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Original Article

# Recent and historical developments in chelated fertilizers as plant nutritional sources, their usage efficiency, and application methods

## Desenvolvimentos recentes e históricos em fertilizantes quelatados como fontes nutricionais de plantas, eficiência de uso e métodos de aplicação

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**Abstract**

Chelates are nutrient-rich compounds that enhance the condition of plant tissues as micronutrients. Micronutrient deficiencies particularly iron (Fe) and zinc (Zn) leads to various problems for plant including chlorosis and necrosis etc. An adequate intake of Fe and Zn etc. is required by the human body. Biofortification of cereals with Fe and Zn is seen as a cost-effective solution to the problem of Fe and Zn deficiencies as well. In recent decades, many chelating compounds have been established and incorporated into agricultural systems. The most recent formulation involves the use of amino acids synthesized with one or more nutrient ions to improve fertilizer efficiency and better respond to environmental conservation. In addition to its primary function as a source of micronutrients, aminochelled are an active nitrogen (N) stimulant in plant nutrition, preventing the negative effects of basic N fertilizers like urea. The use of amino chelates, rather than just chemical fertilizers, has been shown to provide better production and quality as well as higher nutritional concentrations in several experiments. Furthermore, this review sheds light on various aspects of amino chelates fertilizers including types, history, and their effects on agricultural crops. In spite of amino chelates fast dominance in many countries' fertilizer countries, there is not enough scientific data and knowledge on the specific reactions of plants to biotic and abiotic stresses from amino fertilizers.

**Keywords:** amino fertilizers, micronutrient deficiency, health problems, plant growth and yield.

**Resumo**

Os quelatos são compostos ricos em nutrientes que melhoram a condição dos tecidos vegetais como micronutrientes. Deficiências de micronutrientes, particularmente ferro (Fe) e zinco (Zn), levam a vários problemas para as plantas, incluindo clorose e necrose, etc. A ingestão de uma quantidade adequada de Fe e Zn, etc., é exigida pelo corpo humano. A biofortificação de cereais com Fe e Zn também é vista como uma solução econômica para o problema das deficiências de Fe e Zn. Nas últimas décadas, muitos compostos quelantes foram estabelecidos e incorporados em sistemas agrícolas. A formulação mais recente envolve o uso de aminoácidos sintetizados com um ou mais íons nutrientes para melhorar a eficiência do fertilizante e responder melhor à conservação ambiental. Além de sua função primária como fonte de micronutrientes, os aminoquelados são um estimulante de nitrogênio (N) ativo na nutrição das plantas, evitando os efeitos negativos de fertilizantes nitrogenados básicos como a ureia. O uso de aminoquelatos, ao invés de apenas fertilizantes químicos, tem mostrado proporcionar melhor produção e qualidade, bem como maiores concentrações nutricionais em vários experimentos. Além disso, a presente revisão lança luz sobre vários aspectos dos fertilizantes aminoquelatos, incluindo tipos, história e seus efeitos nas culturas agrícolas. Apesar do domínio rápido dos aminoquelatos em muitos países de fertilizantes, não há dados científicos suficientes e conhecimento sobre as reações específicas das plantas aos estresses bióticos e abióticos dos fertilizantes amino.

**Palavras-chave:** fertilizantes amínicos, deficiência de micronutrientes, problemas de saúde, crescimento e rendimento vegetal.

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## 1. Introduction

Fertilization and herbal feeding play an inescapable role in the development and quality production of numerous agricultural and horticulture systems. Chemicals have been routinely used in agriculture for eras to recover plant nutriment output; this has elevated the possibility of significant harm to the health of plants, animals, humans, and ecosystems. Similarly, many fertilization methods have had a negative impact on soil fertility and quality for decades in the global agricultural sector (Basu et al., 2021). Routine use of chemical fertilizers, aiming at boosting production and quality, often resulted in poor soil quality and numerous environmental pollutions. Organic cultivation, on the other hand, is the best management technique in terms of food quality and the environment, as is using less or no fertilisers. In addition to their structural and catalytic functions in proteins, micronutrient metals such as manganese (Mn), iron (Fe), zinc (Zn), and copper (Cu) are necessary for healthy plant growth (Table 1). Micronutrient's deficiency leads to various problems in nutrients uptake, crop growth, yield and ultimately on ecosystem. Micronutrient deficiencies, particularly Fe deficiency, play a major role in lime-induced chlorosis. An adequate intake of iron and zinc is required by the human body. We suffer from a host of health issues when we lack them. Biofortification of cereals with iron and zinc is seen as a cost-effective solution to the problem of iron and zinc deficiencies (Gondal and Tayyiba, 2022; Gondal et al., 2021a). This affects a wide range of yield and quality metrics. When it comes to correcting micronutrient deficits, typical chemical salts with high reactivity and poor efficiency are often ineffective.

Chelates were firstly used in human and animal diets and intended to improve nutritional status and counteract shortfalls such as iron (Fe) and zinc deficits (Zn) and other micronutrients. To increase the availability of metallic ions to plants (Husnain Gondal et al., 2021b; Gondal et al., 2021c; Danish Toor et al., 2021; Sohail et al., 2021), chelation agents shield them from undesirable and inappropriate chemical reactions. For plants, the bioavailability of nutrients depends on the kind of chelating agent used. Common chelating agents include: EDTA, EDDHA, natural amino acids, organic acids, and phenolics. EDTA and EDDHA, two synthetic chelates, are needed for a well-balanced crop diet (Marschner, 2011). However, due of its destiny in agriculture and as a possible pollutant in ecosystems, its usage is not considered a sustainable practice (Souri and Yarahmadi, 2016). Amino chelates are novel fertilizer formulations that are more natural, safe, and efficient in use, as well as having no negative impacts on the environment. They are introduced as modern and semi-smart fertilizers, and they are expected to become the most common fertilizer in the future. Amino chelates come in a variety of types and brands, all of which have been promoted by farmers. Amino chelates have a number of advantages, including reducing mineral competition among cations, reducing antipathy and interference between mineral nutrients, improving environmental conservation by reducing N and metal ion pollution, increasing nutrient element bioavailability, and requiring fewer quantities because they are better absorbed and more effective. Various amino acids

