Cowpea (*Vigna unguiculata* L. Walp.): A choice crop for sustainability during the climate change periods

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**ABSTRACT**

Climate change is significantly affecting food security and environmental health. The effect is more severe for countries with low adaptive capacity in the developing world. Legumes are among the possible solution for agriculture’s sustainability during the climate change times as they minimize mineral fertilizers use because of symbiotic nitrogen (N) nutrition. Cowpea is a multipurpose legume crop, with combined agronomic, environmental, nutritional, and economic advantages. Cowpea provides dietary protein and serves as a source of income for millions of rural poor in the developing countries. Cowpea also enhances soil fertility as it contributes huge amount of N through N fixation. Nevertheless, cowpea productivity remained low in Ethiopia, and there are less awareness regarding the multifold roles the crop can play, its response to climate change and bio-inoculants. Therefore, this review aimed to assess the agro-symbiotic performance, utilization, and climate change response capacity of the crop to exploit its potential toward sustainability. The review result revealed that cowpea performs better than most of the legumes grown in the tropics, achieving acceptable yield performance with limited rainfall of up to 450 mm per annual, and heat stress. Moreover, elevated CO₂ reported to enhance N fixation in cowpea, leading to photosynthesis and seed yield improvement. On the other hand, high temperature and elevated ultraviolet radiation reduced the performance of cowpea crop as these factors inhibit symbiosis. In Ethiopia, mature seed of cowpea, immature pods, and leaves used for food in lowland areas of the country and about 66.5% of Ethiopia’s arable land suits for cowpea production. However, the average yield is limited to 400 kg ha⁻¹, with annual production and land coverage of 55,600 tons and 69,500 ha, respectively. Overall, this review confirmed the excellent nature of cowpea in terms of climate change response and the diversity of services the crop can offer. From the review, an understanding is captured that Ethiopia has the potentials for raising cowpea productivity having suitable land and agro-ecology. Therefore, introduction of improved varieties, and agronomic practices including bio-inoculants, should be a point of focus to raise cowpea yield, and benefit from the manifold roles the crop can play.

**1. INTRODUCTION**

Agriculture, the main economic sector of many developing countries, is a sector most suffering from the impact of the ever-changing climate [1,2]. During the previous periods, the principal driving force of agriculture was increasing productivity. However, during the climate change period, increment in crop productivity should also be consider sustainability [3]. For which, legumes are chosen as a possible solution to agriculture’s sustainability during the climate change times as legumes contribute nitrogen (N) through symbiosis [4]. As legumes provide oil, fiber, and protein-rich food, besides their N contribution to the soil considered as the most important food source with sustainable and inexpensive meat substituting capacity [5,6].

In sub-Saharan African (SSA) countries, cowpea is most important crop among legumes for farmers, whose agricultural systems are largely deficient in plant nutrient, particularly N. This is because it performs under varying environments and fixed large quantity of N through biological N fixation (BNF) [7]. Therefore, cowpea can bring agronomic, environmental, and economic advantages for the rural poor [8]. Moreover, it exceeded most of the legumes to enhance soil fertility due to high N-fixing capacity when inoculated with effective rhizobia [9].

Nutritionally, cowpea provides high protein and carbohydrates, and it is also a source of vitamins, minerals, and micronutrients [10]. Due to its high nutritional value, it supports the rural poor in SSA, where carbohydrate-rich crops serving as a base for their diet [7,11]. Thus, gastrointestinal disorders [12], cardiovascular diseases, hypercholesterolemia, and obesity are among the diseases healed when cowpea is included in the diets [13]. Diabetes and several types of cancer can also be protected by the food sourced from cowpea [14].

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Cowpea is important food source to regulate body weight [15], healthy digestion, and blood circulation systems [12].

