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# Monosodium Glutamate Enhances Vegetative Growth and Grain Yield of Sorghum (*Sorghum bicolor* L. Moench)

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**Abstract**

Sorghum [*Sorghum bicolor* (L.) Moench] is a cereal plant that can be cultivated as a food crop and can serve as a model plant in horticultural cultivation. Monosodium glutamate (MSG) has potential for use in optimizing crop productivity by regulating ions in plants. The research aimed to determine the effect of adding MSG on the growth and productivity of sorghum plants. This research was conducted with a single factor, which is MSG dose with 4 treatments: 0 g, 3 g, 6 g, and 9 g per plant, using a completely randomized design. Research parameters include vegetative growth, such as number of leaves, leaf area, plant height, pigment content, fresh weight, dry weight; and plant productivity, such as flowering time, harvest time, wet weight of seeds, dry weight of seeds, and weight of 100 seeds. Data was analyzed by ANOVA and DMRT. The results showed that MSG treatment with doses of 3, 6, and 9 g per plant increased plant vegetative growth by increasing the pigment content, leaf number, leaf area, plant height, crown fresh weight, shoot dry weight, root fresh weight, and root dry weight. MSG treatments at doses of 3, 6, and 9 g per plant increased plant productivity by accelerating flowering and harvesting times as well as increasing seed weight and number. MSG dose of 9 g per plant resulted in the highest growth and productivity of sorghum plants. Thus, MSG can be applied to horticultural crops to increase their productivity by paying attention to the dosage used.

**Keywords:** growth; monosodium glutamate; productivity; sorghum.

## INTRODUCTION

Horticultural crop productivity faces numerous challenges that impact both yield and product quality. These challenges are diverse, involving biotic and abiotic stresses, technological limitations, and socio-economic factors (Reddy et al., 2024; Pal et al., 2024; Sashika et al., 2024). Horticultural crops, which include a wide variety of fruits, vegetables, and ornamental plants, often require significant time to grow due to factors such as environmental conditions, crop type, and cultivation practices (Sharma et al., 2022; Al-Dairi et al., 2018). Addressing these issues requires a comprehensive approach that integrates advanced technology, innovative agricultural practices, and strategic policy interventions. One step that can be taken is to use model plants to determine improvement strategies (Ahmed et al., 2024).

Sorghum is a versatile and fast-growing plant that is relatively easy to cultivate. Its developmental plasticity also allows sorghum to adapt to a wide range of environmental conditions. Those characteristics make sorghum a highly relevant and promising model plant in the context of horticulture, particularly in agronomic research, plant physiology, and the development of adaptive food crops (Bhat et al., 2020; Ochilovna, 2021). Sorghum is a cereal crop that is high in fiber and minerals, with low gluten content and a low glycemic index (Kumari *et al*., 2013; Sungkono *et al*., 2009). Research by de Sousa *et al.* (2019) showed that *S. bicolor* flour extract contains high levels of dietary fiber and phenolic compounds that can improve gut dysbiosis, inflammation, and oxidative stress. Consumption of sorghum-based products in overweight men can increase carbohydrate and dietary fiber intake and reduce body fat mass compared to wheat consumption (Anunciação *et al.,* 2019). Sorghum is one of the 26 priority crops under the Directorate General of Food Crops based on Ministry of Agriculture Decision No. 104 of 2020.

Monosodium glutamate (MSG) is a food flavoring agent. The composition of MSG is 78% glutamate, 12% sodium, and 10% water (Wijayasekara & Wansapala, 2017). When dissolved in water, monosodium glutamate undergoes ionization into sodium and glutamic acid (Airaodion, 2019). Glutamate can be directly absorbed by roots through the Glu transporter, then transported to tissues or organs via xylem and phloem (Qiu *et al*., 2020). Glutamate is an amino acid that plays a role as a nitrogen donor in plants (Walker & Donk, 2016).