**Table 1.** Average contents of micronutrients in various crops.

| Micronutrients | Crop | Average content ($mgkg^{-1}$) in plant parts | Key functions in plants |
|---|---|---|---|
| Molybdenum (Mo) | Wheat | 0.12 | Help in N uptake |
| | Rice | 0.14 | Enzyme nitrate reductase synthesis |
| | maize | 0.60 | Involved in enzymes activation |
| Copper (Cu) | Wheat | 4.2 | Enhance the plants enzymatic activities |
| | Rice | 16.85 | Required for chlorophyll contents |
| | maize | 8.7 | Help in seed production |
| Iron (Fe) | Wheat | 30 | Metabolic processes |
| | Rice | 2 | Improve microbial activation |
| | maize | 30 | Improve chlorophyll contents in plant parts |
| Manganese (Mn) | Wheat | 43.7 | Cofactor of oxygen-evolving complex |
| | Rice | 16 | Catalyze water-split reaction in photosystem II |
| | maize | 2-40 | Sustains metabolic roles in various cell compartments |
| Zinc (Zn) | Wheat | 28.48 | Involved in IAA production |
| | Rice | 4.8-4.9 | Photosynthetic activities and transportation |
| | maize | 20 | Carbohydrate, chlorophyll formation and protein |
| Boron (B) | Wheat | 0.1-0.58 | Movement of energy or sugar |
| | Rice | 0.10-0.69 | Functionality of biological membranes |
| | maize | 0.10-0.45 | Seed set and pollination |

are the primary components of these fertilisers (Figure 1), with other nutrients, particularly micronutrient metals, serving as minor components. The primary factor in their commercial manufacture is glycine, the most significant and smallest amino acid, which provides a genuine and completely chelated product with high water fascination and bioavailability levels (Souri, 2015). As a result, several industries employ glycine in their fertilizer manufacturing processes. Although amino chelates are rapidly becoming prominent in many countries, there is less study on their specific effects and lipids at the soil and plant cellular levels. Part of this could be due to their combination of multiple nutrient elements, which makes accurate scientific research and conclusions difficult due to nutrient impacts (Gondal et al., 2021c; Bakar Ijaz et al., 2021).

## 2. History

The use of chelate fertilisers is critical to the development of many crops, particularly horticultural and greenhouse plants, in modern agriculture. Even though chelating reactions were identified around 100 years ago, they were only completely realised in agriculture 50 years later. "Morgan and Drew" used the word "chelate" to describe chemicals that form metal complexes and are utilised as food additives for humans or animals. The first-time iron chelates were employed to address Fe shortage in plants was in the early 1950s. Amino acids were regarded as the best ligands for bonding to metal ions when scientists were trying to construct metal amino chelates in the 1960s. As a result, several investigations on amino chelates in human and animal nutrition have been carried out since the 1970s. Amino chelates in plant nutrition; on the other hand, have just recently become more popular. In contrast to plant science, human and animal sciences are more advanced in terms of amino chelate applications, as well as in terms of scientific knowledge and research that can be accessed via databanks. The most widely used fertilisers in many regions of the globe today are amino chelates, despite the fact that reliable evidence on their effectiveness is lacking (Shandell et al., 2021).

## 3. Types

As a Fe supplement for human and animal nutrition, Fe chelates was the first chelate to be introduced, and it is still widely used today. In the future, amino chelates of practically every cationic or anionic type of nutritional element are available in the marketplace. First, ferrous bis-glycinate was created as a food additive for humans and later for livestock. This chemical was first used in plant nutrition as an amino chelate fertiliser little over two decades ago. To put it another way, amino chelates have been used in plant science for two to three decades before they were commercially available for use in human and animal nutrition (Kim et al., 2021; Chiu et al., 2021).

## 4. Benefits of Using Amino Based Fertilizers

Amino acids are the primary element in protein production. More than 20 kinds of amino acids play a part in the biosynthesis process. Some study reveals that the amino acid is directly or indirectly able to alter the activities of plant physiology. Amino acids may be administered by spraying the leaves, and watering on land. This will promote soil microbial activity, and help the process of absorption of nutrients.

### *4.1. Environmental stress resistance*

Crop yield and quality are harmed when plants are subjected to stress conditions such as heat and low humidity or insect assault or flooding. These stress conditions may also be caused by phytotoxic chemicals. Amino acids may be applied before, during, or after the occurrence of environmental stress in order to ensure that plants' metabolic processes are not disrupted as a result of the stress. In plants, proline plays a function in stress response.

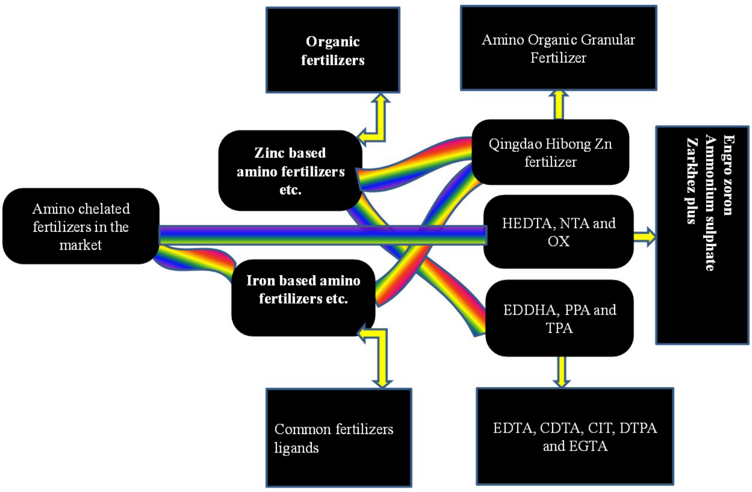


**Figure 1.** Commercial fertilizer of amino chelates available in the market. This figure has been reproduced for the present manuscript.