Its ability to grow in a stressed environment and capacity to fix high amount of N are the reason for the environmental advantage from the crop [16,17]. Raising the yield of cowpea, therefore, is possible using mineral and biologically fixed N. However, due to the pressing climate change effect, and with the recent awareness regarding the environmental polluting potential of mineral fertilizers, a focus on the BNF sourced N is increasing [7]. Cowpea has the capacity to fix atmospheric N2 under stressed environments [18] and reported to contribute about 240 kg N per hectare annually [19]. However, its N2-fixing efficiency and yield affected by several factors including biotic, edaphic, and weather variables [20]. Ultraviolet (UV) radiation, carbon dioxide, temperature, light, and moisture are the major climatic factors affecting N2-fixation process [21]. On the other hand, a rhizobial establishment can be inhibited by factors such as crop species and genotypes, competitive native microorganisms, and poor inoculant adhesion and survival [22].

Due to drought and warm weather adaptive capacity of cowpea, the crop is under production in the lowland areas of Ethiopia and the seeds, pods, and leaves used for consumption [23]. The early maturity behavior coupled with its drought tolerance capacity the crop plays a paramount role for risk aversion in the drought affected lowlands of Ethiopia [24]. Even if, the country is reported as a center of diversity for cowpea, it is not often mentioned in most of the previous studies dealing with cowpea production and productivity. Although about 66.5% of Ethiopia’s arable land suites for cowpea production, its yield remained below the potential [25]. According to Beshir et al. [24], knowledge gap on the manifold uses of cowpea, and sub-optimal crop husbandry including reliance on local varieties and absent of bio-inoculants use, climate and soil fertility factors are attributing to the low yield of the crop. Hence, the current review aimed to assess the cowpea production system and its response to the yield limiting factors and bio-inoculants to raise awareness toward exploiting its potential toward achieving food security.

2. METHODOLOGY

This review used desired scientific materials which are searched and prioritized based on their relevance to the topic of interest. The final review manuscript thereby, prepared by reviewing and synthesizing those selected scholarly materials retrieved from Scopus, Web of Sciences, Google Scholars, ResearchGate, etc. A search for literatures was not limited by time and geographical locations. However, a focus was paid for recently published articles and scholarly materials addressing cowpea producing countries from developing worlds. The key phrases used as a search cord associated to legume N contribution to soil fertility, legume responses to inoculation, cowpea nutritional composition, and factors affecting N2 fixation.

3. RESULTS AND DISCUSSION

3.1. Cowpea Production and Utilization

Across the world, about 45 countries have reported to produce cowpea with a total land allocation of 14.5 million ha per year and estimated 6.5 million metric tons production with 450 kg ha-1 global average yield [26]. The Western African countries accounted for 83.4% of the global production in 2016 [27] as the crop adapts in warm weather and drought conditions in the tropics where other legumes cannot grow [28]. Cowpea is suitably cultivated under mixed system due to its shade tolerance and successfully produced in poorly fertile soil as it fixes high amount of N [29]. Therefore, cowpea’s services go from dietary diversification to food security. Due to this, about 4.3%, 1.5%, and 5.8% growth for area coverage, yield, and production reported for SSA in their respective orders [26]. However, the yield remained low even compared with other legumes. However, Ojiewo et al. [30] projected a yield growth from about 6.2 million MT in 2010 to nearly 8.4 million MT by 2020 for SSA.

In Ethiopia, the crop is under production in the northwest, eastern, central rift valley, and southern region of the country [23]. A national average national yield of about 0.4 t ha-1, and a yield ranges from 2.2 to 3.2 t ha-1 from improved varieties under optimal agronomic practices have been reported for Ethiopia [24]. In Ethiopia, cowpea is estimated to cover 69,500 ha of land with annual production of 55,600 tons [24]. Recently, cowpea is considered as the most important lowland pulse in Ethiopia, due to the interest to benefit from its multiples of roles as it is used for food, feed, soil fertility restoration, and income sources [31,32]. Ethiopian farmers cultivate cowpea mostly on sandy and marginal soil conditions, considering its capacity to perform under water and nutrient limited environments [23], and with sole, intercropped, and mixed cultures [33].

Dry grain and leaf of cowpea used as a high-protein sources of food and animal fodder in many countries of Africa. Leaves and immature pods have been exploited as vegetables, and different forms of food prepared from the seeds of cowpea [34]. The leaves can be consumed in a boiled, blanched, dried, or fermented forms [35]. This will play a paramount importance for fighting hunger, especially in SSA during those months from planting to harvesting when the farmers experience food shortage. Moreover, cowpea plays a role toward sustainable soil fertility improvement, particularly in smallholder farming systems, as it fixes high amount of N through BNF [36]. Therefore, the crop significantly contributes to the sustainability, which thereby serve to mitigate climate change [24].

