Effects of Polyglutamic Acid Controlled - Release Formulations on the Growth of Different Crops

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Abstract. With the continuous growth of global food demand, enhancing agricultural productivity has become crucial. Traditional fertilization methods suffer from significant nutrient loss, whereas polyglutamic acid (γ-PGA) has attracted considerable attention owing to its capabilities in retaining water, enhancing fertilizer efficiency, amending soil, and boosting crop growth. However, commercially available polyglutamic acid products are predominantly quick-release formulations, characterized by rapid nutrient release, low utilization efficiency, and an inability to meet the sustained nutrient demands of long-cycle crops. This study developed three controlled-release polyglutamic acid powders—fast-acting, medium-acting, and slow-acting—and investigated their effects on crops with different growth cycles (chili peppers, tomatoes, and maize) through pot experiments when combined with blended fertilizers. Studies have shown that fast-acting polyglutamic acid significantly enhances stem diameter and other growth indicators in plants.aboveground fresh weight in chili peppers; medium-acting formulations were more effective in enhancing plant height and stem diameter in tomatoes; and medium- to slow-acting formulations demonstrated superior performance in improving plant height, stem diameter, and aboveground fresh weight in maize. The research confirms that controlled-release polyglutamic acid formulations exhibit significant adaptive differences in promoting crop growth, providing a theoretical basis for precisely selecting polyglutamic acid products according to crop characteristics in agri-

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cultural practices. This approach aids in optimizing fertilization strategies and enhancing fertilizer utilization efficiency.

Keywords: Polyglutamic Acid, Controlled-Release Formulations, Crop Growth

1 Introduction

As the global population continues to rise, there has been a consistent and unyielding increase in food demand. Addressing this challenge through enhancing agricultural productivity and optimizing the food supply system has become a central issue of widespread concern in contemporary society.[1,2] Traditional crops require multiple applications of various fertilizers during their growth to promote plant development and high yields.[3] However, conventional fertilizers and fertilization techniques often result in significant environmental impacts.ficant nutrient loss from the fertilizers.[4] Polyglutamic acid (γ-PGA) is a high-molecular-weight amino acid polymer formed by the polymerization of L-glutamic acid and D-glutamic acid monomers through amide bonds, with the intermonomeric linkage occurring via amide bonds between α-amino groups and γ-carboxyl groups.[5] Research has found that polyglutamic acid exhibits a synergistic effect with other fertilizers, effectively improving fertilizer utilization efficiency and significantly enhancing soil quality.

γ-Polyglutamic acid (γ-PGA) not only synergistically interacts with other fertilizers but also exerts numerous beneficial effects on plant growth, such as improving soil quality, promoting plant development, regulating rhizosphere microbial communities, remediating heavy metal contamination, and managing agricultural waste.[6,7,8,9,10] Treatments with different concentrations of polyglutamic acid can significantly increase the plant height, chlorophyll content, aboveground and underground biomass of alfalfa in desert environments. They can also improve the quality of sandy soil and the structure of the rhizosphere microbial community.[11] Polyglutamic acid also demonstrates efficacy in enhancing plant stress tolerance; for instance, under drought stress conditions, it strengthens plant drought resistance, improves soil structure, and enhances soil water retention capacity. It has been found through research that the combination of polyglutamic acid and sesame cake fertilizer can improve the utilization efficiency of fertilizers, reduce fertilizer runoff, and improve soil quality. In addition, polyglutamic acid has also been proven to have antibacterial effects.[12,13] Although the agricultural value of polyglutamic acid (PGA) has been widely validated, most commercially available PGA powder formulations are fast-release types, which fail to meet the sustained nutrient demands of long-growth-cycle crops. This technical limitation hinders its broader application in perennial cash crops and staple field crops.