*4.2. Effect on photosynthesis*

For the production of carbohydrates, plants engage in photosynthesis. This is due to the low pace at which photosynthesis takes place, which results in less glucose production (photosynthate). In order for photosynthesis to take place, chlorophyll has to be present in the plant. The more chlorophyll a plant has, the more efficient it is at photosynthesis. A glutamic acid and glycine base combination is necessary for the creation of vegetative tissue and the production of chlorophyll. The chlorophyll content in the leaves will rise as a result of the application of amino acids.

*4.3. Chelation nutrient*

Chelation of micronutrients is a function of amino acids. When the chelating agent and metal ion form a chemical link, this is called chelation. Micronutrients are more easily absorbed and transported inside the plant when administered in combination with macronutrients. Chelating agents such as glycine and glutamic acid are quite efficient.

*4.4. Hormones and plant growth regulator*

These amino acids are the building blocks of several hormones and growth regulators, such as insulin and growth hormone. Auxin, cytokinins, gibberellin, and other plant hormones, as well as hormones involved in the synthesis of amino acids, all play a role in hormone development. Methionine, tryptophan, and arginine are all precursors of ethylene, auxin, and flowering hormones, respectively.

*4.5. Opening organize stomata*

Stomata play a major role in gas exchange, water balance management, and the absorption of macro and micro components in plants via transpiration. Both environmental (temperature, $CO_2$ content, light, and humidity) and internal (stomatal conductivity) elements influence stomata's opening and shutting processes (concentration of the amino acid, abscisic acid, etc.).

When there is little humidity and high temperature, the stomata shut. Stomata close, reducing photosynthesis and transpiration, which reduces the absorption of macro and micro elements. Plants' metabolic activities are disrupted, which results in a drop in crop yield. The stomata of plants would open longer as a result of the use of amino acids, resulting in an increase in plant metabolism.

*4.6. Soil microbiology balance*

It is important for soil bacteria to consume amino acids. The activity and microbial population of soil microorganisms will grow as a result of the application of amino acids into the soil. The mineralization of organic materials in the soil will improve if there is a balance and strong microbial activity in the soil. The plant's capacity to obtain nutrients is increasing as the nutrition cycle progresses. One way to improve soil quality is to maintain a healthy balance of soil microbiology.

## 5. Application Methods

In most cultivation methods, there are two basic fertilizer applications: soil and foliar. Amino chelates are very good for soil and foliar nutrition. Different fertilizers application methods have been briefly shown in Figure 2. The fertilizer application method has a considerable impact on fertilizer efficiency and environmental potential. Foliar feeding is a good technique for balanced nutrition, optimal yield, and high-quality crop development, particularly in hard weather. Foliar spray is preferred in many situations, particularly Fe and Zn in calcareous settings and salts. In extremely calcareous soils, foliar application of a synthetic chelated nutrient form has been the single approach to meet the demand for Fe and other plant micronutrients (Römheld, 2000). From an environmental standpoint, foliar fertilizer sprays are more ideal for

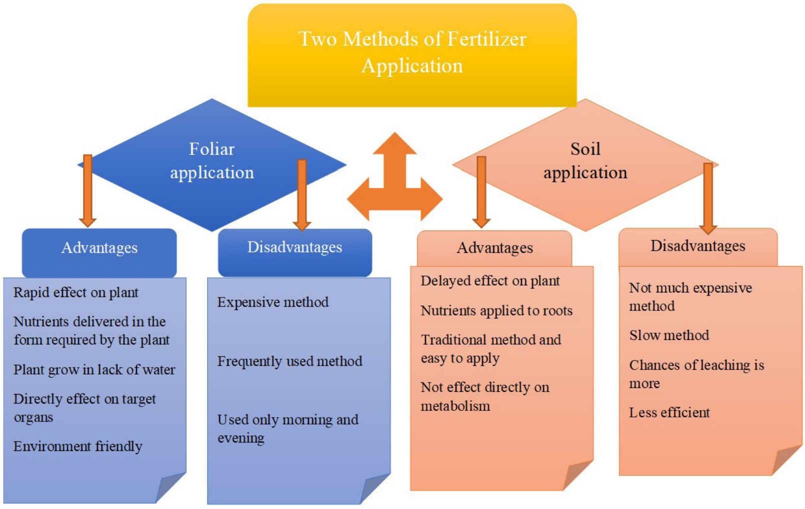


**Figure 2.** Methods of application and their merits and demerits. This figure has been reproduced for the present manuscript.

agricultural sustainability owing to lesser application but greater utilization efficiency than soil applications (Dehnavard et al., 2017). Plant tissue nutrient levels may be successfully reduced and nutrient shortages can be effectively countered by combining foliar feeding tactics with the application of amino chelates. This combination also helps plants to be more resistant to biotic and abiogenic stress (Ghasemi et al., 2014).