Glutamate can be synthesized through glutamate synthase (GS) or glutamate dehydrogenase (GDH) (Seifi *et al.*, 2013). Glutamic acid can play a substantial role as a starter for proline biosynthesis, which is a cyclic amino acid that accumulates under various environmental stresses (Kan *et al.,* 2017). Glutamate is involved in the synthesis of *5-aminolevulinic acid* (ALA) in chlorophyll formation (Zhao *et al*., 2020), a precursor of the hormone gibberellin (Gupta & Chakrabarty, 2013), and regulates plant signaling and metabolism (Kan *et al.*, 2017). Sodium in plants can replace potassium (K) in maintaining turgor pressure (Wakeel *et al.*, 2011).

In $C_4$ plants, sodium ($Na^+$) plays a role in promoting the uptake of pyruvate into chloroplasts using the $Na^+$-pyruvate transporter (Furumoto *et al.,* 2011). $Na^+$ ions are required for the conversion of pyruvate to PEP (Kronzucker *et al.*, 2013). $Na^+$ uptake can aid in the phytoremediation of moderately saline soils. Additionally, the presence of Na+ in growth media has been shown to enhance the growth of *Atriplex* sp. and several other $C_4$ species (Maathuis, 2014). In hydroponic systems, gradual $Na^+$ accumulation can enable melons (*Cucumis melo* L.) to adjust their physiological mechanisms, maintaining growth and yield without compromising fruit quality (Neocleous et al., 2017). $Na^+$ plays diverse roles in tomato (*Lycopersicon esculentum* Miller) growth, especially under potassium ($K^+$) deficiency and salt stress conditions. $Na^+$ can replace $K^+$ in certain physiological processes, affecting growth and stress response in tomato plants. This dual role of $Na^+$ is mediated through various transport systems and regulatory pathways to maintain ion homeostasis and enhance stress tolerance (Amo et al., 2024).

Monosodium glutamate (MSG) can enhance growth and productivity in some plants. Research by Septiyana *et al.* (2019) showed that MSG at a dose of 3 g per plant increased plant height, fresh weight, dry weight, leaf area, number of flowers, number of fruits, fruit size, and flower-to-fruit conversion rate in okra (*Abelmoschus esculentus* L. Moench). The study by Awang *et al.* (2020) showed that the application of MSG at 2 and 2.5 g/l increased plant height and the number of leaves in *Solanum melongena*. *S. melongena* is an important vegetable crop grown in tropical and subtropical regions around the world, exhibiting great diversity (Singh et al., 2024). This research aimed at improving sorghum growth and productivity, such as this study on the application of MSG, which has a potentially significant impact on national food security and economic development in the horticulture sector.

## MATERIALS AND METHODS

### Study area

The research was conducted at the Experimental Garden and Laboratory of Plant Structure and Function, Biology Study Program, Department of Biology, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia.

### Tools and materials

The main materials used were sweet sorghum seeds of the super 2 variety (*Sorghum bicolor* (L.) Moench) from the sorghum observer group and MSG from the Ajinomoto brand. The main tools used were digital scales, an oven, and a UV spectrophotometer.

### Procedures

*Seed and planting medium preparation*

Seed selection was carried out by soaking the seeds in water. The seeds that sank were used. The sorghum seeds were sown in 40x40 cm polybags containing a growing medium mixture of soil, manure, and rice husks in a ratio of 3:2:1. Seedling selection was carried out after the sorghum plants were 7 days old after planting. Seedlings are selected based on plant height uniformity and number of leaves, followed by acclimatization for 7 days to allow sorghum plants to adapt.

*Treatment and maintenance*

Treatment is carried out when plants are 14 days old after planting. The MSG dosage used is 0 g, 3 g, 6 g, and 9 g per plant. The treatment was applied once a week until the end of the vegetative phase by sprinkling MSG around the root zone and then watering with 500 ml of water. Plant maintenance consisted of watering each plant with the same volume of water and controlling pests and diseases.

*Harvesting and measurement of parameters*

Harvesting and measurement of vegetative organ parameters were conducted at the end of the vegetative growth phase, 56 days after planting, marked by the appearance of the flag leaf. Sorghum seeds were harvested when they showed optimal maturity, characterized by plump and firm seeds, red color, and yellowing of the lower leaves (Rifa et al., 2015). Sorghum harvesting is done in the morning at two-day intervals. Vegetative growth parameters include the number of leaves, leaf area, plant height, pigment content, fresh weight, and dry weight of the plant. Plant productivity parameters include flowering time, harvest time, fresh seed weight, dry seed weight, and weight of 100 seeds.

