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Roles of Foliar Fertilization on Growth, Yield and Quality of Tomato (*Solanum lycopersicum* L.) Cultivars (Review)

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Abstract: Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops, and it is a source of daily diet and cash crop in Ethiopia. However, its production is affected by nutrient application methods of which foliar fertilization is a popular method. The objective of this review paper is to synthesize literatures on the effects of foliar fertilization on growth, yield and quality of tomato cultivars. Both macro and micronutrient concentrations were evaluated. The articles addressing that foliar fertilization effectively increased growth, yield and quality of tomato cultivars. Foliar fertilization to be effective and maximize crop yield and nutrient uptake, the "right type," "right rate," "right time “and” right place" are essential. The right nutrient selection satisfies crop requirements, and the optimal rate of application avoids stunted development. Applications should be timed for optimal absorption conditions to maximize efficacy and avoid waste by focusing on absorbent plant sections. These elements work together to promote sustainable and effective crop management. Over all, the results showed that with 10,000 ppm of urea fertilization, the Marglobe tomato cultivar achieved a plant height of 155.63 cm, fruit weight of 151 g, and a yield of 63.69 t/ha. Additionally, the findings indicated 9.05 ± 0.32% total soluble solids (TSS) and a chlorophyll content of 51.6 ± 1.31 SPAD values with 100 ppm of ZnO nanoparticles. In conclusion, foliar fertilization of nutrients increased growth, yield and quality of tomato cultivars however, the result vary from cultivar to cultivar. The foliar fertilization depends on appropriate time, weather condition, genotypes of tomato, leaf area index, amount of foliar fertilization, type of nutrient, and stage of crop.

Key words: Cultivars, Concentration, Foliar fertilization, Macronutrient, Micronutrient, Tomato.

Introduction

Tomato (*Solanum lycopersicum* L) belongs to family solanaceae, is an important vegetable crop which ranks second to potatoes in the world. However, they are the first crop used for processing worldwide, where the crop demands substantial fertilizer application for high yields (Ali *et al.,* 2015). Due to increasing demand, tomatoes are one of the most important vegetable crops in the world (Bello *et al.,* 2024, Rahman *et al.,* 2023). Tomato is source of income and employment opportunity in Ethiopia (Brasesco *et al*., 2019).

According to Dixit *et al.* (2018), maintaining an appropriate amount of nutrients through soil or foliar treatment can improve tomato growth, yield and quality of tomato. Tomato growth, yield, and quality optimization are enhanced by foliar fertilizers containing micro and macronutrients (Ali *et al*., 2015), were applied on leaves to prevent deficiencies of several nutrients and improving productivity of the crops. Tomato cultivars sprayed with solution containing at 2.5 ml L^{-1} concentration of organic ca foliar fertilizer as compared to control the highest (1.59%) nitrogen, (0.41%) phosphorous, (2.03%) potassium, (0.83%) calcium, fruit firmness (3.61kg.cm^{-2}) and vitamin content (25.30 mg100ml^{-1}fresh juice) were reported (Majeed & Al-Bayat, 2023). The macro and micronutrients present in both organic and inorganic inputs, whose release is influenced by the chemical properties of the inputs as well as the organic resource quality of tomato production are crucial for tomato production. According to Dixit *et al.* (2018), it is now widely accepted that chemical fertilizers directly promote plant growth.

Foliar application of nutrients has long story and it is a popular method for encouraging crop growth; its research may have begun in the late 1940s or early 1950s (Tanou *et al*., 2017). The use of nutrients is crucial to the growth of horticulture crops, yet, as is well known, the cost of inorganic fertilizers has skyrocketed, making them unaffordable for small and marginal farmers. Applying foliar treatments or maintaining a sufficient amount of nutrients in the soil can help improve tomato quality and yield potential (Rahman *et al.,* 2023).

Tomato crops can absorb essential elements through their roots and or foliar (leaves). When nutrients are applied foliarly, the stomata, or leaf cuticle, and epidermis allow the nutrients to reach the cells. A higher leaf area index is necessary for foliar fertilization (Fageria *et al.,* 2009). It is a method of feeding plants that involves moistens their leaves with liquid fertilizer. While, transport through the stomata is usually faster, even though total absorption may be just as great through the epidermis. Foliar spraying is the process of directly applying water-soluble nutrients as a spray solution to the crop's fully spread leaves. It is a good idea to use foliar spray fertilizer to supplement plants' nutritional needs (Chethan, 2018). Time of foliar spray have on different fertilization had different Spraying twice with 0.5% FeSo4 and 1% FeSo4 produced the highest chlorophyll and (number and weight of fruit) of tomato respectively, as compared with one time spraying (Sakya & Sulandjari, 2019) different (150 ,200, 250 and 300mgL^{-1}) concentration of chitosan were sprayed at two different times of at 10 days after transplanting and then at the beginning of flowering (Reyes-Pérez *et al*., 2020).

The foliar fertilization of nutrients is mainly done on the basis of visual foliar symptoms or plant tissue tests, whereas soil applications of fertilizers are mainly done on the basis of soil tests. Hence, correct diagnosis of nutrient deficiency is vital for successful foliar fertilization (Fageria *et al*., 2009). Souri & Dehnavard (2017) reported that foliar application of ammonium shown some improvement in fruit quality parameters by spraying lower concentrations weekly rather than using daily sprays during early morning. However, there was limited information about interval and time of application of foliar fertilization on crop growth, yield and quality of tomato crops.

Foliar application increases the effectiveness of nutrient utilization in situations with limited soil fertility or environmental restrictions. Applying nutrients through the foliage is an essential crop management strategy to boost yields (Chethan, 2018). When plants are stressed, foliar feeding is a useful technique for giving them the nutrients they need. Application of ammonium inthe form of Nitrate vital than form sulfate during the production process, particularly for vegetables (Souri & Dehnavard, 2017). According to outer's foliar fertilization of ammonium sulfate shown negative effect on growth and yield of tomatoes. The goal of foliar boron spraying on summer tomatoes is to boost plant growth and yields, since Rahman *et al.* (2023) demonstrated that boron availability to the plant throughout critical growth phases eventually leads to increased plant growth and greater harvests. The foliar application of nano-nutrient solution (NNS) has been shown by Mubashir *et al.* (2023) to dramatically reduce the growth and production of numerous crops while mitigating the adverse effects of drought stress. Khan et al., (2008) report tha t in Ethiopia foliar treatments of the organic liquid fertilizers such as fulvic and humic acid are employed as an extra nutrient required for tomato production. Humic acid (HA) supplementation in tomatoes has been found to improve growth and yield metrics in Ethiopia. Foliar fertilization of crops can complement soil fertilization. If foliar fertilization is mixed with postemergence, herbicides, insecticides, or fungicides, the probability of yield response could be increased and cost of application can be reduced (Fageria *et al*., 2009).