3.2. Cowpea Nutritional Composition

Nutritionally, legumes often are called “poor people’s meat” as the legumes are rich in quality protein, carbohydrates, oil, fiber, and sucrose [37]. In the recent times, nutritional value of legumes is attracting the interest of people across the globe due to the increasing demand for healthy food as legumes contribute to healthy diet and treat metabolic diseases [38]. Cowpea nutritionally complements low-protein cereal and tuber crop staples and serves millions of people in the developing countries as the crop provides a major source of dietary protein [39]. The seeds of cowpea also identified for its richness for minerals and vitamins [40]. Not only its grain but also the leaf serves as an important source of food having high proximate composition in it [35] [Table 1]. In Ethiopia, although the grain is mainly used for consumption, the leaf has also found to be consumed in some parts of the country [23]. The combined use of the grain, leaf, and the green pod is already been observed in major cowpea growing regions of Ethiopia [24] [Table 2].

3.3. Legume Cowpea-N Contribution to Soil Fertility

In Africa, the main factor limiting crop yield is N deficiency [41,42]. N2-fixing legumes including cowpea are found to improve soil fertility through symbiotic N contribution [43]. The input for N to agricultural production systems is sourced from atmospheric N2 fixation or mineral fertilizer application. The critical problem the farmers are facing is the declining capacity of the soil for N supply [44]. On the other hand, the population is increasing drastically across the globe, inquiring for
the production of more food, thereby increased N uptake. To maintain productivity at least at the current level or to improve it in the future, either N derived from mineral fertilizers, or BNF must replace the N removed in agricultural produce. However, the production and environmental cost of mineral fertilizer sources coupled with the poor utilization of N from mineral fertilizer by crops (rarely exceeding 50%) increased the interest toward symbiotic sources of N [45]. In this regard, cowpea, as a legume, contributes a lot in soil nutrient cycling, because of its nature to form symbiosis with Rhizobium bacteria with a reported contribution of 70–350 kg N ha^{-1} through BNF [46,47]. This indicates the importance of legumes symbiosis to enhance crop yield with economic and ecological sustainability [3]. In Ethiopia, soil fertility restoration is the top priority reasons why cowpea is incorporated in the farming systems [25].

3.4. Effects of Rhizobial Inoculation on Growth and Photosynthesis

Crop production is vulnerable to climate change, indicating the urgent need for increased attention for improved agronomic practices including the use of bio-inoculants [48]. The low N contents of most tropical soil are an important factor in limiting crop growth and photosynthesis rates [49]. Thus, the supply of N to crops through symbiosis can increase leaf growth, photosynthesis, and net assimilation rates [50].

Being a legume, cowpea, meets its photosynthetic N requirements from symbiotic N\textsubscript{2} fixation [51]. Inoculation with effective rhizobial strain found to significantly enhance development of cowpea in Ethiopian soils with an increase in the height of plants and dry mass of shoot in 12.4% and 31.3%, in their respective orders due to inoculation [52]. Significant improvement in cowpea leaf growth in terms of leaf area and leaf area index with inoculation has also been reported elsewhere [53,54]. Improvement in LAI due to inoculation leads to increased photosynthesis as the N nutrition enhances the synthesis of macromolecules responsible for CO\textsubscript{2} interception and radiation capture, ribulose-1, 5-bisphosphate, and carboxylase-oxygenase (Rubisco), in their respective orders [55]. The improvement in photosynthesis rate in inoculated plants is achieved as symbiotic N supply promotes stomatal functioning, with reported improvement in leaf conductance of up to 24% with inoculation [56].