A superb soil fertiliser, amino chelates are also a wonderful addition. Some fragile vegetable crops, including cucumbers and garden cress, get amino chelates in the soil rather than on their leaves, resulting in phytotoxicity in the leaves (Fahimi et al., 2016). Chemical fertilisers aren't always the best option when it comes to feeding plants, but they may be used in a variety of ways. Plant roots benefit from amino chelates even if they aren't present in their composition when they are applied to soil. Amino chelates may also be employed in the fertiliser irrigation system as a deep and banded placement. Nitrogen reduced to amino acids and ammonium has been demonstrated to compete better with plant roots than nitrate. Like organic acids and humic acids, amino chelates may help correct salty and alkaline soils over time. In calcareous soils, the use of amino chelates in foliar or soil or irrigation water may meet plants' nutrient requirements, which is likely the major reason for farmers' higher tolerance in these areas.

*5.1. Utilization and usage efficiency*

The usage efficiency of fertilizer is the most important factor that has a direct impact on plant development and output, as well as indirect effects on the environment and economic difficulties. In agriculture, a number of variables interact to result in inadequate nutritional efficacy of fertilisers applied. The physiochemical characteristics of applied fertilizer, plant genotype, and environmental factors all have a role in nutrient absorption efficacy (Marschner, 2011). Chemical fertilizers in general are made up of two or three ionic forms that are susceptible to various harmful interactions in the soil solution, resulting in low absorption and efficiency. Reactions like as complex formation, fixation, precipitation and leaching all have a part in lowering fertilizer efficacy. Amino chelates improve plant bioavailability by avoiding many of these reactions when used in soil directly or foliar applications. These formulations are suited for foliar application, which results in increased absorption efficiency, and avoidance from environmental pollution. The pH of most commercial liquid amino chelates is 6-7, which increases stability, storage, and consumption. Chelating chemicals are capable of enhancing the efficiency of nitrogen consumption in agricultural systems in general. During the previous century, several chemicals and other chelating agents, notably Fe plant concentration and remedial metal nutrient shortfalls, were created, introduced, and employed in huge quantities to enhance micronutrients. Chelated minerals are typically neutral substances that have increased plant uptake and transport (via root or foliar treatments) (Marschner, 2011). As a result, amino chelates have completely different supply methods and efficacy than simple minerals like oxides, sulphate, and even trace elements based on EDTA. Because the release and transport of elements to agricultural regions is somewhat slow, simple and minerals can help to mitigate metal deficiencies. Glycine amino acid molecules are recognized by the plant and are converted into sink tissues via phloem (Fahimi et al., 2016). Metals have limited movement throughout the facility (Marschner, 2011). They are especially important for nutrients like Fe, Zn, Mn, Cu, potassium (K), and boron (B) and other elements like calcium (Ca), that show deficiency in calcareous soil in general (Souri and Yarahmadi, 2016). Several researches on amino chelates show that they are more efficient fertilizers than chemical fertilizers in terms of plant productivity (Zhou et al., 2007).

The roots may consume a significant amount of minerals like calcium and metal cations, particularly if glutamic acid and glycine are used (Mohammadi and Khoshgoftarmanesh, 2014). Chelated binding between amino acids and micronutrients in soil or nutrient solution is essential for increased efficacy in amino chelate fertilisers (Ghasemi et al., 2013). The amino acid molecule shields nutrient ions from potentially harmful reactions. Also, it may promote root cells to develop channels or triggers, which help plants, absorb nutrients more quickly and effectively. This optimizes nutrient transport and translocation by using conduits and membrane conveyors in the plant (Ghasemi et al., 2013). Plants tissues contain various amino acid transporters (Haydon and Cobbett, 2007), revealing new knowledge on the significance of plant nutritious amino chelates in the future. The oligopeptide transporter YS1 was the first metal ion ligand transporter discovered in plants, which incorporates three-, tetra-, penta- and hexapeptide-transporter members (Svennerstam et al., 2008). Plant reactions with amino chelates Fertilizers have a strong effect on plants, especially in circumstances of nutritional deficiency. Amino acids have physiological and morphological effects on plants (Sadak et al., 2015). Numerous studies have shown the importance of amino acids in plant biology and metabolism in recent years. As a result, amino chelate formulations have been more readily available in recent years. The trace minerals used in amino chelates are easily chelated and split by plant and soil systems due to their organic makeup. Hydroponics makes extensive use of amino acids, which has a significant influence on plant development and productivity (Rizwan et al., 2017).

*5.2. Plant's reaction against amino fertilizers*

Plant responses to amino chelate fertilisers vary depending on species, plant growth, and environmental circumstances. Amino chelates can also help plants adapt to a variety of abiotic stimuli, which is why amino chelates like Delfon Plus were developed (Souri and Yarahmadi, 2016). Amino chelates have been shown to improve stress tolerance in a variety of plants. The faba bean has improved its salt tolerance, tomato, wheat, strawberry and maize (Zhou et al., 2007; Sadak et al., 2015; Ghasemi et al., 2014; Rizwan et al., 2017; Abdul-Qados, 2009; 27]. Amino acid is an osmolytes involved in ion transport, stomatal opening, protein synthesis, antioxidant activity, and biomembrane integrity (Forsum et al., 2008). Micronutrient metallurgy includes elements like as Fe, Zn, Mn, and Cu, which play structural and catalytic functions in metabolism and developmental proteins. The availability of Fe is the most important micronutrient limiting factor in plant development in dry and calcareous soils. The amount of soluble and bioavailable iron in calcareous soils is quite low (Garcia et al., 2011), As a result, the yield and quality of the plants suffer. In agricultural systems, however, numerous approaches are utilized to ameliorate Fe or even other micronutrient deficits (Römheld, 2000). In order to address Fe crop needs in soil and hydroponic systems, commercial chelates have been employed for decades (Ghasemi et al., 2014). There is a lot of controversy and worry about several elements of their action; dynamics; efficiency; and safety. Amino chelates, according to current study, might be a viable alternative to conventional treatments.