The tomato crop is typically grown with a larger intake of fertilizers, more precision irrigation, and a higher degree of management to produce a higher yield, particularly in China, where smallholder farms predominate (Gao *et al.,* 2012). The variety and level of foliar fertilization significantly affect the yield of tomato. The highest yield (25.14 t.ha^{-1}) was achieved by Cv. Roma when 1600 ml.100 l^{-1} of foliar fertilizer was applied. Subsequently, using 800 ml 100 l^{-1} of foliar fertilizer, Cv. Roma yielded a maximum of 25.14 t ha^{-1}. This shows how the type of tomato and the amount of foliar fertilizer used are related. Cv. Money Maker generated the highest (16.73 $t.ha^{-1}$) and Cv. Super stone the lowest (16.09 $t.ha^{-1}$) in the control treatment (Ali *et al*., 2015). The growth of sustainable agriculture depends on creative foliar fertilization techniques that both increase tomato yield and guarantee farmers' income. Although the role of foliar fertilization has been widely studied worldwide, research on its influence on the nutritional status, yield, and fruit quality of tomatoes has been limited. Numerous researchers have examined the effects of foliar fertilization of both organic and inorganic fertilizers on tomato yield under various soil conditions, genotypes, crop stages, weather conditions, nutrient types, and concentrations of nutrients. This review article was examined tomato yield and quality in considerable detail; however, the summary produced inconsistent results. It proved that the tomato crop was receiving foliar fertilizer treatments.

Methods

This evaluation is based on a careful review of the information available in the global literature. This investigation's data was gathered from the electronic publications on the internet. We sought for work content using terms and keywords such as "cultivars," "growth," "yield," "quality of tomato," and "foliar fertilization, macronutrient, micronutrient.

The aim of current study is to assess role of foliar fertilization of tomato cultivars including its performance of growth, yield components, yield and quality to evaluate its high productivity. Different articles that focused on the foliar fertilization of tomato nutrients were reviewed. In this study, out of majority of literature carried out outside of Ethiopia, one articles responded foliar application of humic compounds and potassium fertilizer on tomato production in the Central Rift Valley of Ethiopia. Regarding to this review article different types of fertilizer were sprayed on tomato plant leaves for the purposes of enhancing growth, yield, and quality which shown positive and negative in tomato cultivars as assessed.

Both macro and micronutrient foliar fertilization of both inorganic and inorganic fertilizer has therefore been a technique in field and greenhouse management to optimize tomato productivity and quality. High yield tomato crops require a lot of foliar fertilizer, and high-quality tomato production depends on adequate levels of both macro and micronutrients. Nutrient foliar fertilization is essential for tomato production in terms of growth, yield, and quality. This review is a result of the world literature on the use of macro and micronutrient foliar fertilization as well as naturally occurring compounds such as chitosan foliar application by spraying on the growth, yield and quality of tomato crops. This review suggests the use of foliar fertilizers to improve tomato growth, yield and quality. However, the analysis of studies on the topic shows that it is difficult to consistently produce large yields of a particular macronutrient as well as a micronutrient on tomato cultivars due to each had own features and concentration. This is mostly because tomato fertilization, or foliar application, is influenced by the integration of macro and micronutrient on tomato cultivars and other factors assessed.

Overview of foliar fertilization

The primary applications of essential plant nutrients are on the soil and leaves of the plants to maximize economic yields. Both inorganic and organic fertilizers, have a major impact on tomato productivity (Ali *et al*., 2015). In contrast, using inorganic fertilizers over an extended period of time usually results in negative impact in soil conditions (Mooy *et al.,* 2019) due to lack of soil quality. For example, plants do not absorb a significant amount of the nutrients that are supplied to the soil. More than half of the nitrogen and 90% of the phosphorus in chemical fertilizers are lost to the environment (Simpson *et al.,* 2011). Foliar nutrients are fertilizers, but they do not replace soil fertilizers. They may be an alternative if crop demand is high and soil treatment is prohibitively expensive, time-consuming, and often ineffective.

Advantageous of foliar fertilization

Foliar fertilizers have advantages including, giving enrichment plants nutrients, micronutrients, minerals, and vitamins that improve plant health and aid in production, they are 100% water soluble and easy to apply, increase soil fertility and stimulate the production of microbial biomass, prevent the growth of pathogens in plants, stimulate healthy plants, determine the production of compounds that stimulate natural defense mechanisms of plants are preferred in many countries (El-Fouly, 2001; Mengel, 2001). Hassnain *et al*. (2020) discovered that foliar fertilization of an organic chemical called chitosan activates a protective mechanism against many plant diseases. Muhammad *et al.* (2020) stated foliar calcium concentrations (0.5%, 1%, and 1.5%) reduce the occurrence of blossom end rot problem. The other scholar supported that foliar fertilization was advantageous for N, B, and Zn six, four, and twenty times greater than soil application (Dixon, 2003). Additionally, applying macronutrient-rich foliar fertilizer can guarantee adequate yield increases while also enhancing the nutritional balance of plant tissues, improving mineral nutrition, and enabling plants to withstand stress (Shaaban & El-Fouly, 2001). However, foliar application, like soil application is also less effective when soil moisture is limited and during heavy rains macronutrient is washed away.

Foliar application reduces fertilizer application volume and associated environmental loss. For maximum effectiveness, the fertilizer source should be soluble in water and the nutrient concentration and day temperature should be at their ideal levels to prevent scorching of the leaves. According to the paper, the likelihood of a yield response could be enhanced and the application cost could be decreased if foliar fertilization is combined with post emergence herbicides, insecticides, or fungicides (Fageria *et al*., 2009).

Disadvantageous of foliar fertilization

Foliar fertilization is not an option for crops that are still in the early stages of growth and have not yet developed a substantial amount of leaf area. Foliar application is only possible with water-soluble fertilizers, which come at a little higher cost. Increased fertilizer concentrations may cause plant tissues to burn so that use lowers doses to avoid burning, which means that repeated applications are required. Additionally, foliar micronutrient treatment is one of the most crucial methods since it can better satisfy micronutrient requirements than macronutrient requirements (Mengel, 2001), this is way macronutrient are sometimes washed away by heavy rains, in addition to Fageria *et al.* (2009) indicated that in modern high-production cultivars, foliar treatments rarely exceed nutritional requirements of macronutrients. Cultivar Rio-grand and spray of calcium concentration at 1.5% respond better yield and quality tomato production than cultivar Roma, supper classic, and bambino at treatment 0.5, 1.0 and 1.5% of foliar Calcium fertilization (Muhammad *et al*., 2020).

Effect of foliar fertilization on growth and yield of tomato

Macro and micronutrients on growth and fruit quality of tomato plants

A field experiment was carried out to assess the potential effects of various macros and micro nutrients using varying concentration levels of 0.2% FeSO4 spray, 0.2% spray of Calcium nitrate, 0.1% Boron of spray, 0.2% spray of ZnSO4, a mixture of all spray, and, tap water as a control, was applied as a foliar application. Twenty-one days after transplanting, the first dose of the nutrient solution was administered foliar to each block using a knap sack sprayer. The second dose was applied twenty-one days later. According to this review, fertilizing tomato crops with foliar applications is a good method to increase their growth, flowering, and marketable output. Maximum growth, yield, and quality production were recorded by the mixture of all sprays; the availability of macronutrients (Ca) and micronutrients (boron & Zinc, Fe) as foliar feeding was thought to be one of the possible causes of the maximum number of average tomato fruits in T5 (Dixit *et al.,* 2018). As per the findings of Dixit *et al.* (2018), the mixture of FeSO4 (0.2%), CaNO3 (0.2%), B (0.1%), and ZnSO4 (0.2%) were applied two times (15 and 21days after transplanting) resulted maximum plant height, girth, number of fruits per plant, length and diameter of fruits, weight, yield.plant^{-1} and yield.ha^{-1} when compared to the other specific nutrients and control treatments.