3.5. Effects of Inoculation on Agronomic Performance of Cowpea

Rhizobia are known to improve nodule development when legumes inoculated with effective strains [57]. In confirmation to this, a cowpea nodule number and dry weight increase of 67.3 and 77.1% due to inoculation with Bradyrhizobium reported in their respective orders [52]. However, nodule formation rate is firmly linked with the inherent soil fertility status. For instant, higher soil N will have an antagonistic effect on symbiosis, but without negative effect on yield [Figure 1a and b] [57]. Symbiotic N\textsubscript{2} fixation by legumes is the important process in nature bringing in the atmospheric N to the soil with annually estimated amount of 35 million tons, an amount slightly exceeded by the amount of N supplied to the soil with the use of mineral fertilizers [58].

As legumes meet more than 70% of their N demand through symbiosis, the continuous N supply by BNF for plant growth and soil restoration has considerable contribution to environmental and economic sustainability [59]. Therefore, BNF is considered as a biological process playing a role for sustainability and serving as
an alternative ways of environmental risk free production of food in the changing climate [60] [Table 3]. Among the legumes, cowpea has a huge role in maintaining soil health, as it found to contribute about 200 kg N per hectare [61]. Therefore, improvement in the assimilate production due to inoculation enhanced photosynthesis, which thereby leads to yield increment in cowpea [55]. A yield improvement of up to 2334 kg ha⁻¹ [62] and 1223 kg ha⁻¹ [63] was reported in cowpea when inoculated with effective rhizobial strains. Crops followed symbiotic legumes can also benefit as the fallen senescent leaves and belowground parts of the legumes enhance soil fertility [64]. For instance, sorghum yield advantage of 290% was reported when it succeeded cowpea crop [64].

Water is among the most important natural resources threatened by the clime change effect [65]. In this regard, improvements reported in legume crops water use efficiency (WUE) due to N₂ fixation will have paramount importance when the water is becoming scarce during climate change periods [66]. A significant improvement in WUE of cowpea due to inoculation was reported elsewhere [67]. Improvement in WUE of inoculated cowpea may be associated with optimal nutrition, which thereby lead to healthier physiological functions and assimilation. Although several researches showed an increase in WUE with increased N nutrition, a contrasting finding, stating lower UWE in nodulated legumes was reported elsewhere [Figure 2] [68]. The difference in WUE between nodule forming legumes and the other plants is related with N fixing cost of plants [69].

3.6. Factors Affecting N₂ Fixation

Sustainable agricultural systems development in the tropical N deficient soil largely linked to BNF by legumes. However, the legume root nodule formation and function in the tropics are constrained by different factor including climatic, soil, and management factors [73].

3.6.1. Soil and nutrition effects on N₂ fixation

Excessive soil moisture, drought, soil acidity, phosphorus deficiency, and excess mineral N are the most important edaphic factors that limit BNF [73].

Waterlogging conditions inhibit root hair development and sites for nodule formation, and hinder O₂ diffusion in plant roots. As logging decreases water activity below critical tolerance limits and indirectly alters plant growth, root architecture, and exudations, it influences the growth of rhizosphere microorganisms, like rhizobia [74]. Legumes in arid regions found to show poor nodulation performance and N₂ fixation [74,75]. Several steps in the development of symbiosis, including the exchange of molecular signals between the legume and the microsymbiont, are affected by soil acidity, thereby affecting nodulation and N₂ fixation [73]. However, naturally, there are rhizobia adapting to soil acidity [74], and the effect of soil acidity and aluminum toxicity on symbiosis can be reduced through liming treatment [73].

### Table 3: Effects of inoculation on cowpea symbiosis and agronomic performance.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Contribution</th>
<th>Location</th>
<th>Unit</th>
<th>Retrieved</th>
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<tbody>
<tr>
<td>Symbiosis (N contribution)</td>
<td>35,000,000</td>
<td>Globally</td>
<td>Tons</td>
<td>[58]</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>Ghana</td>
<td>Kg ha⁻¹</td>
<td>[20]</td>
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<tr>
<td></td>
<td>70–350</td>
<td>Nigeria</td>
<td>Kg ha⁻¹</td>
<td>[47]</td>
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</table>