### Data analysis

Data were analyzed using ANOVA with a confidence level of 95%, followed by Duncan's Multiple Range Test (DMRT).

## RESULTS AND DISCUSSION

### Leaf Pigment Content

The results of the study indicate that MSG treatment at doses of 3, 6, and 9 g per plant increased the content of

chlorophyll a and chlorophyll b, but had no significant effect on the carotenoid content of sorghum leaves. MSG treatment at 3 g per plant decreased chlorophyll a content compared to the control, while doses of 6 and 9 g per plant increased chlorophyll a. Treatments of 3, 6, and 9 g/plant increased chlorophyll b content (Table 1).

**Table 1.** Chlorophyll a content (µg/g), chlorophyll b content (µg/g), and carotenoid content (µg/g) of sorghum leaves at the end of the vegetative observation period with different MSG dose treatments

| Parameter | MSG dosage (g per plant) | | | |
|---|---|---|---|---|
| | 0 | 3 | 6 | 9 |
| Chlorophyll a (µg/g) | 1092,60$^{c}$ | 888,40$^{d}$ | 1820,80$^{b}$ | 1986,80$^{a}$ |
| Chlorophyll b (µg/g) | 408,60$^{c}$ | 654,60$^{b}$ | 1099,40$^{b}$ | 1676,80$^{a}$ |
| Carotenoid (µg/g) | 127,60$^{a}$ | 109,60$^{a}$ | 127,20$^{a}$ | 145,80$^{a}$ |

Note: Numbers followed by the same letter in the same row indicate no significant difference based on the DMRT test α = 0.05

## Vegetative Growth

The results of the ANOVA analysis indicate that monosodium glutamate (MSG) enhances the vegetative growth of sorghum plants, as evidenced by the parameters of leaf number, leaf area, plant height, fresh weight of the shoot, dry weight of the shoot, fresh weight of the roots, and dry weight of the roots of sorghum (Table 2).

**Table 2.** Number of leaves, leaf area ($cm^2$), plant height (cm), fresh weight of canopy (g), dry weight of canopy (g), fresh weight of roots (g), and dry weight of roots (g) at the end of vegetative observation with different MSG dose treatments

| Parameter | MSG dosage (g per plant) | | | |
|---|---|---|---|---|
| | 0 | 3 | 6 | 9 |
| Number of leaves (pieces) | 9,00$^{b}$ | 12,80$^{a}$ | 11,60$^{a}$ | 11,80$^{a}$ |
| Leaf area ($cm^2$) | 86,63$^{c}$ | 219,06$^{a}$ | 218,84$^{a}$ | 188,90$^{b}$ |
| Plant height (cm) | 80,88$^{d}$ | 138,20$^{a}$ | 130,70$^{b}$ | 121,34$^{c}$ |
| Fresh weight of canopy (g) | 18,99$^{c}$ | 72,99$^{ab}$ | 76,10$^{a}$ | 49,58$^{b}$ |
| Dry weight of canopy (g) | 2,97$^{b}$ | 11,38$^{a}$ | 14,35$^{a}$ | 10,27$^{a}$ |
| Fresh weight of roots (g) | 1,22$^{c}$ | 11,44$^{b}$ | 15,26$^{a}$ | 14,10$^{ab}$ |
| Dry weight of roots (g) | 0,35$^{b}$ | 2,60$^{a}$ | 2,73$^{a}$ | 2,50$^{a}$ |

Note: Numbers followed by the same letter in the same row indicate no significant difference based on the DMRT test α = 0.05.

The ANOVA results indicate that the application of MSG at doses of 3, 6, and 9 g per plant increased the number of leaves, but there were no significant differences between treatments. MSG treatments of 3 and 6 g per plant increased leaf area, but there was no significant difference between 3 g and 6 g. However, at 9 g per plant, the increase in leaf area was smaller compared to the 3 and 6 g treatments. Plant height increased at all treatment doses. The greatest increase in plant height occurred in the 3 g per plant treatment, while in the 6 and 9 g per plant treatments, plant height increased progressively. Fresh weight and dry weight of both the canopy and roots increased in all treatments (Table 2; Figure 1).