Ammonium sulfate on growth and fruit quality of tomato plants

Foliar application of ammonium sulfate had a significant effect on tomato plant development and yield. Tomato plants were sprayed with four various ammonium sulfate concentrations: 0, 50, 100, and 200 mM once a week, and 50 mM every other day. Stem diameter, yield and TSS parameters decreased with the foliar application of ammonium sulfate, and the reductions were stronger at 200 mM once a week higher ammonium concentration as compared to control treatment (Souri & Dehnavard, 2017). When ammonium sulfate sprays were applied to tomato plants, their fruit yield was lower than that of the control group. By applying lesser quantities 50nM once a week as opposed to daily, fruit quality metrics did, however, show modest improvement (Souri & Dehnavard, 2017).

Calcium improves growth, yield and quality of tomato cultivars

In the life cycle of plants, calcium affects the uptake of nitrogen and boron, encourages the formation and growth of early roots, lowers the risk of blossom end rot, increases the production of seeds and grains, is crucial for cell at the apical growth of shoots and roots, and raises the calcium content of food and feed crops. In terms of cultivars, Riogrand cultivar as compared to Roma VF cultivar, Riogrand had the highest percentage of survival (83.33%), the tallest plants (7.1%), the most branches (33.8%), the highest total fruit yield per hectare (18.2%), and the highest total soluble solid (27.7%), along with the fewest days to blooming, days to fruit set, and fruit infestation plot^{-1}. With a minimum of one contaminated fruit plot-1, the foliar spray of 1.5% calcium enhanced the plant height, number of branches, total yield, fruit firmness, and TSS content significantly. When compared to untreated plants of cultivar Roma VF, the foliar spray of $CaCl_2$ at 1.5% decreased the intensity of fruit infection in cultivar Riogrand. According to the findings, the tomato cultivar Riogrand should receive a 1.5% calcium spray for improved development, production, quality, and reduced blossom end rot infestation in the Swat valley's agro climatic conditions (Muhammad *et al*., 2020). In line with findings, Birgin *et al.* (2021) investigated the effect of foliar calcium application in tomato under drought stress in green house conditions and found that 1%CaSo4 increased dry matter as well as chlorophyll content.

Boron on the growth and yield of summer tomato

Acrucial element for plant growth and development is boron. It is essential for the synthesis of proteins, the creation of cell walls, the metabolism of carbohydrates, and the fixation of nitrogen in the body. Plants deficient in boron may exhibit stunted growth, inadequate root formation, decreased flowering, and decreased fruit set. Summer tomato plant growth and output have been found to be significantly enhanced by foliar boron spray. The correct absorption and utilization of other nutrients, especially calcium, which is necessary for the formation of robust cell walls and healthy fruit, depend on boron. Applying foliar boron can help restore deficient soil boron levels and enhance general plant health. It is crucial to remember that applying too much boron can harm a plant's ability to develop and produce. Accordingly, appropriate treatment can support robust and fruitful tomato plants, resulting in higher yields and better fruit quality (Rahman *et al*., 2023). The 175 ppm boric acid produced the maximum yield of 22.83 tons, which was then followed by the treatments. There were recorded 22.08 tons and 22.5 tons of boric acid at 150 ppm and 125 ppm, respectively. According to Rahman *et al*. (2023), the lowest yield from no treatment was 21.33 tons. Haleema *et al.* (2018) investigated the effect of foliar application of calcium (0, 0.3%, 0.6%, and 0.9%), boron (0, 0.25%, and 0.5%), and zinc (0, 0.25%, and 0.5%) on tomato growth and fruit production. They found that the application of calcium (0.6%), boron (0.25%), and zinc (0.5%) as a foliar fertilization can be used alone or in combination to improve growth and fruit production of tomato.

Iron (Fe) on growth and yield of tomato

An investigation on how applying FeSO4 affected the quantity and weight of fruit was carried out. Up until the third harvest, the greatest quantity and weight of fruit were generated by using 1% FeSO4 sprayed twice, at 15 and 30 days after transplanting (Sakya & Sulandjari, 2019). The outcome showed that when the concentration of Fe was applied more frequently, the weight and quantity of fruit responded in a different way. Plant development is unaffected by FeSO4 concentrations and spraying frequency up to 1%. With two applications of 0.5% FeSO4, the maximum total chlorophyll content was obtained. Tomato fruit with the largest quantity and weight were those sprayed twice with 1% FeSO4. Fe helps manufacture specific hormones that promote flowering and fertilization, which made this improvement possible (Sakya & Sulandjari, 2019).

Zinc and zinc oxide nanoparticles in tomato production

For tomatoes to grow and yield properly, zinc (Zn) and zinc oxide nanoparticles (ZnO-NPs) must be applied topically. However, this has an impact on tomato leaves' absorption of N, P, K, S, Mg, B, and Zn (Ahmed *et al*., 2023). In Ahmed *et al.* (2023), zinc oxide nanoparticles (ZnO-NPs) and zinc fertilizer were applied at seven different levels across 14 treatments. These levels included Control (0), 1500 ppm ($mg.L^{-1}$) Zn nutrient, 2000 ppm ($mg.L^{-1}$) Zn nutrient, 2500 ppm ($mg.L^{-1}$) Zn nutrient, 75 ppm ($mg.L^{-1}$) ZnO nanoparticle, 100 ppm ($mg.L^{-1}$) ZnO nanoparticle, and 125 ppm ($mg.L^{-1}$) ZnO nanoparticle, in addition to two tomato varieties, MT-1 and MT-3. The outcomes also showed that, in glasshouse soil conditions, foliar spraying with 100 ppm ZnO-NPs can be recommended to increase tomato quantity and quality. According to Ahmed *et al.* (2023), applying zinc oxide nanoparticles topically proved to be more effective than applying zinc fertilizer conventionally.

Nano-nutrients on growth and biochemical of tomato under drought stress

The aim of this study was to determine whether all pots received four different levels of Nano nutrients, namely 0%, 1%, 3%, and 5%, following two weeks of drought stress treatment with a 5-day interval during the vegetative stage. The length, fresh and dry weight, number of leaves, and number of flowers of the shoots all improved after the application of 1% of the Nano nutrient solution. The highest concentrations of leaf chlorophylls, carotenoids, and total phenolics were identified, while the least amount of electrolyte leakage was noted at 3% application in comparison to the control. Furthermore, the amount of flavonoids, total soluble sugars, and leaf relative water content (RWC %) all increased with a 1% application of NNS. In tomato leaves under a drought, 5% NNS application showed greater total free amino acids with the lowest rate of lipid peroxidation (Mubashir *et al.,* 2023).

Foliar application of Organic fertilizers in tomato yield and fruit quality

Organic fertilizers are environmentally friendly and provide nutritional requirements and increase growth, yield and quality of crop (Laily *et al*., 2021). Spraying two organic fertilizers, the organic liquid NPK (18:44:0) fertilizer fortified with phosphorous included three concentrations such as (0 water only, 1, 2) ml.-1as a factor. The organic liquid calcium (160g of $Ca.L^{-1}$) was applied with three concentrations such as (0 water only, 1.25, 2.5) ml^{-1} as the other factor (Majeed & Al-Bayat, 2023).