In summary, this study selected three polyglutamic acid products with distinct release profiles: a quick-release type (achieving 80% release within 1 hour), a medium-release type (sustained nutrient release over 1 month), and a long-release type (sustained nutrient release over 3 months). Utilizing potted peppers, tomatoes, and corn as experimental subjects, the research systematically compared the effects of blending these three polyglutamic acid powders with fertilizers on the growth of different crops. The results align with previous studies that have shown polyglutamic acid's ability to enhance water retention, nutrient release, and plant growth. For instance, research has demonstrated that polyglutamic acid improves soil moisture retention and nutrient availability, leading to increased plant height, leaf number, stem thickness, and yield in crops such as corn. Additionally, polyglutamic acid has been found to promote root development and nutrient uptake, resulting in thicker leaves and darker green coloration, which are indicative of enhanced photosynthesis [1]. Furthermore, the application of polyglutamic acid has been associated with increased crop resistance to environmental stresses, such as drought and salinity, and improved overall crop quality and market value [2,3]. plant species. Furthermore, the experimental outcomes were quantitatively analyzed by examining indicators such as plant biomass accumulation and agronomic traits, as demonstrated in studies that assess the impact of density on crop performance.

2 Methodology

2.1 Fertilizer Mixing Ratio

The blended fertilizer used in this study is compounded in a certain proportion from urea (with a nitrogen content of 46%), diammonium phosphate (with an effective nutrient content of 64% and an N-P_2O_5-K_2O ratio of 18-46-0), and potassium chloride (with a potassium content of 60%). After compounding, the total nutrient ratio is N-P_2O_5-K_2O = 12.56-12.56-12.56. Subsequently, the compounded materials are fully ground by a grinder to form a powder, and finally evenly mixed with the polyglutamic acid sample.

2.2 Plant Cultivation

This experiment was conducted in a glass greenhouse, with chili peppers, tomatoes, and corn selected as the test crops. Based on the different release characteristics of the polyglutamic acid powder, four base fertilizer treatment groups were established (quick-release type-QT; medium-release type-MT; long-release type-LT). Each treatment was replicated 4 times, resulting in a total of 16 experimental pots. The specific procedures were as follows: For each pot, 5 kg of garden soil was weighed, and 2.5 kg of the upper-layer garden soil was thoroughly mixed with the fertilizer. Subsequently, the evenly mixed soil was filled into containers, and plant seedlings were transplanted. All remaining management practices adhered strictly to local conventional protocols for planting and managing chili peppers, tomatoes, and corn.After the cultivation period, the plants were carefully washed, and agronomic traits such as plant height and stem diameter were measured to determine the effect of polyglutamic acid products in enhancing the fertilizer efficiency of blended fertilizers.

3 Results

The combined application of blended fertilizers and polyglutamic acid powder has been shown to enhance pepper growth by improving plant height, branching, fruiting, and chlorophyll content, as evidenced by field trials and research studies.

Table 1. Impacts of Various Treatments on Pepper Growth and Development.

Handle	Stem diameter / mm		Aboveground fresh weight / g		Fresh weight of stem / g		Leaf fresh weight / g	
	Value	Increase %	Value	Increase %	Value	Increase %	Value	Increase %
CK	5.28	-	40.76	-	14.01	-	26.75	-
QT	5.86	11.04	43.36	6.37	14.67	4.68	28.69	7.25
MT	5.41	2.51	42.31	3.80	13.99	-0.16	28.32	5.87
LT	5.47	3.60	39.25	-3.70	13.02	-7.08	26.24	-1.93

Fig. 1. The impact of various treatments on the plant height and branching height of peppers, as demonstrated by growth records and environmental factors.

Applying blended fertilizer with polyglutamic acid powder can reduce pepper branching - point height, increase stem diameter and above-ground fresh weight while maintaining plant height. The results are shown in Table 1 and Figure 1. Compared to the CK group, the 1st, 2nd, and 3rd branching-point heights in polyglutamic acid treatments decreased by 6.66%, 9.33%, and 6.63% on average. The quick - acting treatment had the most significant impact on stem diameter, with an 11.04% increase compared to CK. All treatment groups except the long-acting one had higher above-ground fresh weights than CK. Analysis shows polyglutamic acid mainly increases above-ground fresh weight by boosting leaf fresh weight. The quick-acting and medium - acting groups had 7.25% and 5.87% higher leaf fresh weights than CK respectively. Overall, the quick - acting polyglutamic acid powder is more beneficial for pepper growth.

Effects of Combined Application of Blended Fertilizers and Polyglutamic Acid Powder on tomato Growth

Table 2. Impacts of Various Treatments on tomato Growth and Development.

