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A recent report on the effect of moringa leaf (*Moringa oleifera* Lam.) as a biostimulant in the growth and physiochemical traits of agricultural crops

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Abstract

Biostimulants are natural growth enhancers that stimulate crop yield *via* enhanced nutrient uptake and efficiency, improved tolerance to biotic and abiotic stresses, and enhanced rhizospheric activities. One such biostimulant is moringa leaf extract (MLE). Moringa leaf juice contains a significant amount of zeatin. Zeatin is a cytokinins compound, which stimulate cell division, grow cell tissue, delay the process of senescence and ageing in plant tissue, and promote nutrient partitioning and uptake. A high level of zeatin makes moringa leaf extract more effective as a natural compound promoting plant tolerance under stress conditions. In this article, we suggest that the use of moringa leaf extract as a biostimulant increases the biochemical and physiological as well as the growth and yield parameters of the crops under moisture stress conditions. This updated review report includes citations from MEDLINE (PubMed), Google Scholar, Science Direct, Scopus, Scientific Information Database, SciFinder, and other well-known resources and online databases that are both relevant and recent.

1. Introduction

Since the current societal level of living has increased, it has become crucial for agriculture to provide high-quality agricultural goods. To enhance the quality of products, *Moringa oleifera* Lam. leaves extract (MLE) has been utilized as a plant growth promoter. The positive elements of MLE, which include minerals, plant hormones, secondary metabolites, amino acids, and bioactive substances, are linked to the success of the treatment (Yuniati *et al*., 2022).

Bioenhancers, or natural growth promoters, increase nutrient intake and efficiency, biotic and abiotic stress tolerance, and rhizospheric activity, all of which increase crop output. In recent years, researchers have focused a lot of emphasis on the use of biostimulants as yield boosters and growth promoters. Biostimulants boosting nutrient uptake control stress responses and enhance plant vigour and yield characteristics. Plant biostimulants are one of the methods used to produce high-quality goods in a sustainable manner. Due to the inclusion of plant growth regulators, vital nutrients, and plant protection chemicals, plant biostimulants are products made from biological components that increase plant productivity, such as yield, quality, or production efficiency (Yakhin *et al*., 2017; Bushra *et al*., 2020). These components affect how plants grow and develop by changing their metabolism, transduction, and hormonal control (Paradikovi'c *et al*., 2019). Earlier research has documented how biostimulants improve product quality both under routine and challenging circumstances (Rehman *et al*., 2018; Maach *et al*., 2020). Biostimulants are used to counteract oxidative stress and stop a drop in production and purity (Desoky *et al*., 2019; Rady *et al*., 2019). This is because biostimulants are very good antioxidants.

Natural products include seaweed extraction, protein hydrolysates, amino acids, humic acid, fulvic acid, complicated organic compounds, chitin and chitosan analogues, bacterial inoculants, biochar, and botanicals are among the most extensively used biofertilizers in farming (Duraisami *et al*., 2021; Vijai Selvaraj *et al*., 2022; Sivakumar *et al*., 2022). Extracts from *M. oleifera*, sorghum aqueous extracts, and mulberry aqueous extracts are frequently used as growth promoters when used as a germ primer agent and for foliar spraying (Nivethadevi *et al*., 2022). It has been scientifically proved that changes in metabolic processes under various growing approaches favourably affect plant growth and productivity. According to Rehman *et al.* (2014), the use of plant growth boosters along with mineral elements enhanced seedling establishment, early growth, and other parameters that affect production.

The *M. olifera* tree, also known as Mother's Closest Buddy and the Wonder tree, is a member of the Moringaceae family. There are approximately 13 different types of *M. oleifera* are the most popular. The moringa tree is found in Asia, Arabian Peninsula, Africa, and South and Central America. The tree is called the "miracle tree" because it is full of nutrients and has many chemical and therapeutic compounds that can be used in different ways (Osman and Abuhassan, 2015). It generates a lot of biomass, and its leaves are rich in secondary metabolites, vitamins, plant hormones, and minerals (Rehman *et al*., 2017; Khan *et al*., 2020). Proline, an amino acid, soluble sugar, α-tocopherol, and glutathione are among the

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strong antioxidants and osmoprotectants found in MLE (Desoky *et al*., 2019; Zaki and Rady 2015). Given this characteristic and its geographic spread, the tree has unique relevance since it grows in areas with high poverty rates and high population densities (Osman and Abohassan, 2015). The leaves extract of moringa plant is used as a crop growth and as hormone promoter (Muhamman *et al*., 2013; Amirigbal *et al*., 2014; Muhammad, 2014).