Chitosan on improved in tomato

Chitosan is one of bio fertilizers from organic waste obtained mainly from crustaceancoticules, arthropod exoskeletons, and the shells of shrimp and crabs and bone plate of squids (Philibert *et al*., 2017; El Knidri *et al*., 2018). The molecule of chitosan triggers a defensive mechanism with the plant, which leads to the formation of physician and chemical barriers against invading different plant pathogens (Hassnain *et al*., 2020). Shrimp waste remains a useful and sustainable practice of reduction of environmentally harmful wastes' rate to increase the agricultural yields and to have effective maintenance of soil fertility due to shrimp waste is rich in nitrogen, high in phosphorous, an alkaline (Fatima *et al*., 2018). According to Fatima *et al*. (2018) the physiochemical properties of chitosan (shrimp waste) contain pH 8.55, organic matter 56%, carbon (C) is 28%, N 4.98%, P 1.42%, K 0.05%, and C/N is 5.62%.

Chitosan is biological products which promote nutrition, growth, yield and quality of tomato crops which is why it has been considered as bio stimulants (Reyes-Pérez *et al*., 2020). The number of leaves, number of flower clusters, length of fruit, duration of flowering, yield, and main biochemical and mineral components of tomato are all influenced by varying chitosan treatment techniques and quantities (Table 1). According to Parvin *et al.* (2019), chitosan can be extracted from the exoskeletons of most insects as well as marine crustaceans like prawns, shrimp, and crabs. In order to investigate the effects of various chitosan application methods and levels on the efficiency of tomato growth and yield under net houses, research has been conducted using chitosan at levels of T0= Control, T1= Soil application of chitosan (SAC) @80 ppm, T2= SAC @120 ppm, T3= Foliar spraying of chitosan (FSC) @60 ppm, T4= FSC @80 ppm, T5= FSC @100 ppm, T6= Combination of T1 and T3, T7= Combination of T1 and T4, T8=

Combination of T2 and T5, T9= Combination of T2 and T3, T10= Combination of T2 and T4, and T11= Combination of T2 and T5. Based on this investigation, the tomato with the maximum lycopene content and fruit yield was T10 (i.e., soil application of chitosan @120 ppm + foliar application of chitosan @80 ppm), and T10 (i.e., soil application of chitosan @80 ppm + foliar application of chitosan @60 ppm). The number of leaves per plant of the tomato (L. *esculentum*) increased significantly when chitosan was applied topically compared to the soil application. According to the results, applying foliar 80 parts per million chitosan at 50, 70, and 80 days after transplanting produced the highest number of leaves plant^{-1} of tomato (36.75). Furthermore, studies using various chitosan treatment techniques and concentrations revealed a significantly significant variation in the production of tomato fruits as well as biochemical markers such as vitamin C (Parvin *et al.,* 2019). Similarly, Hassnain *et al*. (2020) investigated 100mg L^{-1} chitosan foliar application of chitosan along with 6 days water interval had positive impact on growth and quality of tomato. According to Hassnain *et al.* (2020) and Lakshari *et al.* (2023), foliar application of chitosan initially increased plant height and leaf area; however, higher concentrations led to reductions. Hassnain *et al.* (2020) found that under water stress, the maximum plant height (80.74 cm) and leaf area (81.05 cm2) were achieved with 100 mg L^{-1} of chitosan; however, when the concentration increased to 150 mg L^{-1}, plant height and leaf area increased by 5.6% and 4.7%, respectively (Figures 1 and 2).

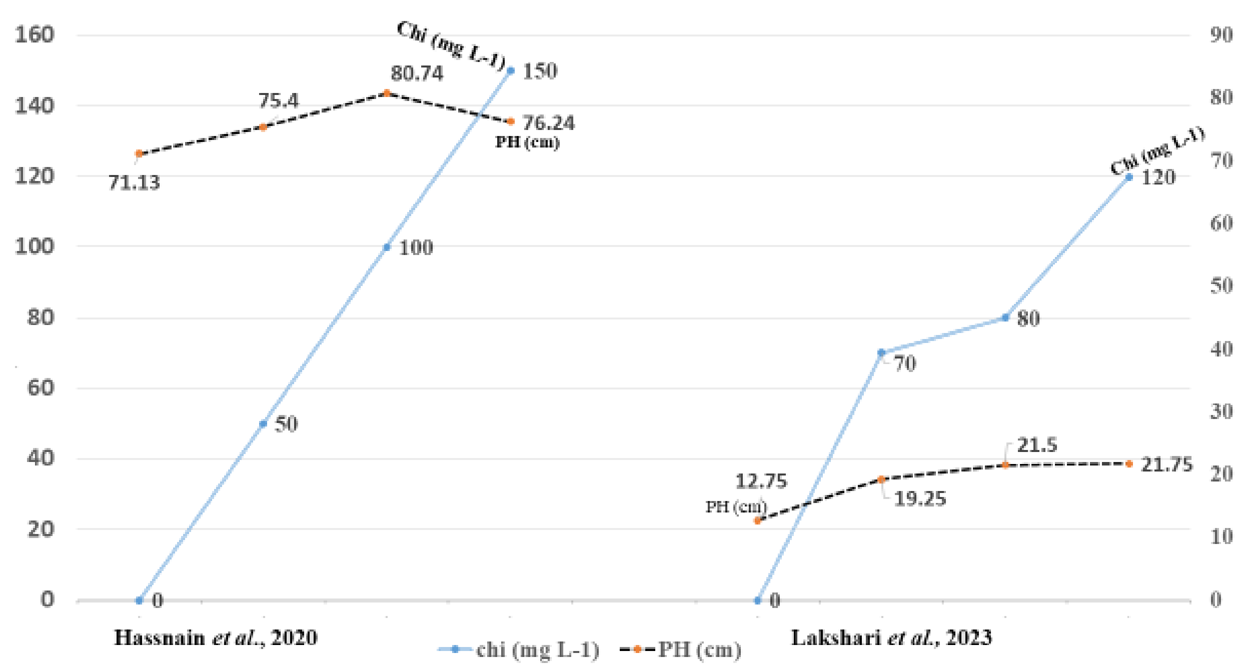


Fig. (1): Effect of chitosan on plant height (cm).