Handle	Plant height / cm		Stem diameter / mm		Aboveground fresh weight / g	
	Value	Increase %	Value	Increase %	Value	Increase %
CK	43.13	-	5.04	-	32.16	-
QT	43.90	1.80	5.12	1.54	33.89	5.37
MT	44.88	4.06	5.23	3.77	33.17	3.13
LT	43.63	1.16	4.94	-1.93	31.94	-0.68

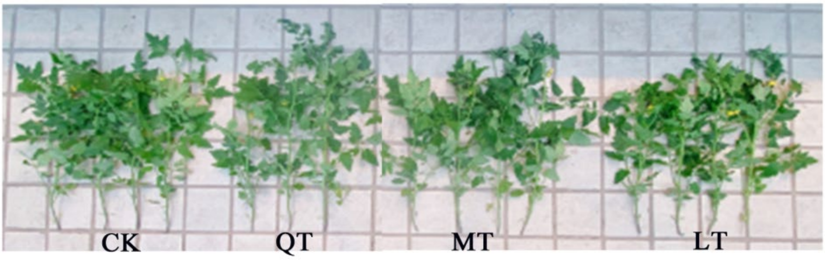

Fig. 2. The impact of various treatments on the plant height of tomato, as demonstrated by growth records and environmental factors.

In terms of tomato growth, the results are shown in Table 2 and Figure 2. Compared with the control group (CK), the combined application of blended fertilizer and polyglutamic acid powder has a certain effect on increasing the plant height, stem diameter and aboveground fresh weight of tomatoes. Among them, the medium-effect group shows stronger advantages in terms of plant height and stem diameter. In comparison to the control group, the observed increase in plant height was 4.06%, and the stem diameter showed a 3.77% increase, indicating a positive response to the experimental conditions. As for the aboveground fresh weight, the quantity has also seen an increase, albeit slightly less pronounced than the other metrics.uick-acting type shows a better effect, which is 5.37% higher than that of the CK group. Through comprehensive analysis, the medium-effect polyglutamic acid powder exhibits a more significant effect on the growth of tomatoes.

Effects of Combined Application of Blended Fertilizers and Polyglutamic Acid Powder on maize Growth.

Table 3. Impacts of Various Treatments on maize Growth and Development.

Handle	Plant height / cm		Stem diameter / mm		Aboveground fresh weight / g	
	Value	Increase %	Value	Increase %	Value	Increase %
CK	90.67	-	10.02	-	30.96	-
QT	93.08	2.66	9.63	-3.90	31.70	2.40
MT	105.17	15.99	11.41	13.87	51.61	66.66
LT	100.58	10.92	11.70	16.76	46.26	49.41

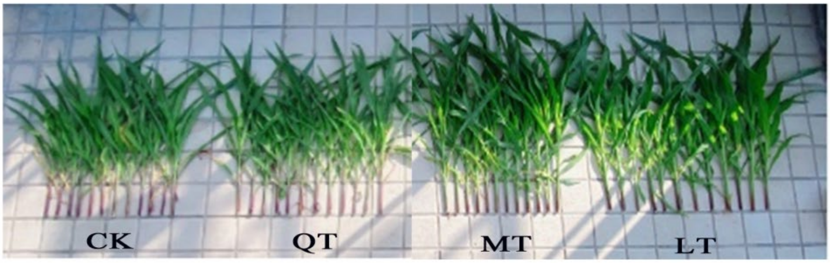

Fig. 3. The impact of various treatments on the plant height of maize, as demonstrated by growth records and environmental factors.

Regarding maize growth, the results are presented in Table 3 and Figure 3. As compared to the control group (CK), the combined application of blended fertilizer and polyglutamic acid powder demonstrated significant effects in enhancing plant height, stem diameter, and aboveground fresh weight. The quick-acting group demonstrated an increase in plant height and aboveground fresh weight by 2.66% and 2.40%, respectively, in comparison to the CK group. In contrast to the CK group, the medium-effect group showed a 15.99% increase in plant height, with notable improvements in stem diameter as well.ameter is increased by 13.87%, and the aboveground fresh weight is increased by 66.66%. In the long-acting group, compared with the CK group, the plant height is increased by 10.92%, the stem diameter is increased by 16.76%, and the aboveground fresh weight is increased by 49.41%. In conclusion, the medium-effect group and the long-acting group show better effects on the growth of maize.