Field crop productivity has been observed to increase when MLE is exogenously given through plant leaf or seed, both under favourable and unfavourable conditions. It has great importance due to its parts (root, bark, gum, leaf, flower, fruit, seed, and seed oil), which have incredible effects on food, medication, and industrial purposes. MLE is rich in proteins, amino acids, phytohormones, including cytokinins, antioxidants (including ascorbic acid, flavonoids, polyphenolic compounds, and carotene), essential minerals (including P, Ca, Fe, K, Cr, Cu, Mg, Mn, and Zn), and amino acids (zeatin). *M. oleifera* has an extraordinarily high zeatin concentration. Zeatin controls growth and repair, preventing damage from free radicals and influencing cell division to safeguard the cells. Similar functions are performed by zeatin and other plant cytokinins in crops, animals, and humans. Plant defence against osmotic damage is dependent on antioxidants such as ascorbic acid and glutathione, which are abundant in moringa chlorophylls and other cellular elements such as natural polyphenols (Pakade *et al*., 2013).

Extracts from young *M. oleifera* may be used as an effective plant growth promoter to enhance agricultural output by 25-30% in order to meet the growing demand for food worldwide. Number of studies indicated that the development of *M. oleifera* biostimulant improve the crops growth under moisture stress. Since they have the ability to disrupt the biological equilibrium of ecosystem and render plants much more vulnerable to pests and diseases, the regular and occasionally extensive use of synthetic chemicals has been charged with having negative impacts on environmental integrity (Panayotov *et al*., 2010; Fawzy *et al*., 2012). There is a growing need for safe, ecologically sustainable, and environmentally friendly farming techniques that might generate sufficient food for the world's expanding population while maintaining the condition of the soil and enhancing both the quantity and quality of crop production (Russo *et al*., 2012). Exogenous MLE has been demonstrated to increase growth and physiological characteristics in a variety of agricultural plants, including pear (*Pyrus communis*), wheat, maize, quinona (*Chenopodium* spp.), and sorghum, as well as ameliorate abiotic challenges such as moisture stress, heat, and salt (Nawaz *et al*., 2016).

Zeatin, a substance found in moringa leaf juice and it is important phytohormone that has a significant role in the structure of proteins and oils is zeatin (Mir *et al*., 2009). Cytokinins in moringa leaf juice stimulates cell division, increases cell size, slows the ageing and senescence processes in plant tissue, and enhances nutrient partitioning and absorption (Emongor, 2002; Andrews, 2006). MLE is utilised as a biostimulant in several crops to assist the plants endure biotic and abiotic stressors (Taiz and Zieger, 2002).

In this article, the uses of MLE as a biochemical enhancer, physiological enhancer, and yield enhancer of crops have been reviewed. This beneficial impact of MLE on development and production has been seen for numerous crop varieties, including onions and kidney beans (Emongor, 2015; Mohammed *et al*., 2013), tomato (Muhamman *et al*., 2013; Mvumi *et al*., 2012; Alkinbode and Ikotun, 2008; Foidle *et al*., 2001; Abdalla, 2013). A number of species, notably mint, kale, lettuce, corn, daikon, brinjal, peppers, tomatoes, grapes, strawberries, and much more, have indeed been studied in the past to determine how MLE treatment affects their value. The findings in terms of physical, dietary, and chemical properties are generally favourable and this summary looks at recent research on how MLE can be used as a plant growth promoter to improve quality traits as well as how it works. The effect of moringa leaf extracts on the growth and physiochemical traits of plant crops are presented in Figure 1.

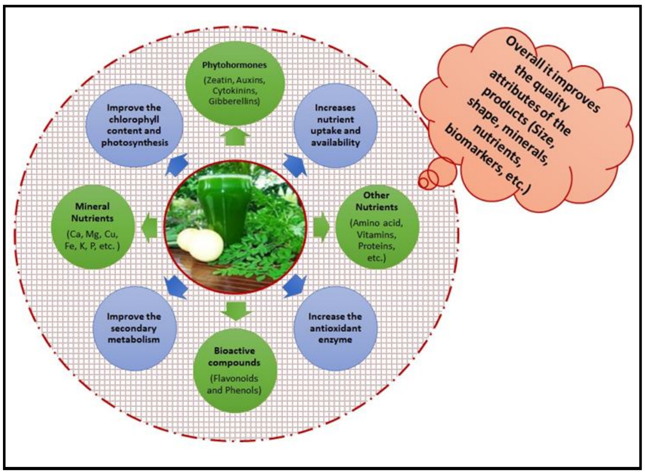

Figure 1: Effect of moringa leaf extracts on the growth and physiochemical traits of plant crops.