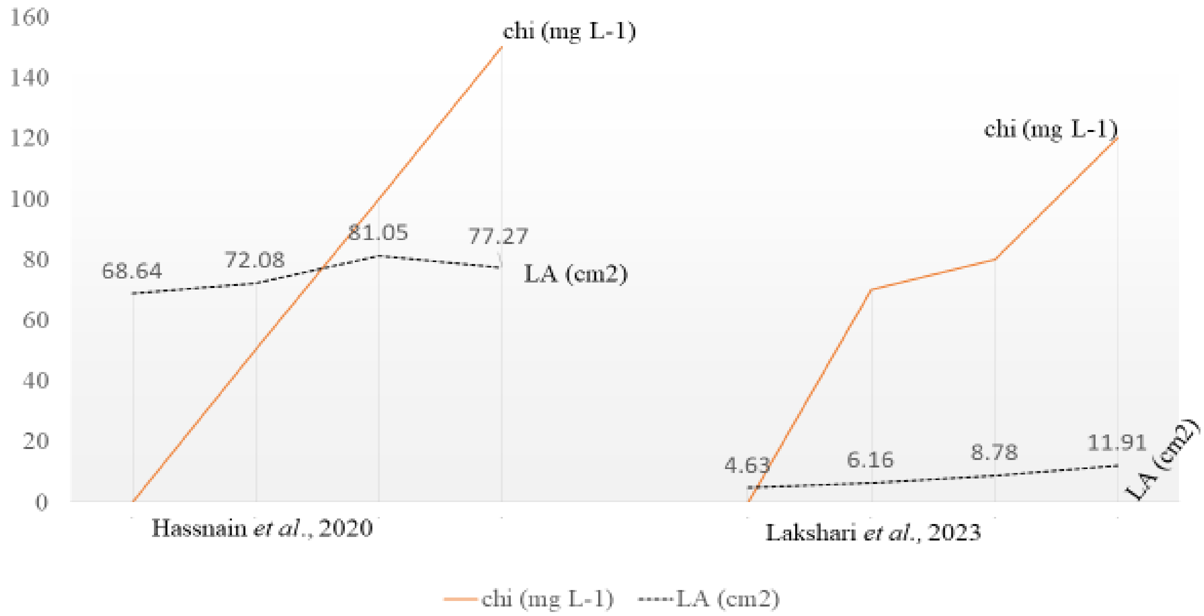
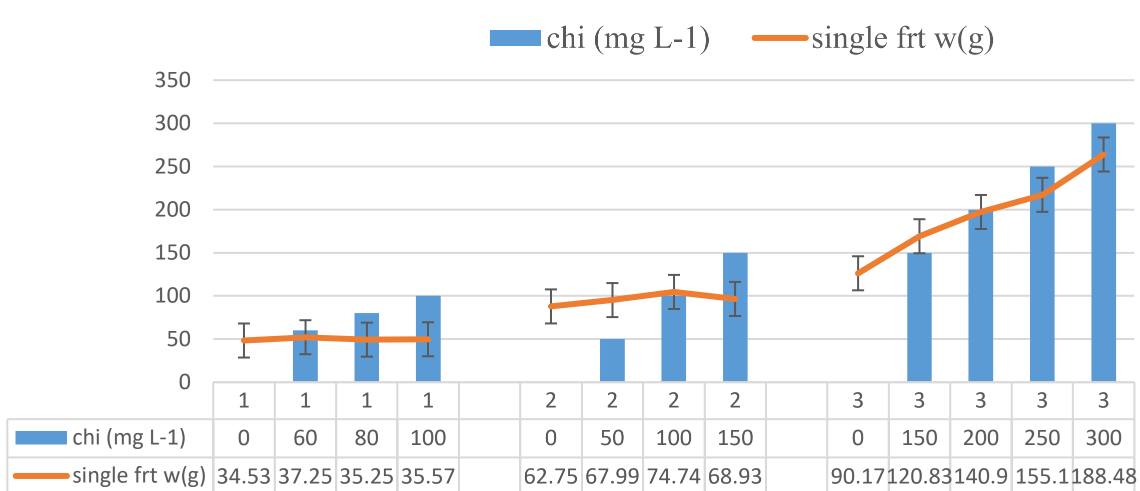


Fig. (2): Effect of chitosan on leaf area (cm^2).

The application of chitosan affects the weight of individual fruits (Figure 3). Reyes-Pérez et al. (2020) study found that plants treated with 300 mg L^{-3} of chitosan yielded significantly larger fruits (188.48 g), while untreated plants produced the smallest fruits (90.17 g). Similar results were reported by Hassnain *et al*. (2020). The foliar spray of chitosan did not significantly alter the production of individual tomato fruits, as reported by Reyes-Pérez *et al.* (2020).



Where 1=Parvin *et al.,* 2019, 2=Hassnain *et al.*, 2020 and 3=Reyes-Pérez *et al.*, 2020

Fig. (3): Effect of chitosan on single fruit weight (g).

Application of chitosan changes pH levels at various phases (Figure 4). According to Lakshari *et al.* (2023), plants treated with 120 ppm of chitosan had the greatest pH (4.3), whereas untreated plants had the lowest pH (3.2). Nevertheless, Reyes-Pérez *et al.* (2020) discovered that higher chitosan concentrations (300 mg L^{-1}) led to a lower pH in contrast to 520 mg L^{-1}, where no change in pH (4.3) was noted, or no application at all.

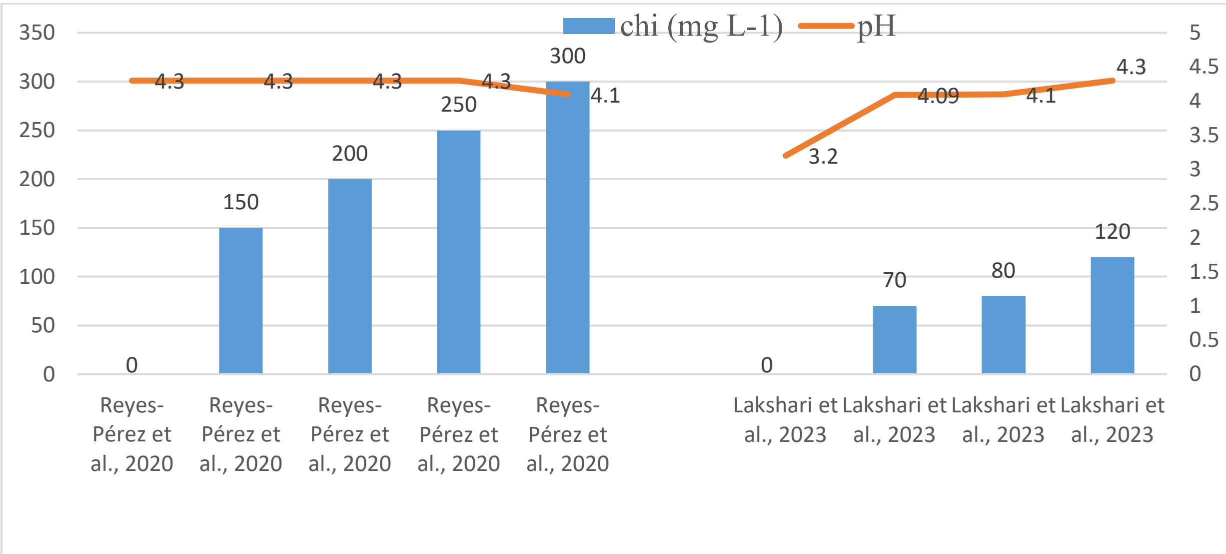


Fig. (4): Effect of chitosan on pH.