<table>
<thead>
<tr>
<th>Yield component</th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Pod number</td>
<td>28</td>
<td>Ethiopia</td>
<td>Percent</td>
<td>[70]</td>
</tr>
<tr>
<td>100 seed weight</td>
<td>21</td>
<td>Ethiopia</td>
<td>Percent</td>
<td>[70]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grain yield</th>
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<th></th>
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<tbody>
<tr>
<td>955–1223</td>
<td>25</td>
<td>Mozambique</td>
<td>Percent</td>
<td>[36]</td>
</tr>
<tr>
<td>54</td>
<td>533–693</td>
<td>Portugal</td>
<td>Kg ha⁻¹</td>
<td>[63]</td>
</tr>
<tr>
<td>37</td>
<td>54</td>
<td>Kenya</td>
<td>Percent</td>
<td>[71]</td>
</tr>
<tr>
<td>37</td>
<td>533–693</td>
<td>Brazil</td>
<td>Kg ha⁻¹</td>
<td>[72]</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>Ethiopia</td>
<td>Percent</td>
<td>[70]</td>
</tr>
</tbody>
</table>
Soil nutrient conditions have a significant effect on symbiosis, because survival and growth of rhizobia and host plant affected by soil nutritional condition [74]. *Rhizobium* infection process and N₂ fixation in legumes inhibited by mineral N application [57] [Figures 1 and 3]. These two problems are because of impairment of the recognition mechanisms by nitrates, and due to diversion of photosynthates toward the assimilation of nitrates, respectively.

Although, large quantity mineral N fertilizer application inhibits N₂ fixation, low doses of <30 kg N ha⁻¹ aseral N fertilization can stimulate early growth of legumes thereby increase the overall N fixed [76]. For instance, a negative exponential relationship was observed between N₂ fixation and mineral N fertilizer rate [Figure 3] [77]. In tropical Africa, phosphorus deficiency is common place and reduces nodule formation, symbiotic N fixation in legumes, and plant growth. This is because P enhances N₂ fixation process due to its growth stimulating growth.

### 3.6.2. Climate change effects on N₂ fixation

Climate change is already causing significant impacts on water resources and environmental. Accordingly, temperature, carbon dioxide concentration, and light (UV radiation) are among the important climatic factor affecting BNF [78]. The temperature has a marked influence on the survival and persistence of rhizobial strains in soils, thereby, adversely affect enzymatic process, N₂ fixation [79]. Soil temperature also greatly influences competition for nodulation which might be due to a temperature-induced delay in nodulation or the restriction of nodules to the sub-surface region [80]. High root temperature influences rhizobial infection, N₂ fixation ability, and legume growth [81]. The effect imposed on N₂ fixation by higher temperature might be direct or indirect. This means that increased temperatures can directly decrease the nodule development [82], nodule activity [83], and hasten the senescence of nodules [84]. Even if nodules are formed, nodule might be ineffective and plants miss to accumulate N in shoots [81]. Temperature stress also affects the N₂ fixation process through its effect on nodule forming rhizobia [85], with a maximum temperature of 32–47°C for their growth [73]. Therefore, it is reasonable to look for temperature stress tolerant strains of rhizobia to assure the success of symbiosis during the climate change time. In this regard, *Bradyrhizobium* reported to perform better than *Rhizobium* species under stressed conditions [86].

One of the changes happening during the climate change times is ozone depletion resulting in an increase in UV-B (280–315 nm) radiation at the Earth’s surface [87], with negative impacts on plants and animals [88]. The depletion of stratospheric O₃ and consequent increase in the terrestrial UV-B radiation can cause deleterious effects on plants [89]. According to former researches on the UV-B effect, UV-B radiation has considerable photobiological consequences on the growth, development, and photosynthesis of plants [90]. The effect may be immediate on cowpea since the crop mainly produced in the tropical and subtropical regions, thinner ozone zone [89]. Raised UV-B radiation cause first-order effects including reductions in vegetative growth of plant and photosynthesis resulting with lower yield [91]. The sensitive nature of cowpea to UV-B radiation will aggravate the effect of the change on this crop calling for the identification and development of resistant varieties and agronomic technologies [92].