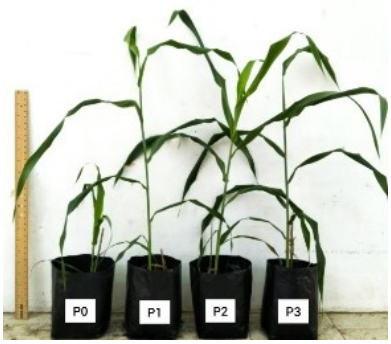



**Figure 1.** Sorghum plants at 56 days after planting with different MSG treatments. P: MSG dose, P0 (0 g/plant), P1 (3 g/plant), P2 (6 g/plant), and P3 (9 g/plant).

The decrease in vegetative growth of sorghum in the MSG treatment at 9 g per plant was caused by a decrease in pH. pH observation data at the end of the study showed a change in soil pH toward acidity in the MSG treatment (Table 3).

**Table 3.** Average initial and final pH of sorghum with different MSG doses

| Parameter | MSG dosage (g per plant) | | | |
|---|---|---|---|---|
| | 0 | 3 | 6 | 9 |
| Initial pH | 7 | 7 | 7 | 7 |
| Final pH | 6,45 | 6,55 | 6,25 | 6 |

Note: Initial pH (average pH at the start of planting), Final pH (average pH at the end of observation)

## Generative Growth and Productivity

The results of ANOVA on generative growth parameters indicate that MSG accelerates the flowering time of sorghum, but there are no significant differences between treatment doses of 3, 6, and 9 g per plant. MSG application accelerates harvest time by up to 11 days earlier than the control. MSG treatment at 3, 6, and 9 g per plant increases the number of sorghum seeds. MSG treatment did not affect the dry weight of 100 seeds. This indicates that the increase in sorghum productivity was due to an increase in the number of seeds per sorghum panicle and not due to an increase in seed size (Table 4; Figure 2).

**Table 4.** Number of seeds, fresh weight of seeds (g), dry weight of seeds (g), and weight of 100 seeds (g) of sorghum at the end of generative observation with different MSG dose treatments.

| Parameter | MSG dosage (g per plant) | | | |
|---|---|---|---|---|
| | 0 | 3 | 6 | 9 |
| Flowering time (days) | 71,80$^{b}$ | 64,40$^{a}$ | 62,40$^{a}$ | 60,80$^{a}$ |
| Harvest time (days) | 116,80$^{b}$ | 109,20$^{a}$ | 108,20$^{a}$ | 106,20$^{a}$ |
| Number of seeds (grains) | 425,80$^{b}$ | 444,20$^{b}$ | 669,40$^{a}$ | 789,80$^{a}$ |
| Fresh weight of seeds (g) | 11,20$^{b}$ | 12,09$^{b}$ | 14,93$^{ab}$ | 17,96$^{a}$ |
| Dry weight of seeds (g) | 10,59$^{b}$ | 10,76$^{b}$ | 13,62$^{ab}$ | 16,16$^{a}$ |
| Dry weight of 100 seeds (g) | 2,81$^{a}$ | 2,24$^{a}$ | 2,47$^{a}$ | 2,35$^{a}$ |

Note: Numbers followed by the same letter in the same row indicate no significant difference based on the DMRT test α = 0.05.