### *5.3. Effects on plant growth*

Finding in-depth research on the effects of amino chelate on plant metabolism is tough to come across in the scientific literature. The utility of amino chelate compounds as efficient and appropriate fertilisers for agricultural uses was recently shown in various well-designed trials (Figure 3). Wheat cultivars sprayed with Zn-amino acid chelates, such as Zn-arginine, Zn-glycine, and Zn-histidine, had greater grain Zn, Fe, and protein contents than those sprayed with $ZnSO_4$. Foliar application of Zn fertilisers also reduced grain phytic acid by an average of 17.9 percent. It was demonstrated in another research that the zinc amino chelates synthesized, i.e. Zn-arginine, Zn-glycine and Zn-glutamine, may somewhat ameliorate damages (caused by salinity) to lettuce root and shoot development in nutrient solution, absorption by lettuce growing under salt stress. Glycine, on the other hand, outperformed the other two amino acids in this respect (Andrews et al., 2020). Zinc-glycine amino chelate increased Fe and Ca concentrations under salt stress the most, but the other two amino acids increased K concentrations in lettuce roots and shoots. Fe (II)–amino acid chelates, on the other hand, have been demonstrated to dramatically reduce the negative effects of salt stress on tomato plants. Fe (II)–amino acid chelates were used to raise shoot Fe, Zn, N, and K concentrations, which were reduced by salinity (Hamelryck, 2005). The activity of catalase (CAT) and ascorbate peroxidase (APX) in tomato leaves subjected to salt stress was boosted by the application of Fe (II)–amino acid chelates. This study shown significant improvements in plant growth parameters as plant height, flower number, flower stem length, plant fresh and dry weight, and leaf N concentration when amino chelate fertilisers were applied to marigold by foliar application (Sinclair et al., 2008). Compared to calcium chloride in nutritional solution, amino chelate fertilisers considerably enhanced the concentration of calcium in flowering stems, the quantity of flowers, and the postharvest life of Lisianthus cut flowers. The fresh weight of the shoots and the yield of the pods were both enhanced significantly by amino acid treatments in soybean Tomato plants' development and mineral concentrations in their leaves were increased by fertilization with amino acid combinations of alanine,

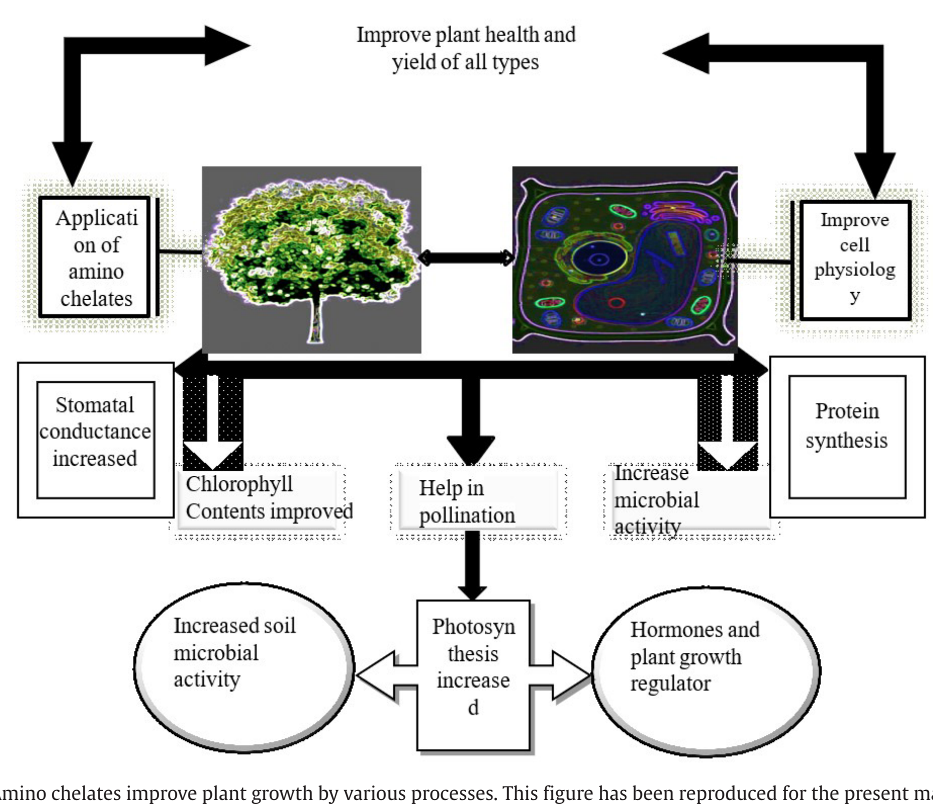


**Figure 3.** Amino chelates improve plant growth by various processes. This figure has been reproduced for the present manuscript.

serine, phenylalanine, and tyrosine in a nutrient solution. This led to greater chlorophyll levels, plant height, and lateral shoots in the plants.