Numerous studies on CO₂ enrichment have demonstrated an increase in productivity of most C₃ crops with a doubling of [CO₂] [93]. Legumes can overcome N supply limitation in future climate change times as elevated CO₂ stimulates N₂ fixation rate in their nodule symbionts [94]. Stimulation of N₂ fixation by eCO₂ can be driven by increasing nodule size and nodule numbers or stimulating nodule activity (amount of N₂ fixed per unit of nodule mass) [93]. About 38% greater N₂ fixation under elevated CO₂, which attributed to the elevated CO₂-induced stimulation of nodule number (33%), nodule biomass (39%), and nitrogenase activity (37%) were reported elsewhere [95]. Such stimulation of N₂ fixation by elevated CO₂ can result in a more proportion of total plant N coming from symbiotically fixed N, limiting the N uptake from the soil [96]. An increase in N uptake was reported in legumes with elevated CO₂ concentration, which is linked to the increases in N fixed per legumes nodule in response to elevated CO₂. The increase in N nutrition due to increased fixed N drives an increment in leaf chlorophyll content, nodulation, and N₂ fixation, resulting in crop growth and biomass [97]. The increase in the growth performance improves the photosynthesis, leading to yield improvement under high CO₂ concentration [Table 4] [98].

![Figure 3: Mineral nitrogen (n) supply versus fixed N, Source: Salvagiotti et al. [77].](image)

A nodule may be immediate or indirect. This means that increased temperature influences rhizobial infection, N₂ fixation ability, and legume growth [81]. The effect imposed on N₂ fixation by higher temperature might be direct or indirect. This means that increased temperatures can directly decrease the nodule development [82], nodule activity [83], and hasten the senescence of nodules [84]. Even if nodules are formed, nodule might be ineffective and plants miss to accumulate N in shoots [81]. Temperature stress also affects the N₂ fixation process through its effect on nodule forming rhizobia [85], with a maximum temperature of 32–47°C for their growth [73]. Therefore, it is reasonable to look for temperature stress tolerant strains of rhizobia to assure the success of symbiosis during the climate change time. In this regard, *Bradyrhizobium* reported to perform better than *Rhizobium* species under stressed conditions [86].

### 3.6.3. Biotic factors effect on N₂ fixation

Quality of inoculants, ineffective nodules, leaf defoliation, and crop competition are among the biotic factors limiting the inoculants effectiveness [99]. The amount of N fixed by the legume – *Rhizobium* symbiosis influenced by the rhizobia used as a source of inoculation [99]. The major constraint in the N₂ fixation process attributed to the absence of the required rhizobia species. This is because the competitive ability of an inoculated *Rhizobium* strain in comparison to indigenous strains, influences the proportion of the nodules formed on a particular host. Therefore, the introduced inoculum strain should outcompete the indigenous soil bacteria [100].

When the indigenous strains occupied the root nodules rather than the inoculum strains, the inoculation fails to improve legume

### Table 4: Yield attributing parameter under sub-ambient and superambient CO₂.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>CO₂ concentration (μ mol mol⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>160</td>
</tr>
<tr>
<td>Number of branch plant¹</td>
<td>4.4</td>
</tr>
<tr>
<td>Number of pod plant¹</td>
<td>24.0</td>
</tr>
<tr>
<td>Number of seed plant¹</td>
<td>45.1</td>
</tr>
<tr>
<td>Number of seed pod¹</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Source [98]
productivity [101]. Although nodules were formed on the roots of legumes, some might not capable of fixing N\(_2\) [102]. For instance, in Australia, only 36% of the strains isolated from Acacia spp. found to significantly increase plant growth [103]. The important reasons for the formation of ineffective nodule can be (i) nodules are induced by incompatible rhizobia, (ii) nodules are induced by agrobacteria, or (iii) proper rhizobial strains are impaired in their symbiotic properties [104].

Leaf defoliation of host plant, which decreases the photosynthetic ability of legumes, is also among the limiting biotic factors. Defoliation weakens symbiotic N fixation and also leads to decaying of nodules, since the assimilation process constrained by impaired photosynthesis. In perennial legumes, nodule decay sheds a high number of rhizobia in the root zone, and as new roots develop in subsequent growth cycles, nodule formation will be improved [105]. This will be particularly a problem, for those legumes consumed as a leafy vegetable like cowpea, in Africa [105]. The nematodes can impose a competition on the rhizobia by affecting the root system of legumes [106].