4 Discussion

Studies have demonstrated that various polyglutamic acid formulations enhance crop growth, with notable differences in their suitability for different crops. In the pot experiment of chili peppers, the application effect of the quick-acting polyglutamic acid is particularly remarkable. Compared with the control group, after the application of this substance, the stem diameter of chili pepper plants has significantly increased by 11.04%, and the fresh weight of the leaves has increased by 7.25%, demonstrating a highly efficient promoting effect on the growth and development of crops.In terms of the growth of tomatoes, the medium-effect group exhibits stronger advantages in terms of plant height and stem diameter. Compared with the control group, the plant height is observed to have increased by 4.06%, and the stem diameter has increased by 3.77%.In terms of maize growth, both the medium-effect and long effect groups demonstrated superior performance compared to the control group. Specifically, the medium-effect group exhibited remarkable growth enhancements: plant height increased by 15.99%, stem diameter expanded by 13.87%, and above - ground fresh weight surged by 66.66%. Meanwhile, the long-effect group also showed significant improvements, with plant height rising by 10.92%, stem diameter increasing by

16.76%, and above - ground fresh weight growing by 49.41%. These findings underscore the substantial positive impacts of the medium - effect and long - effect treatments on maize growth. Based on current research, we hypothesize that poly-γ-glutamic acid (γ-PGA) primarily promotes plant growth by enhancing root nutrient uptake capacity and maintaining soil nutrient balance, thereby increasing stem diameter and plant height.[14] Although pot experiments have preliminarily confirmed significant differences in the growth-promoting effects of different poly-γ-glutamic acid (γ-PGA) formulations on various crops, large-scale field trials are still required to evaluate their practical application value in agricultural production.

Future research directions include: optimizing controlled release technology to precisely meet the needs of crops; elucidating molecular mechanisms and exploring the synergistic action modes with biofertilizers; conducting long-term ecological impact assessments with a focus on biodiversity conservation strategies and the evaluation of ecosystem services; integrating smart agriculture to develop standardized application protocols; and promoting the transformation of research achievements to contribute to the development of green agriculture.

5 Conclusion

Polyglutamic acid, when combined with blended fertilizers, significantly promotes crop growth, but its effectiveness varies depending on the crop's growth cycle. For chili peppers, a short-cycle crop, the quick-acting polyglutamic acid powder is most beneficial. It notably increases stem diameter by 11.04% compared to the control group (CK), and also raises above-ground fresh weight mainly through enhancing leaf fresh weight. The medium-acting polyglutamic acid formulation shows the best performance for tomatoes. It increases plant height by 4.06% and stem diameter by 3.77% relative to the CK group, having a more significant impact on tomato growth compared to other formulations. In the case of maize, a long-cycle crop, both the medium-acting and long-acting polyglutamic acid formulations are highly effective. The medium-acting group increases plant height by 15.99%, stem diameter by 13.87%, and above-ground fresh weight by 66.66%, while the long-acting group increases these indicators by 10.92%, 16.76%, and 49.41% respectively compared to the CK group.

These results confirm that different polyglutamic acid controlled-release formulations have distinct adaptive differences in promoting crop growth. This provides a crucial theoretical basis for precisely choosing polyglutamic acid products according to crop characteristics in agricultural practices. By selecting the appropriate polyglutamic acid formulation, farmers can optimize fertilization strategies, enhance fertilizer utilization efficiency, and potentially increase crop yields while reducing environmental impacts caused by nutrient loss from traditional fertilization methods.

