobacteria is a significant technique for delivering N and P nutrients for pulse crops [99]. P is essential for the establishment of nodules, improved Nitrogen fixation, root development, and as well as legume yield [100]. P shortage is a normal occurrence in tropical soil. Additionally, the majority of the P is fixed, rendering it useless for planting. In tropical soil, it is thought that 75% of the superphosphate sprayed fixes, leaving just 25% accessible for plant development. Phosphate-solubilizing microorganisms (PSM) are bacteria and fungi that may convert inaccessible forms of P into available forms by secreting lactic acid, succinic acid, acetic acid, fumaric acid, and other organic acids [101].

7.5. Inoculation of PSM (phosphate-solubilizing micro-organism) with rhizobia

The use of PSM in pulse crops may result in more efficient and cost-effective P-fertilizer usage. BioPhos (PSM inoculants) boosted P-uptake and P content in numerous leguminous plants. In terms of nodulation, P-uptake, pod yield, and net utilization of pulse production, PSM surpassed uninoculation. The use of a 75:25 MAP: SSP (Mono-ammonium phosphate : Single super phosphate) ratio had a favorable influence on agricultural yield [105]. Furthermore, PSM has the potential to replace 25% of phosphate fertilizers. The use of rock phosphate and PSM in the field has increased pulse output. P solubilization and release from rock phosphate by PSM were influenced by higher P-uptake and dry matter synthesis in pulses [102]. The type of phosphorus available has a significant influence on BNF. As a result, co-inoculation of N fixers and PSMs benefits the plant more than either group of bacteria alone since it delivers both N and phosphorus (P). Under field conditions, the dual inoculation of phosphobacterium (*Bacillus megaterium* var. *phosphaticum*) and *Rhizobium* increased plant height, nodule number, and nodule weight of black gram [103]. Phosphate solubilizing bacteria (PSB) can enhance the rival capability and symbiotic efficacy of inoculation of *Rhizobium* sp. in *Lens culinaris*, as well as the leghemoglobin content of Cicer arietinum nodules in field conditions and nodules [104]. This is due to the fact that P, in the form of Adenosine triphosphate (ATP), is required for the *Rhizobium* enzyme nitrogenase, which is critical to plant energetics and biocontrol impact, and the generation of siderophores is a substantial component [105].

7.6. Vesicular Arbuscular Mycorrhizal (VAM) fungi

VAM shows a synergetic relationship between a certain class of fungus and the transport and absorption of phosphorus by plants is accelerated by the roots of plants. In agriculture, horticulture, and tropical forestry, vesicular-arbuscular mycorrhizal fungi (VAM), often referred to as Arbuscular Mycorrhizal (VAM) fungi (AMF), there are many agricultural plants' roots colonized by fungus and have 10 fungi genera*: Paraglomus, Glomus, Gigaspora, Geosiphon, Scutellospora, Diversispora, Sclerocystis, Acaulospora, Entrophospora*, and *Archaeospora* comprise the phylum Glomeromycota, is responsible for their formation [106]. The photobiont comprises more than 170 identified species and even more than 87% of all vascular flowering plant families. These are obligatory symbionts that must have live hosts to reproduce and develop. The presence of AMF increases the surface area of roots that can absorb water and encourages plant development through enhanced Phosphorus nutrition, absorbed and transfer soil solution and uptake of phosphorus pathway is relatively high, phosphorus makes roots in this larger volume of soil available to the host [107]. It has also been demonstrated that N, Zn, B, Cu, K, S, Ca, Mg, Na, Fe, Mn, Al, and Si are among the extra nutrients that VAM hyphae more readily absorbed from the soil than other hyphae. By, supplementing the host plants with Phosphorus and other immobile nutrients, such as copper and zinc, which are necessary for biological nitrogen fixation, AMF indirectly speeds up BNF in legumes [108]. At low nutrition availability, BNF can fall or even be blocked without AMF [109].