*5.4. Effects on vegetative growth*

To balance plant nutrition in adverse weather conditions, several chemicals and chelating agents are used (Römheld, 2000). Amino acids and amino acids have lately been widely used to supplement plant nutrition. Because amino chelate fertilisers may best promote plant growth and production, it can play a big role in balanced nutrition (Garcia et al., 2011). Because of their nature and components, which are critical for their safe production, enhance the plant freshness and health, particularly in green vegetables. Amino chelates can promote chlorophyll synthesis and prevent degradation in leaf green, which is most significant plant freshness indicators, especially under hard environmental circumstances (Fahimi et al., 2016). Another important vegetative aspect of the leaf area is that it contributes to overall growth and biomass output, which may be significantly increased by applying amino chelated compounds in a variety of ways. Similarly, the amino chelated fertilizer benefits numerous aspects of vegetative development, such as plant height, leaves, lateral plants, and plant economic life (Amin et al., 2011). However, leaf chlorosis has been documented when amino chelates are applied foliar to specific plant species, such as cucumbers (Fahimi et al., 2016). Several studies have found that utilizing amino chelate fertilisers increased plant vegetative qualities considerably (Fahimi et al., 2016; Souri et al., 2017). Under some situations, such as salinity, the impact is very noticeable (Sadak et al., 2015) and calcareous soils (Souri et al., 2017). The Ca, K, Fe, Cu, and Mn concentrations in the leaf were determined by combining the amino acids alanine, serine, phenylalanine, and tyrosine. Amino acids were added to the nutrition solution, which improved the leaf mineral status and chlorophyll content (Garcia et al., 2011; Carillo et al., 2019). Various amino chelate components, including as nitrogen, amino acids, and one or more micronutrients, can dramatically boost chlorophyll synthesis. Amino chelates normally contain a range of nitrogen types as well as one or more micronutrients for leaf development (Khan et al., 2019; Cerdán et al., 2013). Nitrogen and several micronutrients, like as zinc, are useful in increasing leaf area (Marschner, 2011), also, chlorophyll biosynthesis. The bio stimulation of organic compounds as amino acids can also have a function in leaf shape in amino chelated formulations (Souri and Hatamian, 2019).

*5.5. Effects on quality production*

Higher crop output and quality may be predicted when amino chelate fertilisers are used, owing to greater nutrient absorption and efficiency, as well as improved vegetative growth (Marschner, 2011). Several plant yield components, including number of flowers, number of fruit and number of fruits, fruit size, number of seeds, and seed size, were boosted with the use of amino chelated fertilizer. The usage of amino chelate has been shown to extend the life of plants in ornamental plants or after harvest. In ornamental plants, amino chelates are used to extend the life of the flora on the plant and after harvest. Nutrient components such as K, B, and Zn are included in the post-harvest quality of agricultural goods. Amino chelated fertilizers may contain one or all of these elements in their composition and deliver them to plant tissues more effectively and in a balanced manner than conventional fertilizers. Furthermore, amino acids comprise one or more amino acids that are typically critical to crop quality in the postharvest period (Marschner, 2011). In this regard, proline and glycine have been well-established for improved stress response and tolerance. Aside from crop productivity, amino chelate fertilisers have a significant impact on a number of biochemical and plant quality indicators. Fruit quality has improved as a result of amino chelate fertilization, with higher levels of L-ascorbic acid, titrable acidity, total soluble substances (TSS), carotenos, and antioxidants (Keutgen and Pawelzik, 2008). In compared to artificial fertilisers, amino chelates treatment resulted in lower nitrate levels in plant tissues in vegetables; it means they have a bright future in the growth of vegetable crops, where their low nitrate content will be used to substitute chemical fertilizers. The majority of nitrogen in amino acids or ammonium is found in amino acids (Souri and Yarahmadi, 2016). The rapid and direct absorption of other nitrogen avoids nitrate accumulation. The rapid and direct absorption of other nitrogen avoids nitrate accumulation. Under a variety of environmental situations, amino chelate therapy can considerably lower oxidative damage (Rizwan et al., 2017).

The use of amino chelates boosts the activity of numerous enzymes involved in plant metabolism (Anamul Hoque et al., 2007). The usage of $FeGly_2$ and $Fe\text{-}Arg_2$ in tomato culture resulted in increased shooting activity of CAT and ascorbate peroxidase antioxidant enzymes compared to the Fe-EDTA treatment. The nutrients and nutrients of plant products may be substantially larger when using amino chelate fertilization than when using chemical fertilizer. Higher nutritional components, vitamins, and enzymes of plants have also been recorded as alternatives to traditional fertilizers (Naiji and Souri, 2018; Abou-Sreea et al., 2021). Foliar sprays of proline and tryptophan improved all growth, yield, and quality indices while lowering the proportion of fragmented fruit in pomegranates. Foliar sprays of proline and tryptophan improved all growth, yield, and quality indices while lowering the proportion of fragmented fruit in pomegranates. Tryptophan (100 ppm) was the most effective therapy (El Sayed et al., 2014).

*5.6. Effects on stresses*

An amino chelate fertiliser may help plants cope with environmental stressors such as high temperature, cold, and frost as well as biotic stressors such as disease and insect assault, which have detrimental impacts on plant quality (Figure 4) (Sharma et al., 2014; Areche et al., 2022; Jiang et al., 2022). In many temperate countries, recent climate change has resulted in significant losses of horticultural crops, mostly as a result of spring frost damage and, on occasion, early fall frost damage (Redondo-Gómez, 2013). Amino chelates may help protect plants against cold or frost stressors, since certain amino acids have been shown to have a function in this area. In general, plants that have been supplemented with amino acids have higher levels of sugar, osmolytes, and other essential ingredients, making them more resistant to freezing conditions (Römheld and Kirkby, 2010).

### *5.7. Water deficiency and amino chelates*

In dry locations, water is the primary limiting element for plant development and output. More effective approaches are urgently needed to preserve significant amounts of water consumed by crops in certain countries, which account for 90-95 percent of total water usage. One of the most successful techniques to enhance water efficiency in agricultural systems is to employ nutritional crop management (Guo et al., 2003). Nitrogen fertilization, such as ammonium, amino acids and urea, can improve plant water efficiency and boost the application and use of reduced nitrogen forms (Table 2).

Plants with a decreased shape of nitrogen, such as nitrate, require less water than plants with an oxidized form of nitrogen. Amino acids are a reduced nitric form, and plants have been shown to absorb a variety of amino acids through their roots or feed. Higher plants, on the other hand, were only activated by a few numbers of amino acids (Forsum et al., 2008). Amino acids, as opposed to ammonium, are more suited to plant general development since they may enter plant metabolic pathways (Marschner, 2011).