2. Moringa leaf extracts on the growth of diverse plant crops

2.1 Wheat

When administered alone or in conjunction with growth-promoting drugs, MLE treatment was linked to improved productivity and growth features in both regular and delayed wheat. This report was documented according to Khan *et al.* (2019). The emerging features of the wheat were enhanced by each priming technique. Increased emerging features (time to start emergence, duration to 50% emergence, average emergence period, and emergence score), in wheat versus controls may be due to improved water uptake activity, seed coat cracking, and seedling-induced enzyme activation (Anjum *et al*., 2011; Jena *et al*., 2017). Their research was in line with other findings (Farooq *et al*., 2008; Zheng *et al*., 2016) that demonstrated how seed priming improved emergence and seedling strength. For instance, MLE priming of wheat seeds significantly boosted seedling strength and emergence. This report has been documented by Afzal *et al.* (2008). The use of MLE has shown favourable synergy with various pharmacological stimulants in biochemical measures. Foidl *et al.* (2001) studied the existence of several phytochemicals and bioactive components, such as ascorbate, phenolic compounds, and zeatin, may be responsible for the improvements in biochemical markers. The foliar application of MLE raises pigment "a" and "b" levels due to boosted the crop's rate of growth as well. Overall, emergence, biochemical, growth, and yield data supported the use of MLE alone or in conjunction with pharmacological growth boosters to provide favourable outcomes. Furthermore, wheat that was planted late is a better candidate for MLE treatment. The results of this study further support the foliar application as compared to priming agents, as shown by the data given here. Nawaz *et al.*, (2016) and Rashid *et al.* (2018) have found that adding MLE to wheat raises the amount of antioxidants in the leaves and reduces the bad effects of drought and heat stress.

2.2 Rubber

Nayanakantha *et al.* (2019) reported that under less-than-ideal climatic circumstances, the exogenous application of MLE is efficient in enhancing physiochemical characteristics and development of Hevea, presumably through enhancing antioxidant levels. As a climate change mitigation indicator, the implementation of MLE, ideally 5%, may be used successfully as a cost-effective and ecologically friendly growth promoter to enhance Hevea's effectiveness under heat and drought stressful conditions. MLE includes antioxidants, amino acids, growth-promoting hormone, and macronutrient and micronutrient (Yasmeen *et al.*, 2013; Rady and Mohamed, 2015). MLE foliar sprays have indeed been demonstrated to promote agricultural crop growth by boosting the number of leaves and photosynthetic rates (Yasmeen *et al.*, 2013). This is because MLE contains minerals that make it a great foliar feed and a natural growth promoter that affects physiological processes in a good way.

2.3 Maize

Kiran Pervez *et al.* (2017) stated that under drought stress, the exogenous administration of MLE dramatically increased maize leaf soluble proteins, leaf relative water content, fresh and dry weights of the shoots and roots, as well as root area, root length, and root breadth. Drought stress caused an accumulation of cell wall-bound phenolics, which were decreased by foliar application of MLE. MLE was suggested as a possible bioregulator for enhancing maize development under drought stress. Increased meristematic activity in growth zones, which has previously been found for seaweed extracts, is likely the cause of MLE's favourable effects on maize growth (Wu and Lin, 2000; Mvumi *et al.*, 2013). The amelioration of the harm full effects of water deficit on the growth parameters of corn may be attributed to the phenolic content of MLE as well as the existence of zeatin, a naturally occurring cytokinin component (Siddhuraju and Becker, 2003; Yasmeen *et al.*, 2013; Hura *et al.*, 2013). Spraying MLE on the leaves of maize plants caused them to make more soluble proteins, which made it harder for drought stress to hurt their growth.