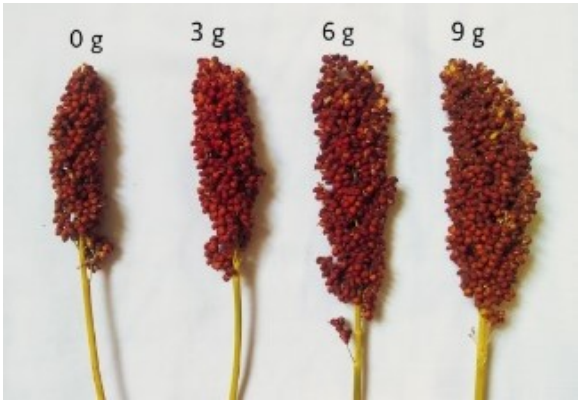



**Figure 2.** Sorghum panicles at the end of generative observation with different MSG dose treatments

## Discussion

The increase in pigment content is due to the presence of glutamate in MSG. Glutamate is converted into α-ketoglutarate through the glutamine synthetase (GS) cycle in chloroplasts (Forde & Lea, 2007; Qiu *et al*., 2020). The conversion of glutamate and α-ketoglutarate strengthens the signaling pathway for controlling nitrogen metabolism (Kan *et al.*, 2017). Nitrogen can increase PSII activity and phytochemical activity, thereby influencing light capture in the photosynthesis process, increasing pigment content, and enhancing photosynthesis rate efficiency (Peng *et al*., 2021). Glutamate influences the synthesis of *5-aminolevulinic acid* (ALA) in the chlorophyll formation process (Zhao *et al.*, 2020). ALA is synthesized from glutamate (Glu) through the C5 pathway, which consists of three enzymatic steps: GluRS, GluTR, and GSA-AT, to form porphobilinogen (Tanaka *et al*., 2011). Chlorophyll and carotenoids play a role in the absorption, transmission, and distribution of light energy in the process of photosynthesis (Peng *et al*., 2021). The higher the pigment content, the faster the rate of photosynthesis. The photosynthetic products formed are translocated for plant growth and development. According to Septiyana *et al.* (2019), the final product of photosynthesis, glucose, becomes an organic material in plant cells that forms the cytoplasm, cell nucleus, and cell wall.

In addition to increasing pigment content, MSG also promotes vegetative growth due to the presence of glutamate, which acts as a nitrogen donor (Walker & Donk, 2016). Sufficient nitrogen availability promotes shoot growth, thereby enhancing plant growth (Chrysargyris *et al*., 2016). This growth increase is also due to nitrogen's influence on chlorophyll formation in leaves, thereby enhancing photosynthesis (Kusuma, 2013). Apical and primordial leaf growth requires assimilates from photosynthesis as metabolic substrates that produce ATP for leaf formation (Haryanti, 2008). According to Leghari *et al.* (2016), nitrogen influences photosynthesis, leaf production, and leaf area development. Larger leaves can capture and absorb more light, resulting in greater photosynthate production for plant growth (Sari *et al.*, 2016). Photosynthates are translocated to the vegetative parts of the plant to form new organs. The larger the plant organs that form, the more water the plant can absorb, thereby increasing the fresh weight of the plant (Pramitasari *et al*., 2016).

Sodium ($Na^{+}$) from MSG influences the vegetative growth of sorghum because sodium can replace

potassium ($K^+$) as a controller of osmotic pressure in vacuoles and cell turgor (Wakeel *et al*., 2011). Turgor pressure controls the flow of water and solutes from vacuoles. In plant cells, turgor pressure promotes cell expansion, cell growth, and metabolism (Zhang *et al.*, 2017). Sodium can replace the role of K bound to molybdenum, thereby not disrupting the activity of nitrate reductase, which converts nitrate into nitrite (Wakeel *et al.*, 2011). The dry weight of sorghum plants is influenced by the accumulation of organic compounds synthesized by the plants. According to Yan *et al.* (2022), root dry weight is related to the plant's ability to absorb water. Roots with high fresh weight and low dry weight indicate that their water requirements are met. MSG treatment did not inhibit the rate of water absorption in plants. However, the presence of MSG reduced vegetative growth at a concentration of 9 g per plant due to a decrease in pH. Matsumoto *et al*. (2017) stated that acidic soil inhibits plant growth. Low soil pH inhibits the activity of nitrate reductase, thereby slowing the rate of nitrogen denitrification (Neina, 2019). Toxic elements for plants are easily soluble under low soil pH conditions, thereby inhibiting plant growth (Matsumoto *et al.*, 2017).