### *5.8. Saline conditions and amino chelates*

In arid and semi-arid locations, soil and water salinity are common, but endangering sustainable food production is a global problem. Cultivation, irrigation, and the use of chemical fertilizers have all contributed to increasing salinity in soils during the previous century (Marschner, 2011; Souri and Yarahmadi, 2016). Salinity can impact the absorption and translocation of important nutritional

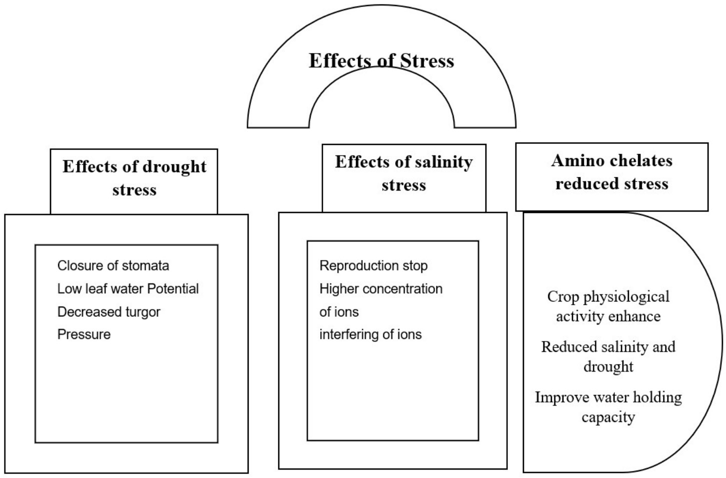


**Figure 4.** Stresses on plant and amino chelates. This figure has been reproduced for the present manuscript.

**Table 2.** Amino acids application improve the plants health by various mechanism.

| Sr. No | Micronutrient+ amino acids | Plants | Mechanism | Reference |
|---|---|---|---|---|
| 1 | Sulphur +free amino acid | Potato | Reduced glucose concentration | Muttucumaru et al. (2013) |
| 2 | FAA | Wheat | increased enzymatic and non-enzymatic antioxidant activities | Abid et la. (2018) |
| 3 | Fe+ Zn+Mn amino chelates | Soya Bean | Increased grain yield<br>Increased leaf chlorophyll concentration | Vaghar et al. (2020) |
| 4 | exogenous amino acids | Cabbage | increased photosynthesis and root fresh and dry weight | Haghighi et al. (2020) |
| 5 | Free amino acid | Rapeseed | increased in precursors pyruvate and glutamate | Good and Zaplachinski (1994) |
| 6 | Fee amino acid | Cotton | Increased pigments and total soluble sugars | Souri et al. (2009) |
| 7 | Amino acid | tomato | Increased the osmoprotectants role such as proline and glycine | Hussain et al. (2016) |

Fe: Iron; Zn: zinc; Mn: manganese; FAA: free amino acid.

elements in the roots, particularly with micronutrients like Fe and Zn. Plant root phytosiderophores are similarly inhibited by salinity. Salinity in soil or nutrient solutions is reduced by the ion activity of essential nutritional components. Plants do, however, have unique skills and processes for coping with soil salt (Marschner, 2011). One of the most important processes is the increase in amino acid synthesis in plant tissue. Amino acids can enhance the amino acid and nutritional content of plant tissue. Similarly, plants with amino chelates have the ability to to tolerate salinity by various mechanism as show in Table 3. The majority of amino chelate research has been done under salt stress. Many detrimental salinities impact on plants have been shown to be mitigated when amino chelates are used. Various components in amino acid formulas, particularly amino acid A, may alter Na and Cl intercellular distribution and reduce their influence on plant toxicity (s). A variety of amino chelated components, such as amino acids, organic acids, Zn, B, and macronutrients including K and Ca, greatly reduce lipid peroxidation and improve membrane integrity in saline plant cells.

Control tactics, such as fertilization strategies, can have a significant influence on soil salinity management. In dry and semiarid locations, amino chelates can reduce soil salinity and promote the utilization of soil water resources. Because to their low application rate, great effectiveness, and mostly foliar spray administration, amino chelates do not substantially contribute to soil salinity (Souri et al., 2017). NaCl salt's harmful effects on plants may be mitigated to a great extent if amino acids are delivered (Gondal et al., 2021e; Ghasemi et al., 2012). Polyamines and amino acids were also used to decrease the negative effects of salt on crop development. Salinity damages from amino acids and polyamines are most likely to be mitigated by maintaining a balanced intake and improving membrane integration. Amino acids, for example, contain proline. Antioxidant enzymes like catalase and peroxidase become more active in response to stress. Salt tolerance in plants may be improved by the application of amino acid supplements. Under high salinity, amino chelated and amino acids may help plants maintain hormonal balance in their tissues. Amino chelates work to reduce salt stress by increasing protein synthesis and strengthening the cell membrane (Gondal et al., 2021d). Comparatively, tomato plants' Fe (II)-amino acid chelates had larger quantities of K in their shoots than Fe-EDTA plants' (Ghasemi et al., 2014). An improved cell membrane integrity and lower root permeability to potentially damaging salts and chlorides might be to blame for this. Amino acids help in photosynthesis, plant growth, and the production of a number of plant hormones. Amino acids can help plants grow and produce more by increasing photosynthesis, mRNA transcription, and sugar and protein synthesis activation (Ghasemi et al., 2013).