Ali *et al.* (2011) and Kiran Pervez *et al.* (2017) both found that putting frozen MLE on the leaves of maize plants made them less stressed by drought. Different research (Basra *et al.*, 2011) on the beneficial effects of seed priming with MLE indicated the vigour and yield of maize plants was enhanced. Rehman *et al.* (2017) worked on maize plants about the height of the plants, the number of tillers, the grain yield, and the time until the leaves turned brown were all improved.

2.4 Cereal forage

According to Abusuwar and Abohassan (2017), the greater % of moringa juice isolates considerably boosted the fodder output. Based on the results of the investigation, the MLE alone or with little dilution can promote the growth and output of cereal forages grown under harsh circumstances. Additionally, the juice from moringa leaves contains micronutrients in the ideal concentrations and ratios to aid a variety of crops in growing and producing more (Price, 2007; Muhamman *et al.*, 2013; Amirigbal *et al.*, 2014). These crops include cereals, oil crops, fibre crops, sugar crops, forages, and tuber crops.

According to Rania (2017), the effect of drought on soybean plants increased as water hold capacity decreased to 60% and 40%. Additionally, compared to untreated plants, spraying MLE alone resulted in a considerable improvement in each of the growth criteria previously mentioned, demonstrating the increased effectiveness of growth and development when MLE supplementation is present. On the other hand, foliage spraying with MLE dramatically enhanced plant development metrics and physiochemical characteristics in drought-stressed soybean plants under difficult water shortage circumstances. According to Ali *et al.* (2011), *Zea mays* plant development metrics (shoot and root lengths, fresh and dried masses of roots and shoots) were reduced considerably with rising drought conditions when compared to control crops. These findings are consistent with their findings. According to their research, MLE might activate biological chemicals that are present in plants and reduce the oxidative stress induced by stress, which would promote biochemical and physiologic components of plant development in *Glycine max* during drought circumstances. The negative consequences of water shortage stress could be reduced using MLE.

2.5 Rice

Shahbaz Khan *et al.* (2021) reported that the MLE-LF (moringa leaf extract from Faisalabad), the rice crop's panicle length, was greatly increased. Their research showed that the use of MLE greatly enhanced the physiological reactions, enzymatic activity, gas exchange characteristics, and yield of rice crops under drought stress. Chlorophyll and carotenoids, two specific plant pigments with demonstrated antioxidant capabilities, are particularly concentrated in the leaves of the moringa. Additionally, the presence of numerous macroelements in moringa leaves increases the amount of chlorophyll a and b in rice (Owusu, 2008). Khan *et al.* (2017) found that the moringa landrace from Faisalabad (MLE-LF) leaf extract had stronger biostimulant potential, which may have been brought on by the presence of more biostimulant components, compounds that encourage plant development, mineral nutrients, and antioxidants in higher quantities. According to Khan *et al.* (2021), rice plants' development, production, and functional properties as well as their capacities for gas exchange, chlorophyll content, and enzymatic reactions suffer when they are subjected to water scarcity conditions. Also, MLE from the Faisalabad landrace treatment had the strongest biostimulant effect on improved gas exchange, higher chlorophyll levels, and the most enzyme reactions in rice plants that grew both in normal conditions and when there wasn't enough water.

2.6 Chickpea

The Kabuli chickpea was grown under normal and late-sown circumstances, and the foliar application of potassium and MLE considerably enhanced the morphological, biochemical, and yield properties. Agricultural performance can be enhanced by enhancing plant development, hydration status, membrane stability, enzymatic system, and foliar spraying of MLE (Rady *et al.*, 2015). The application of potassium and MLE combination led to the greatest increases in stomatal conductance, transpiration rate, photosynthetic pigments, antioxidants (catalase, superoxide dismutase, and ascorbate peroxidase), and osmolytes (proline). The reason for the improved overall growth and production characteristics may be due to the maximum intake of nutrients and development substances that raise enzyme reactions, chlorophyll content, and numerous biological processes. Furthermore, their findings corroborated those of Chattha *et al.* (2015) and Yasmeen *et al.* (2013), who claimed that the administration of MLE resulted in an increase in seed weight and cereal output. The study of Mathew and Ahmad *et al.* (2016), who also improved agricultural output by using MLE, supports the findings of Afzal *et al.* (2012) on enhancement in the production of late seeded maize by foliar spray of 3% MLE during the root growth and booting phase. As a consequence, potassium and MLE could be combined to boost the production of Kabuli chickpeas. This report was submitted by Irshad *et al.* (2022).