7.7. Inoculation of AMF with rhizobia:

Due to the presence of two symbionts in the roots of legumes, the Rhizobia, Arbuscular mycorrhiza fungi, and bacteria can occasionally interact [110]. Where nodulation and N-fixation were significantly boosted along with P-uptake and growth when *Glomus fasciculantum* "E3" and rock phosphate were combined. The enhanced Phosphorus uptake by AMF thereby promoted *Rhizobium* activity, which relies on an adequate supply of phosphate. AMF and rhizobia may coexist in a dual symbiotic relationship with the majority of legumes. Rhizobia and AMF work cooperatively to govern crop production, productivity, resistance, and organization in natural environments [111]. The performance of legumes as a whole was significantly enhanced by a specific habitat's tripartite symbiosis between rhizobia and arbuscular mycorrhizal fungus [112]. It demonstrates that the positive impacts of dual colonization of legume roots, especially pulse roots, have been studied by several researchers. Most studies have concentrated on the indirect interactions between AMF and rhizobia, where a successful symbiosis has been defined as an increase in the plant's intake of nutrients, particularly P nodule biomass, and nitrogen fixation. However, non-nutritional impacts show more on AMF and rhizobia [113].

Researchers investigated the effects of Arbuscular mycorrhiza fungi and *Rhizobium* dual inoculation on pigeon pea chlorophyll, nitrogen, and phosphorus content. When pigeon peas are inoculated with *Rhizobium* alone or with both *Rhizobium* and *glomus fasculantum*, the nitrogen and phosphorus content in legumes increases, and the plant's chlorophyll content improves, improving the photosynthesis rate. The combination of microsymbiont inoculation had a synergistic effect [114]. It demonstrates that there is an increase in chlorophyll content, transpiration rate, nitrogen-fixing capacity, and absorption of phosphorus from the soil to the plant following dual inoculation of AMF and *Rhizobium*.

7.8. PGPR (Plant Growth-Promoting Rhizobacteria) and biological control Agents:

Root microbiomes having favorable traits that are intimately linked to roots are known as plant growth-promoting rhizobacteria (PGPR) [115], By associating with several other soil microorganisms and directly stimulating the growth of beneficial microbes such as rhizobia and phosphate solubilizing bacteria, or by preventing the growth of detrimental bacteria, the varied range of soil bacteria included in PGPR might enhance host plant growth [116]. In multilocational experiments, single rhizobia inoculation increased the Production increased by 12.4% as compared to simultaneous inoculation with PSB and PGPR, which resulted in a 22.1% rise in grain yield of Chick pea (*Cicer arietinum*) [90].

8. FUTURE PROSPECTS

The future prospects of pigeon pea-based intercropping systems hold immense potential for sustainable agriculture and food security. Investing in research and development in key areas, such as climate resilience, nutrient management, pest control, market integration, and policy support, will advance intercropping practices and contribute to the transformation of agricultural landscapes. Through collaborative efforts between researchers, policymakers, and farming communities, pigeon pea intercropping can play a crucial role in building resilient and environmentally friendly farming systems, paving the way for a sustainable and food-secure future [58-73]. Despite its lengthy history, intercropping is of little interest to academics and farmers as a way to produce diverse food through sustainable farming. Multidisciplinary fieldwork including marginal and small-scale farmers, extension agents, and stakeholders is required to enhance knowledge about the significance of legumes in nitrogen fixation, yield maintenance, soil quality, and economic rewards. Biofertilizer also plays an important role in increasing worldwide pulse output [90]. It is vital to produce intercropping-specific species, technology, and methodological approaches that can be distributed not just to farmers but also to grow out [117,118].

9. CONCLUSION

Intercropping systems can potentially increase food production's long-term sustainability in many places around the globe with modest inputs While some of the processes by which they provide advantages are recognized, there is a significant opportunity to enhance intercropping systems in order to get a higher yield while using the same inputs. Further, intercropping of pigeon Pea cultivation has been crucial in many developing countries. The ability of pigeon pea to provide nutrient-rich grain and enhance soil nutrition Smallholders' agricultural output per unit area can be enhanced by using intercropping in several cropping systems. and there is great potential in marketing by increasing the production of pigeon pea. intercropping with the combination of cereals, legumes, and oilseed crops there is a reduction in pest incidence due to different plant habitats, and the intercropping of legumes and cereals show a synergetic effect on the plants with less use of nutrients and low infestation of weeds. Thus, Pigeon pea based Intercropping system has enormous potential as well as several benefits.

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