### *5.9. Effects on other stresses*

Plants exposed to additional environmental challenges, such as high temperatures, colds, and frost, or biotic stresses, can benefit from amino chelate fertilisers. These conditions have a detrimental influence on plant quality, producing disease and insect infestation. Climate change has resulted in severe losses of horticulture crops in several temperate nations in recent years, particularly due to late spring frost and early fall freezing losses. Because the involvement of certain amino acids in this region has been well documented, using amino acids can help protect plants against stressors produced by cold or frost. Plant crops supplemented with amino acids are frequently higher in sugars, osmolytes, and other nutrients, making

**Table 3.** Amino chelates reduced the plant stresses by various mechanisms.

| Amino fertilizers | Crop | Salinity level | Possible mechanism | Reference |
|---|---|---|---|---|
| Iron (II) Amino Acid | Tomato | 0, 40, 80 mM | Increased APX and CAT in leaves | Ghasemi et al. (2014) |
| | | | Increased Fe, Zn, N and K contents in shoots | |
| Zinc amino acid | Lettuce | 0, 20, 40 mM | reducing (MDA) content | Mohammadi and Khoshgoftarmanesh (2014) |
| | | | Increased K in root and shoot | |
| Ferrous ion chelating ability (FICA)+ amino acid | Spinach | up to ≈8 dS·m$^{-1}$ | increased membrane permeability | Ge et al. (2009) |
| | | | strong antioxidant activity | |
| Amino acid | Strawberry | 0, 40, 80 mM | Increases asparagine glutamine and proline, | Keutgen and Pawelzik (2008) |
| Calcium sulfate + amino acid | Faba bean | 3.13 and 6.25 dS m$^{-1}$ | Contents of $K^+$, $Ca^{2+}$, $Mg^{2+}$, $K^+$: $Na^+$, and $P^{3+}$ increased | Sharma and Dietz (2006) |
| ZnSO4+amino acid | Wheat | 0.0, 3000, 6000 mg/l | Decreased ROS and increased grain protein content | Diédhiou (2006) |
| Zinc foliar spray+ amino acid | Rice | 0,10 dS m$^{-1}$ | Increased total soluble sugars increased water use efficiency and stomatal conductance | Ashraf and Foolad (2007) |

APX: Activity of ascorbate peroxide; CAT: Catalases; ROS: Reactive oxygen species.

them more resistant to freezing conditions (Souri and Yarahmadi, 2016). Because of its amino acid composition, amino chelates help reduce lipid peroxidation caused by heavy metal exposure. Meanwhile, it's been shown that amino acid treatments have no influence on Cd absorption by plant roots. Amino acids, on the other hand, can mitigate the effects of CD in plantation cells by altering the intercellular distribution and chemical forms of Cd. The Cd content of grains, shoots, and roots was lowered by Zn-lys, and the dose-additional stress of wheat was reduced linearly (Rizwan et al., 2017). The application of zn-lys to cadmium-toxic wheat plant tissues significantly increased photosynthesizers, kernels, enzymes, and Zn levels (Rizwan et al., 2017). In another study, a foliar spray of mixed amino acids reduced glyphosate damage on soybean plants. All of these metrics improved as the usage of amino acids increased, but Glyphosate reduced all photosynthetic variableness and nutritional content, as well as shoot and root parameters of soybean.

## 6. Future Prospects

Options for increasing the effectiveness of phosphate fertilization in agriculture include the use of fertilisers that contain fixation inhibitors, chemically modified and controlled-release fertilisers, Synergistics, blends, and multifunctional fertilisers. Using these fertilisers with techniques ranging from simple soil sampling and the application of limestone and gypsum to complex methods like the no-tillage system, precision agriculture, and integrated crop-livestock systems can increase their effectiveness. It's crucial to disseminate information about the advantages of these technologies and, more specifically, to learn how polymers relate to the interface of organic matter and biotechnologies. So that the results may be studied holistically rather than in isolation, the processes of evaluating their agronomic efficiency should be highly comprehensive, including research with methodologies and equipment suitable under conditions in the laboratory, greenhouses, and the field. The 4R management methods for adequate use of fertilisers (right source, right rate, right site, right time) cover phosphate fertilisers with fixation inhibitors, chemically modified and controlled release fertilisers, synergies, blends, and multifunctional fertilisers. Technological advances in fertilisers have the potential to lessen phosphorus loss in farming systems and boost crop production and quality. In order to adhere to the concepts of sustainability and the circular economy, any effort to improve fertilization efficiency must also result in increased economic profitability and reduced environmental effect. To innovate effectively, the current knowledge base on fertilisers must be translated into patents and scientific papers on technology suitable for the fertiliser business, and consumers must be given easier access to this information.

## 7. Conclusions

Numerous fertilizing procedures have harmed soil fertility and quality for decades. Regular chemical fertilisers have a poor consumption efficiency, which has resulted in lower soil quality and other environmental contaminants in previous decades in the pursuit of higher efficiency and quality. As a result, the demand for safer and more ecologically friendly formulations and procedures has long been pressing.

Amino chelates are a relatively new nutritional management strategy that may potentially benefit the environment in agriculture. It can help with plant output by supplying higher-quality components. Plants in semi-arid and dry environments are frequently subjected to a variety of environmental stressors, which can be mitigated by a variety of approaches to improve plant growth and quality. Due to reduced treatment rates and greater effectiveness, foliar amino chelate spraying can be a sustainable plant nutrition management approach under certain conditions.

They usually include more than one dietary substance, making scientific conclusions difficult to derive. Despite extensive research on amino chelate plants, many aspects of the plant's absorption, transfer, dispersion, and eventual destination remain unknown. However, new findings suggest that amino chelate fertilization may effectively contribute to and boost protein biology, amino acid enrichment, stress tolerance, photosynthesis, stomach behavior, chelating action, biosynthesis and fruit pollination, and soil fertility. They boost nutritious levels while lowering nitrate levels in leafy greens, resulting in significant improvements in human health.

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