According to Zaki and Rady (2015), the levels of overall chlorophyll pigments, total carotenoids, total soluble carbohydrates, free proline, and ascorbic acid may be greatly increased when MLE treatment is used as seed immersion material in conjunction with a foliar application. Additionally, it raised the amounts of N, P, K, and Ca as well as the K/Na, Ca/Na, and K^{+}Ca/Na ratios and antioxidant enzymes such as glutathione reductase, superoxide dismutase, and ascorbate peroxidase. In comparison to the control and the MLE single treatment, it also increased the production of green pods and dry seeds (seed soaking or foliar spray). Na and the catalase levels are decreased by immersing the seeds and spraying using MLE significantly improved the moisture stress development (Zaki and Rady, 2015).

2.7 Cowpea

According to Maishanu *et al.* (2017), the treatment of MLE significantly increased plant growth and seedling strength in comparison to the control treatment. They said that MLE helps cowpea grow and be more productive, and the results of the field tests showed that the more moringa was used, the more plant height, dry matter, and agricultural output went up.

2.8 Canola

According to Amirigbal *et al.* (2014), three sprays of moringa and brassica leaf extracts had a greater impact than a single treatment on the canola plant's height, branch count, pod count, seed production, and biological yield.

2.9 Rocket plant

Mashamaite *et al.* (2022) discovered that the rocket plant's cytokinin, gibberellic acid, and auxin concentrations, as well as its chlorophyll content and stomatal conductance, were all improved by the foliar spray of MLE (*Erusa vesicaria*). Abdalla, (2013) did some research on the rocket plant and found that putting MLE on its leaves increased the plant's altitude, fresh and dry weights, photosynthesis process rates, amount of both chlorophyll a and b, stomatal conductance, protein levels, ascorbic acid, and plant growth hormones like auxins, gibberellic acid, and cytokinins.

2.10 Okra

According to research with *Abelmoschus esculentu*, applying MLE enhanced the soil's organic matter, N, P, K, Ca, and Mg content as well as decreased the soil's bulk density when compared to the control group (Adekiya *et al.*, 2017). Furthermore, Alkinbode and Ikotun (2008) and Foidle *et al.* (2001) studies on moringa leaf extract increased the production of numerous crops (Alkinbode and Ikotun, 2008; Foidle *et al.*, 2001). This beneficial impact of MLE on development and production has been documented by a number of researchers, including Mvumi *et al.* (2012) and Emongor (2015) for kidney beans and onions, Mohammed *et al.* (2013) for tomatoes, Abdalla (2013) for rockets, and Mohammed *et al.* (2013) for onions.

Increasing plant's ability to withstand stress aids in preserving the quality of the cultivated product under stress (Duarte-Sierra *et al.*, 2020). Aslam *et al.* (2016) found that MLE is a significant source of naturally occurring antioxidants that enhance antioxidant components in the final product (Aslam *et al.*, 2016) and have an impact on the plant's ability to fight off oxidative stress (Hassan *et al.*, 2021). This is as a result of its unique antioxidant systems for coping with stress (Kerdsomboon *et al.*, 2016). The potential of MLE to lessen oxidative stress was linked to the preservation of the quality of fresh commodities and cut flowers. In various crops, the administration of MLE under stressful circumstances increased antioxidant enzyme functions that benefited the qualitative characteristics of innovative products (Howladar *et al.*, 2014; Ali *et al.*, 2018). It stimulates the activity of antioxidant enzymes in cut flowers, which aids in the prevention of oxidative stress and floret ageing (Hassan *et al.*, 2019). Hassan *et al.* (2020) found that the ability of MLE to reduce MDA level, which is a sign of lowering lipid peroxidation and keeping membrane integrity, was linked to longer flower life.

3. Conclusion

Based on the aforementioned observation, it is generally known that the application of MLE in agricultural plants improves the quality of agricultural products by increasing leaf area and photosynthetic rate; nutrient absorption; sink capacity; antioxidative enzymes; and secondary metabolism in plants. MLE transforms it into an excellent naturally growth-promoting material (foliar nutrients) under drought and heat stress conditions. An efficient, affordable, and environmentally friendly biostimulant for better crop performance is the MLE treatment. Other MLE application techniques, including seed treatments or soil applications, need to be investigated further. Because of this, more research and development are needed to find more ways MLE can be used as a biostimulant.

Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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