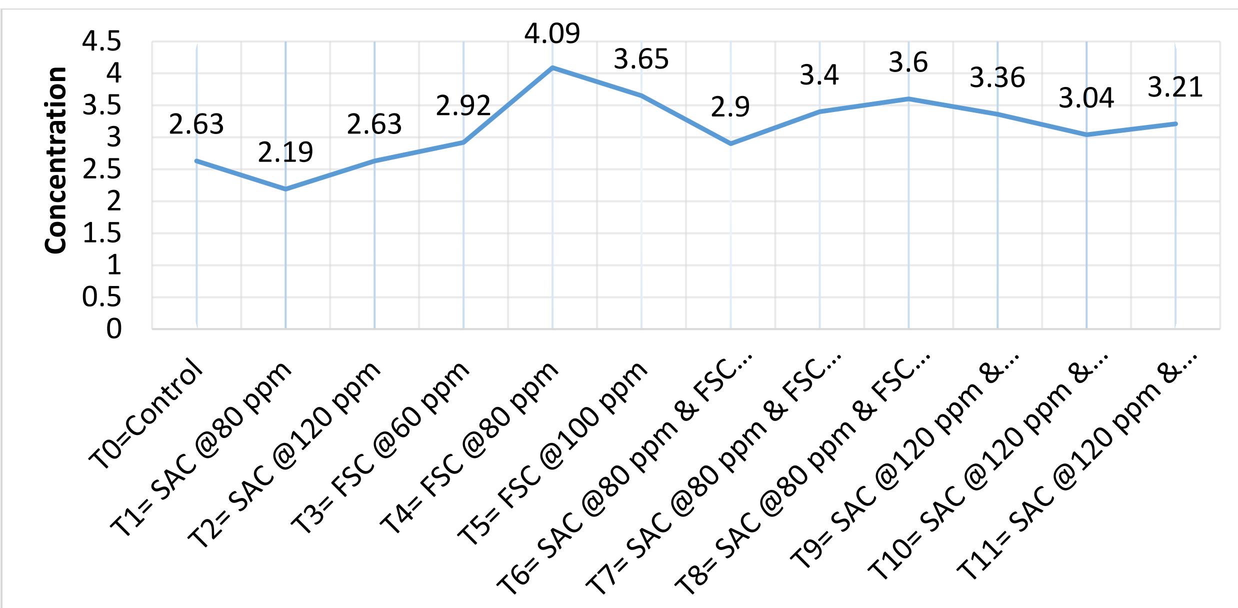


Fig. (5): Effect of chitosan on vitamin-C (mg $100g^{-1}$ sample) of tomato.

Response of tomato to foliar application of fertilizer in Ethiopia

In Ethiopia, studies were conducted on the effects of various foliar applications of nutrients. A superior mean average yield of 42.10 t ha^{-1} was discovered at site Meki, and the highest yield of 57.83 t ha^{-1} was achieved at 75% Rec. HFA. The maximum mean average yield was obtained at treatment Rec. HFA (2.5L ha^{-1}) +50% Rec. NPK (44.01t ha^{-1}). The findings showed that the foliar application of 2.5L of HFA in 1000L of water ha-1 with half recommended rates of NPK fertilizers (1.88L.ha^{-1}) + Rec. NPK yield increased and significantly influenced tomato yield (Khan *et al.,* 2008).

The Ethiopian Central Rift Valley served as the study's site. Total organic matter (45%), total humic and fulvic acids (22.5%), total nitrogen (TN) (1.76%), total phosphorus penta oxide (P2O5) (0.25%), and water soluble potassium oxides (K2O) make up Humic and Fulvic Acid (HFA), an organic liquid fertilizer. Measured amounts of fulvic acid (FA) and humic acid (HA) were combined with a single applicator nozzle in a 2-liter pressurized hand sprayer, and the mixture was sprayed until the tomato leaves were well moistened. As basal fertilizers, triple super phosphate (TSP) and murate of potash (KCl) were applied; half of the urea was administered during planting, and the other half was top-dressed one month following the tomato transplants. For two consecutive cropping seasons (2015–2017), various dosages of HFA liquid fertilizer combined with chemical fertilizer were assessed. The Central Rift Valley of Ethiopia examined the efficacy of foliar application of humic compounds, such as 22.5% total humic and fulvic acid with 7.1% water soluble potassium oxide (HFA), on tomato (*Solanum lycopersicum* L.) (chali variety) at Melkassa, Meki, and Merti. According to Khan *et al.,* (2008), Meki's tomato total yield was greatly increased when 50% HFA (1.25L ha-1) and 75% HFA (1.875L ha^{-1}) with 100% recommended rate of NPK and 100% HFA (2.5L ha-1) with 50% recommended rate of NPK were applied. These results were greater than those of Melkasa and Merti (**Figure 6**).

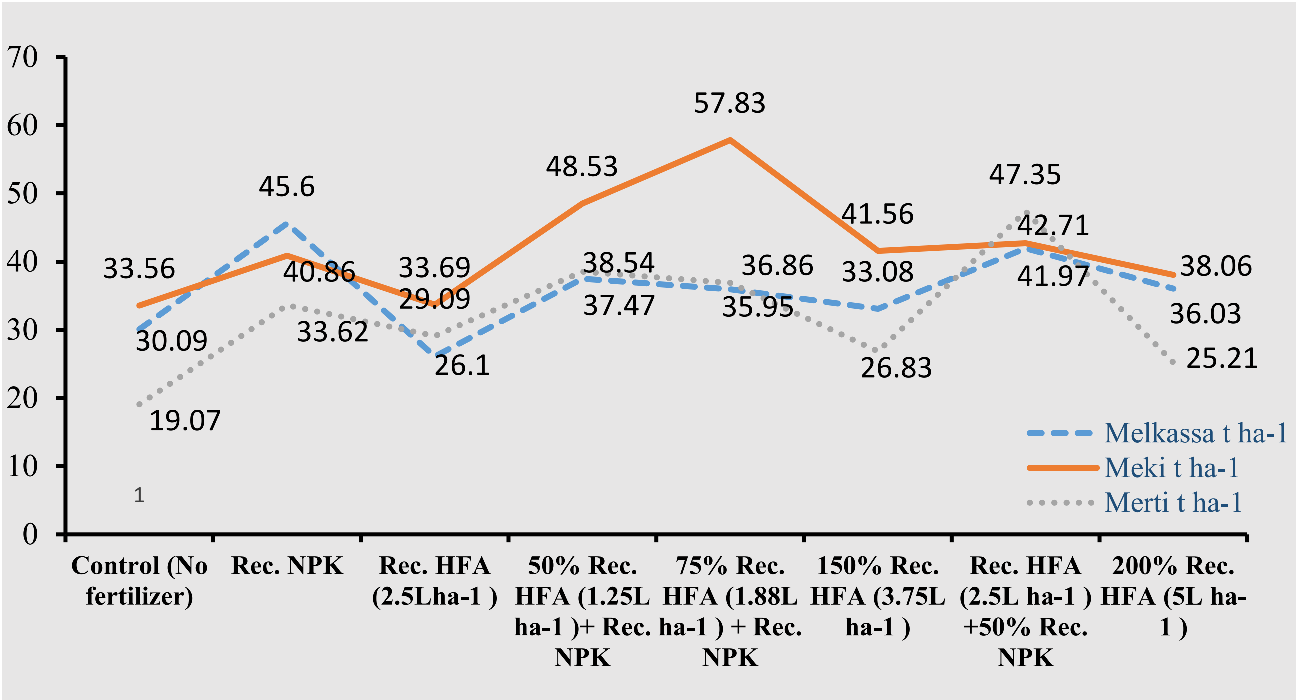


Fig. (6): Total tomato production at Melkassa, Meki, and Merti, Ethiopia, as influenced by foliar application of fulvic and humic acids with and without NPK fertilizers.