3.7. Possible options to enhance N\(_2\)-fixation in legumes

BNF in legumes represents N gain and serves toward mineral N fertilizer savings in cropping systems. Although legumes reported to fix about 250 kg N per hectare, the amount of N contributed through N\(_2\) fixation varies in time and space considerably. This is because the N fixation process is influenced by many factors as detailed in the former session, this, therefore, demands for application of management options to enhance biological fixation process. Inoculating with effectiveness proven strains and microbial screening for improved strains are the common approaches reported to enhance BNF. There are collections of effective rhizobia located at centers around in the world for most, if not all, legumes used in agriculture [107]. Identify the most effective and competitive one(s) through screening of these strains for a given agro-ecosystem may be important to optimize its uses. The identification of elite strains should be followed by the application of proper inoculation procedures to assure the service inoculation can offer.

N\(_2\) fixation in legumes can also be enhanced by selecting suitable host plants, cropping systems, and agronomic practices. Plant varieties with promiscuous nodulation to obviate the need for inoculation with rhizobia have already been developed by breeding programs. The potential benefit of screening these symbioses is underscored by the fact that only about 0.5% of existing leguminous species are presently used for agricultural purposes [108]. Agronomic management practices can also minimize some of the aforementioned factors limiting BNF. Mulching, for instance, can control weeds and fluctuations of soil moisture and temperature. Liming can eliminate soil acidity, and aluminum and manganese toxicities [73]. Some bacteria are able to promote plant growth through different mechanisms and they can do so endophytically, in symbiosis or as free-living cells. Plant growth-promoting bacteria may act directly by facilitating plant nutrients acquisition or influencing plant hormone levels, or indirectly by attenuating the inhibitory effects of pathogens [73].

4. CONCLUSION AND RECOMMENDATIONS

This review demonstrated the multiple roles of cowpea and its wide-ranging interaction with climate variables. Cowpeas have shown several agronomic, environmental, and economic advantages, contributing to further improve the diets and incomes of ruler farming communities. The crop performs well and most popular in the semiarid of the tropics where other food legumes do not perform potentially. It is a resilient crop and cultivated in extreme environments, which makes the cowpea a suitable choice during climate change times. BNF provides a sustainable supply of N for the growth of plants, add organic matter to the soil, and is it environmentally and economically sustainable sources of N. For such benefits, cowpea is an excellent choice due to its high N\(_2\)-fixing potential. The major factors having a strong tie with BNF include temperature, elevated CO\(_2\), and biotic factors. Various studies on CO\(_2\) enrichment have demonstrated the N\(_2\) fixation stimulating effects of elevated CO\(_2\). In contrary, high temperature reported to cause reductions in the development and yield of crops by limiting the crop Bradyrhizobium symbiosis.

In Ethiopia, cowpea is primarily cultivated in lowland areas of the country and used as a source of food, feed, and soil fertility restoration. The leaves, pods, and seeds of cowpea are used as a source of food in Ethiopia. About 66.5% of Ethiopia’s arable land is reported to be suitable for the production of cowpea crop. However, the national average yield, annual production, and area coverage are limited to 400 kg ha\(^{-1}\), 55,600 tons, and 69,500 ha, respectively. Moreover, production and utilization of cowpea in Ethiopia are very limited compared to countries considered as major producers for cowpea. The availability of suitable arable lands and agro-ecological conditions coupled with the multiple role the crop can play calls for the expansion of cowpea production and utilization in the country. Therefore, introducing improved agronomic practices including varieties, and commercialization of inoculant technology is recommended to enhance cowpea productivity and optimize farmers benefit from the multifold purpose of cowpea.

5. AUTHORS’ CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agreed to be accountable for all aspects of the work. All the authors are eligible to be an author as per the International Committee of Medical Journal Editors (ICMJE) requirements/guidelines.

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7. CONFLICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

8. ETHICAL APPROVALS

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9. DATA AVAILABILITY

Data included in article supplementary material referenced in article.
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