MSG treatment also accelerates the flowering time and harvest time of sorghum. According to the database of the Cereal Research Institute (2013), sweet sorghum variety Super 2 has a harvest time ranging from 115 to 120 days after planting. MSG treatment can accelerate the transition from the vegetative phase to the generative phase, as glutamate from MSG acts as a precursor to gibberellin hormones. Glutamate plays a role in the formation of 2-oxoglutarate (2-OD), the primary organic acid in the tricarboxylic acid (TCA) cycle. The organic acid 2-OD is a substrate in the formation of *dioxygenase* (2-ODDs). The enzyme 2-ODDs acts as a catalyst in gibberellin biosynthesis (Araújo *et al*., 2014). Gibberellins are synthesized through the terpenoid pathway and require three enzymes: terpene synthase, P450s, and 2-ODDs to bioactivate GA from GGDP in plants (Gupta & Chakrabarty, 2013). Gibberellins trigger the transition from the vegetative phase to the generative growth phase. Giberellins stimulate cell division during the cell cycle by shortening the $G_1$ and S phases of the cell cycle, thereby promoting faster cell growth (Bao *et al.*, 2020). Giberellins stimulate cell proliferation through the enzyme XET, thereby promoting cell wall expansion (Setiawan & Wahyudi, 2014). Giberelin initiates flowering by increasing mitosis in the apical meristem in response to flowering signals (Gupta & Chakrabarty, 2013).

Glutamate plays an important role in metabolism. Research by Kan *et al.* (2017), shows that 0.1 mM of exogenous glutamate supports growth in rice seedlings by being metabolized quickly by plants into other nitrogen-containing compounds. Increased nitrogen affects photosynthesis, and plants store more carbohydrates for flower formation (Septiyana *et al.*, 2019). The flowering process is influenced by high glucose content in the shoots as an energy source used for flower induction and the formation of flower parts (Cho *et al.,* 2018). The increase in the number of sorghum seeds is due to glutamate stimulating the synthesis of hydrolytic enzymes, such as amylase and protease. Amino acids formed from proteases release tryptophan, which is a precursor of the auxin hormone (Zhao, 2014). Auxin induces the formation of flower primordia, influences meristems, and influences the development of flower organs during flower development (Cheng & Zhao, 2007). Flower organs develop into sorghum seeds.

The dry weight of 100 sorghum seeds is suspected to be influenced by genetic factors. Based on Sahuri (2017) research has shown that the influence of sorghum genotypes on seed weight per panicle, 100-seed weight, and seed yield from 13 tested genotypes resulted in statistically significant differences. Usnawiyah *et al.* (2021) stated that the weight of 100 seeds provides an indication of seed size, where a higher weight of 100 seeds in a variety indicates larger seed size. In this study, it was found that MSG treatments of 0, 3.6, and 9 g/plant induced the same seed size. The number of seeds increases the fresh weight and dry weight of seeds.

This study has demonstrated the potential of MSG in supporting sorghum growth and development. Therefore, MSG can be developed as a biostimulant to enhance vegetative growth and productivity in sorghum plants and has potential for other horticultural crops. The glutamate and sodium content in MSG plays a crucial role in plant physiological processes, such as nitrogen donation, chlorophyll synthesis, gibberellin hormone production, and maintaining turgor pressure (Camut et al. 2021; Okumoto et al. 2016; Velasco-Ramírez et al. 2024). The application of MSG can also accelerate flowering time and harvest time in plants. This is highly beneficial in horticultural crops to increase planting intensity, land efficiency, and manageable crop cycles (Gupta et al., 2023). Faster flowering and harvest times also increased marketable yields and higher profit potential (El-Nakhel et al., 2024; Xu et al., 2024). Therefore, further research is recommended to investigate the effectiveness and optimal dosage of MSG on various other high-value horticultural crops, such as leafy vegetables, fruits, and ornamental plants.

## CONCLUSIONS

MSG treatment on sorghum plants at doses of 3, 6, and 9 g per plant increased leaf chlorophyll content and vegetative growth, accelerated flowering and harvest time, increased seed number and weight, but did not affect the dry weight of 100 seeds. The highest growth and productivity of sorghum plants occurred under the MSG treatment of 9 g per plant. The results of this study can be used as a basis for optimizing the productivity of

horticultural crops while still considering the dosage for different plants.

***Authors' Contributions:*** Example: Sri Darmanti & Endang Saptiningsih designed the study. Indah Tri Intan carried out the laboratory work & analyzed the data. Sri Darmanti & Indah Tri Intan wrote the manuscript. All authors read and approved the final version of the manuscript

***Competing Interests:*** The authors declare that there are no competing interests.

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