Impact of foliar application of nutrients tomato production

A balanced nutrition supply is necessary for the best possible fruit quality and output. Table (4) presents the organizational structure of the several researchers from various countries who applied varying concentrations of nutrients topically. The study found that different tomato plants respond differently to growth and yield, and that these variations were influenced by differences in nutrient kinds, concentrations, application timing, and tomato plant stage (Tables 1-6). According to Sakya & Sulandjari's (2019) foliar spray of 0.75ppm FeSO4 produced the maximum plant height of 155.63cm at 15 days compared to other treatments. Furthermore, in Ethiopia condition, at melkasa ($5L.ha^{-1}$) the application of 5.44cm 200% rr HFA resulted in the maximum fruit diameter (5.144cm) plant (Khan *et al.,* 2008). The combination of FeSO4 at 0.2% spray, Calcium nitrate at 0.2% spray, boron at 0.1% spray and ZnSO4 at 0.2% spray produced a maximum fruit yield of 56.3 t ha-1 (Dixit *et al.,* 2018). Table (5) also shows other metrics that were observed, including fruit diameter, length, number of fruits per plant, total yield, pH of fruit juice, TSS (0Brix), and leaf chlorophyll content (SPAD value).

Table (1): foliar fertilization, time of application on impact of tomato production.

Nutrients	Time of application	Impact		References
Ammonium sulfate	1^{st} and 4^{th} weeks after transplanting	Negative	reductions in growth and quality	Souri & Dehnavard, 2017
FeSO4	15 and 30 days after transplanting	Negative	Concentration up to 1% does not affect plant growth	Sakya & Sulandjari, 2019
NaCl	1 week after transplanting	Negative	Seedlings growth was significantly reduced	Souri & Tohidloo, 2019
ZnO-NPs	Seedling stage for two weeks Vegetative stage for three weeks Fruiting stage for five weeks	Positive	Improve quality and quantity of tomato varieties in glass house condition. Contribute to the highest nutrient uptake	Ahmed *et al.*, 2023
Nano-nutrient solution	Three times at 5 days interval at vegetative stage	Positive	Improve growth and biomass of tomato and ameliorate oxidative stress, enhanced membrane stability	Mubashir *et al*., 2023
CaCl2	At fruit set stage	Positive	reduced the intensity of fruit infestation, reducing blossom end rot of tomato fruit	Muhammad *et al*., 2020
ZnSO4 + Boron + Calcium nitrate + FeSO4	15 and 21 days after transplanting	Positive	Affected phonological data of early to days to first flowering and early days to first fruiting and early days to maturity Growth, and Yield significantly highest	Dixit *et al.,* 2018
Combination of NPK, humic and fulvic acid	At five growth stage (before fruit initiation to after fruit setting)	Positive	Boosting and significantly influenced yield of tomato	Khan *et al.,* 2008
FeSO4	15 and 30 days after transplanting	Positive	Spraying twice with 1%produced highest number and weight of tomato fruit. Spraying twice with 0.5% produced highest total chlorophyll content	Sakya & Sulandjari 2019
CaSo41%	40days after transplanting and application was repeated every 20 days.	Positive	Increase drought stress tolerance, and increased Mg contents of fruits and leaves.	Birgin *et al.,* 2021
Salinity with foliar Salicylic acid (SA) as pretreatment or	1 week after transplanting	Positive	Decreases leaf concentration of Na under salinity. Ameliorating effect on reduced growth traits	Souri & Tohidloo, 2019

treatment			induced by salinity was foliar pretreatment. Foliar SA pretreatment significantly increased leaf K, Ca and Fe.	
Chitosan	At different stage after transplanting	Positive	Similarly, foliar application of chitosan helps maintain water content in tomato leaves and reduce more loss of water from tomato leaves.	Hassnain *et al*., 2020

Table (2): Effects of foliar fertilization of cultivars of tomato.

Nutrients	**Cultivars**	**Result**	ref
ZnO-NPs and Zinc (Zn)	MT-1	123 ± 2.31cm plant height, 1.31 ± 0.09kg plant^{-1} of fruit, 26.1 ± 1.74 (t ha^{-1}) of total yield, 23.6 ± 0.91 (Ƞmol/m2/s) photosynthetic rate, 12.0 ± 0.51 transpiration rate (mmol/m2/s), 5.56 ± 0.21 (g/kg) sulfur content in leaves and 9.44 ± 0.39 (g/kg) sulfur content in fruit	Ahmed *et al*., 2023
	MT-3	125 ± 2.13cm plant height, 1.34 ± 0.08kg plant^{-1} of fruit, 26.7 ± 1.72 (t ha^{-1}) total fruit yield, 24.5 ± 0.96 (Ƞmol/m2/s) photosynthetic rate, 12.4 ± 0.52 transpiration rate (mmol/m2/s), 5.35 ± 0.22 (g/kg) sulfur content in leaves and 9.17 ± 0.39 (g/kg) sulfur content in fruit	
ZnSO4 + Boron + Calcium nitrate + FeSO4	Arka Rakshak	135.75cm plant height, 80.06gm of fruit weight, 4.77 kg plant^{-1} of fruit at combination of 0.2% FeSO4, 0.2% Calcium nitrate, 0.1% Boron and 0.2% ZnSO4 spray,	Dixit *et al.,* 2018
CaCl2	Riogrand	97cm of plant height, 23.77 t ha^{-1} fruit yield	Muhammad *et al*., 2020
	Bambino	95.2cm of plant height, 22.38 t ha^{-1} fruit yield	
	Roma VF	90.6cm of plant height, 19.5t ha^{-1} fruit yield	

Table (3): Effect of foliar fertilization of nutrients on plant height of tomato cultivars.

Cultivars	Nutrient	Concentration	Result	Ref.
Regosol	Fe with constant supper phosphate, urea and KCL	1%FeSO4	155.63cm	Sakya & Sulandjari, 2019
Hybrid tomato-4	Boric acid (H_3BO_3) with constant N, P, K, S, B, Zn and cow dung	175ppm	150.66 cm	Rahman *et al*. 2023
Money Maker	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	150.47cm	Ali *et al*., 2015
MT-1, MT-3	ZnO-NPs	100 ppm (mg/L)	135 ± 4.28cm	Ahmed *et al.*, 2023
Marglobe	urea	10000ppm	132.6 cm	Mondal, 2011
Bambino	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	91.66cm	Ali *et al*., 2015
Super classic	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	89.24	Ali *et al*., 2015
Super stone	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	89.19cm	Ali *et al*., 2015
Riogrande	B	0.25%	88.14cm	Haleema *et al.,* 2018
Riogrande	Ca	0.6%	88.04cm	Haleema *et al.,* 2018
Roma	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn,	1600ml/100L	87.44cm	Ali *et al*., 2015

	0.02% Mg and 0.004% Fe)			
Riogrande	Zn	0.5%	86.53cm	Haleema *et al.,* 2018

Table (4): Effect of foliar fertilization of nutrients on fruit weight of tomato cultivars.