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References

1. Nadimi Mohammad, Hawley Eric, Liu Jing, Hildebrand Kurt, Sopiwnyk Elaine, “Enhancing traceability ofwheat quality through the supply chain,” Comprehensive reviews in food science and food safety. 22(4), 2495-2522 (Jul 2023). https://doi.org/10.1111/1541-4337.13150.
2. Zhang D, Wang H, Lou S, Zhong S, “Research on grain production efficiency in China's main grain producing areas from the perspective of financial support,” PLoS One. 16(3), e0247610 (15 Mar 2021).
3. Liu Q, Xu H, Yi H, “Impact of Fertilizer on Crop Yield and C:N:P Stoichiometry in Arid and Semi-Arid Soil,” Int J Environ Res Public Health. 18(8), 4341(20 Apr 2021). https://doi.org/10.3390/ijerph18084341.
4. Wang X, Zhu H, Shutes B, Yan B, Lyu J, Zhang F, “Nutrient runoff loss from saline-alkali paddy fields in Songnen Plain of Northeast China via different runoff pathways: effects of nitrogen fertilizer types,” Environ Sci Pollut Res Int. 30(43):97977-97989(Sep 2023).
5. Shih IL, Van YT, “The production of poly-(gamma-glutamic acid) from microorganisms and its various applications,” Bioresour Technol. 79(3), 207-25(Sep 2001). https://doi.org/10.1016/S0960-8524(01)00074-8.
6. Wojtowicz K, Steliga T, Kapusta P, Brzeszcz J, Skalski T, “Evaluation of the Effectiveness of the Biopreparation in Combination with the Polymer γ-PGA for the Biodegradation of Petroleum Contaminants in Soil,” Materials (Basel). 15(2), 400(6 Jan 2022). https://doi.org/10.3390/ma15020400.
7. Zając E, Fabiańska MJ, Jędrszczyk E, Skalski T, “Hydrocarbon Degradation and Microbial Survival Improvement in Response to γ-Polyglutamic Acid Application,” Int J Environ Res Public Health. ;19(22), 15066(16 Nov 2022). https://doi.org/10.3390/ijerph192215066
8. Quan J, Zheng W, Tan J, Li Z, Wu M, Hong SB, Zhao Y, Zhu Z, Zang Y, “Glutamic Acid and Poly-γ-glutamic Acid Enhanced the Heat Resistance of Chinese Cabbage (Brassica rapa L. ssp. pekinensis) by Improving Carotenoid Biosynthesis, Photosynthesis, and ROS Signaling,” Int J Mol Sci. ;23(19), 11671(1 Oct 2022). https://doi.org/10.3390/ijms231911671.
9. Xu Z, Ma J, Lei P, Wang Q, Feng X, Xu H, “Poly-γ-glutamic acid induces system tolerance to drought stress by promoting abscisic acid accumulation in Brassica napus L,” Sci Rep. 10(1), 252(14 Jan 2020). doi: 10.1038/s41598-019-57190-4.
10. Lei P, Xu Z, Ding Y, Tang B, Zhang Y, Li H, Feng X, Xu H, “Effect of Poly (γ-glutamic acid) on the Physiological Responses and Calcium Signaling of Rape Seedlings (Brassica

napus L.) under Cold Stress," J Agric Food Chem. 63(48), 10399-406(9 Dec 2015). https://doi.org/10.1021/acs.jafc.5b04523.
11. Guo Z, Wang J, Chen T, Zhang H, Hou X, Li J, "Effects of γ-polyglutamic acid supplementation on alfalfa growth and rhizosphere soil microorganisms in sandy soil," Sci Rep. 14(1), 6440(18 Mar 2024). doi: 10.1038/s41598-024-57197-6.
12. Yu Z, Wei Y, Fu C, Sablani SS, Huang Z, Han C, Li D, Sun Z, Qin H, "Antimicrobial activity of gamma-poly (glutamic acid), a preservative coating for cherries," Colloids Surf B Biointerfaces. 225, 113272(May 2023). https://doi.org/10.1016/j.colsurfb.2023.113272.
13. Fu Y, Li G, Wang S, Dai Z, "Effect of sesame cake fertilizer with γ-PGA on soil nutrient, water and nitrogen use efficiency," Sci Rep. 14(1), 18669(12 Aug 2024). doi: 10.1038/s41598-024-69650-7.
14. Zhang L, Yang X, Gao D, Wang L, Li J, Wei Z, Shi Y. Effects of poly-γ-glutamic acid (γ-PGA) on plant growth and its distribution in a controlled plant-soil system. Sci Rep. 7(1):6090(20 Jul 2017) https://doi.org/10.1038/s41598-017-06248-2.