Cultivars	**Nutrient**	**Concentration**	**Result**	**Ref.**
Marglobe	Urea	10000ppm	151gm	Mondal, 2011
Chali	Humic, fulvic acid and NPK	Rr HFA(2.5L ha^{-1})	97.2gm	Khan *et al.,* 2008
Roma	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	94.35gm	Ali *et al.*, 2015
Bambino	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	93.07gm	Ali *et al.*, 2015
Super stone	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	90.99gm	Ali *et al.*, 2015
Super classic	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	89.31gm	Ali *et al.*, 2015
Hybrid tomato-4	Boric acid (H_3BO_3) with constant N, P, K, S, B, Zn and cow dung	175ppm	83.66gm	Rahman *et al.,* 2023
Money Maker	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	73.11gm	Ali *et al.*, 2015
MT-1, MT-3	ZnO-NPs	100 ppm (mg/L)	48.1 ± 1.59gm	Ahmed *et al.*, 2023

Table (5): Effect of foliar fertilization of nutrients on yield per hectare of tomato cultivars.

Cultivars	Nutrient	Concentration	Result (t ha^{-1})	Ref.
Marglobe	urea	10000ppm	63.69	Mondal, 2011
Chali	Humic, fulvic acid and NPK	75%rec.HFA (1.88 L ha^{-1}) Rec NPK	57.83	Khan *et al.,* 2008
MT-1, MT-3	ZnO-NPs	100 ppm (mg/L)	36.9 ± 1.77	Ahmed *et al.*, 2023
Roma	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	800ml/100L	25.14	Ali *et al*., 2015
Bambino	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	24.61	Ali *et al*., 2015
Hybrid tomato-4	Boric acid (H_3BO_3) with constant N, P, K, S, B, Zn and cow dung	175ppm	22.83	Rahman *et al*. (2023)
Super stone	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1200ml/100L	22.10	Ali *et al*., 2015
Super classic	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	20.57	Ali *et al*., 2015
Money Maker	Foliar Gold (N4%, 4% P_2O_5, 3% K2O, 2.5%S, 2%B, 0.25% Mn, 0.2%Cu, 0.1% Zn, 0.02% Mg and 0.004% Fe)	1600ml/100L	19.13	Ali *et al*., 2015

Table (6): This table displays the factors foliar nutrients concentration affect quality of tomato cultivars.

NO	Parameters	perfor mance	Level of nutrient concentration	ref
	Fruit diameter	high	In melkasa (5L ha-1), 4.13 ± 0.12 @ 100 ppm ZnO nanoparticle, 5.14 cm @ 100 mM B, and 5.44 cm at 200 % rr HFA	Ahmed *et al*., 2023, Souri & Dehnavard, 2017 and Khan *et al.,* 2008
	Fruit Length	high	4.73 ± 0.14 cm@100 ppm ZnO nanoparticle, 2.41 cm, 5.66 cm at a combination of 0.2% $ZnSO_4$ spray, 0.2% calcium nitrate spray, 0.1% boron spray, and 0.2% $FeSO_4$ spray	Ahmed *et al*., 2023, Dixit *et al.,* 2018
	No of fruits per plant	high	38.4 a +/- 1.40 @ 100 ppm ZnO nanoparticle, 65.31 @ 0.2% spray calcium nitrate, 2.7 @ 1% $FeSO_4$	Ahmed *et al*., 2023, Dixit *et al.,* 2018, Sakya & Sulandjari, 2019
	Fruit juice pH	high	4.47@50mM	Souri & Dehnavard, 2017
	TSS (0Brix)	high	9.05 ± 0.32@100 ppm (mg/L) ZnO nanoparticle	Ahmed *et al*., 2023
	Chlorophyll Content in Leaf (SPAD value)	high	51.6 ± 1.31 @ 100 ppm ZnO nanoparticle and 39.3 @ 50mMA	Ahmed *et al*., 2023, Souri & Dehnavard, 2017

Conclusion

In summary, several researchers investigated that foliar fertilization improves the growth, productivity, and quality of tomato cultivars. The findings shows that foliar application of supplementary micronutrient is one of the most crucial methods since it can better satisfy micronutrient requirements than macronutrient requirements, this is way macronutrient are sometimes washed away by heavy rains, in addition to modern high-yielding cultivars rarely require foliar application to achieve their nutritional requirements. The effectiveness of foliar fertilization depends on several factors, such as timing, weather, tomato genotype, and amount sprayed. Further investigation is needed on nutrient type, crop stage, application interval, and time for better results.

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Authors who contributed scientific information to this study

Contribution of authors

All authors gathered various articles, analyzed the data, wrote, initiated, designed, edited the manuscript, reviewed and approved the final version.

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Conflict of Interest

The authors declare that they have no competing of interest.

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تقييم دور التسميد الورقي في نمو وحاصل ونوعية أصناف الطماطة (*Solanum lycopersicum* .L) (مقالة)

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[2]قسم علوم النبات، كلية الزراعة، جامعة ولايتا سودو، ولايتا سودو، إثيوبيا

تعتبر الطماطة (.*Solanum lycopersicum* L) من أهم محاصيل الخضروات، وهي مصدر مهم للنظام الغذائي اليومي والمحاصيل الاقتصادية في إثيوبيا. ومع ذلك، فإن إنتاجها يتأثر بطرق المعاملة بالمغذيات التي يعتبر التسميد الورقي من الطرق الشائعة فيها. تهدف الدراسة الحالية هو تجميع المصادر المتعلقة بتأثيرات التسميد الورقي على نمو وإنتاجية وجودة أصناف الطماطم، تم تقييم كل من تركيزات المغذيات الدقيقة والكبيرة، وقد تتناولت الدراسات السابقة تاثير التسميد الورقي بزيادة نمو وإنتاجية وجودة أصناف الطماطم، لكي يكون التسميد الورقي فعالاً ويحقق أقصى قدر من إنتاجية المحاصيل وامتصاص العناصر الغذائية، فإن "الصنف المستخدم " و"التراكيز " و"الوقت المناسب" و"المكان المناسب" ضروريا في الاختيار الصحيح للمغذيات وتلبية متطلبات الانتاج، كما أن التركيز المثالي للمعاملة يزيد من النمو، ويجب أن يتم توقيت المعاملات وفقًا لظروف الامتصاص المثالية لتحقيق أقصى قدر من الفعالية وتجنب الهدر من خلال التركيز على اجزاء النبات الممتصة، اذ تعمل هذه العناصر معًا لتعزيز الإدارة المستدامة والفعالة للإنتاج وبشكل عام، فقد أظهرت النتائج التركيز 10000 جزء في المليون من اليوريا افضل النتائج ، سجل صنف طماطم مارجلوب ارتفاع النبات 155.63 سم، ووزن الثمرة 151 غم ، وإنتاجية 63.69 طن هكتار$^{-1}$. بالإضافة إلى ذلك، بينت النتائج إلى وجود 9.05 ± 0.32% من إجمالي المواد الصلبة القابلة للذوبان (TSS) ومحتوى الكلوروفيل 51.6 ± 1.31 قيم SPAD عند المعاملة بالتركيز 100 جزء في المليون من جسيمات أكسيد الزنك النانوية. نستنتج من ذلك أن التسميد الورقي بالعناصر الغذائية أدى إلى زيادة نمو وإنتاجية وجودة أصناف الطماطة إلا أن النتيجة تختلف من صنف إلى اخر، اذ يعتمد التسميد الورقي على الوقت المناسب، حالة الطقس، التباين الوراثي لأصناف الطماطة، المساحة الورقية، التركيز المستخدم من السماد الورقي، نوع المادة المغذية، ومرحلة النضج.

الكلمات المفتاحية: الأصناف، التركيز، التسميد الورقي، العناصر الكبرى والصغرى، الطماطة .