Shahid Bahonar University of Kerman
Agricultural Biotechnology Journal
Iranian Biotechnology Society
Print ISSN: 2228-6705 Online ISSN: 2228-6500

Transformation of shrimp shell waste into biochar-nanochitosan slow-release fertilizer for enchanced maize productivity

Astin Lukum

*Corresponding author. Faculty of Mathematics and Natural Sciences, Gorontalo State University, Indonesia. E-mail: astin.lukum@ung.ac.id

Arfiani Rizki Paramata

Faculty of Fisheries and Marine Science, Gorontalo State University, Indonesia. E-mail: arfiani@ung.ac.id

Wiwin Rewini Kunusa

Faculty of Mathematics and Natural Sciences, Gorontalo State University, Indonesia. E-mail: rewinikunusa2014@gmail.com

Magdalena Litaay

Faculty of Mathematics and Natural Sciences, Hassanudin University; Indonesia. E-mail: mlitaay@fmipa.unhas.ac.id

Abstract

Objective

This study aimed to develop and evaluate a biochar-nanochitosan-based slow-release fertilizer (SRF-Bio Pjhonska Plus) derived from agricultural and fisheries waste, and to determine its optimal application dose for improving vegetative growth and yield of maize cultivated on degraded tropical soils. Specifically, the research investigated the effects of diffrerent SRF-Bio Phonska Plus dosages on plant height, leaf number, stem diameter, and maize ear weight, compare to conventional Phonska fertilizer.

Materials and methods

The research was conducted from June to September 2025 at the Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Gorontalo State University. Nanochitosan was synthesized from shrimp shell chitosan using the ionic gelation method with sodium tripolyphosphate as a crossliker, followed by spray drying. Biochar was produced from corn cob waste through pyrolysis at 500 °C under limited oxygen conditions. The ferilizer formulation was prepared by granulating Phonska fertilizer and biochar at 3:7 ratio using molasses as a binder, followed by surface encapsulation with a 1% nanochitosan solution to form SRF-Bio Phonska Plus granules. Nutrient release bahvior (N, P, and K) was evaluated using a static water immersion test. A completely randomized design with four treatments and three replications was applied to maize cultivation experiments, and data were analyzed using ANOVA followed by Duncan's Multiple Range Test (DMRT) at $\alpha = 0.05$.

Results

Characterization result showed that the synthesized nanochitosan had a average particle size of approximately 552 nm with porous and near-spherical morphology, suitable for nutrient encapsulation. Biochar exhibition low moisture and ash content, indicating good structural stability and adsorption capacty. The SRF-Bio Phonska Plus demonstrate significantly slower and more controlled N, P, and K release compared to conventional fertilizer. In maize application, the 7.5 g SRF-Bio Phonska Plus treatment produced the highest plant height, leaf number, stem diameter, and cob weight, outperforming both lower and heigher dosages as well as conventional fertilizer.

Conclusion

The integration of corn cob biochar and nanohitosan derived from shrimp shell waste into SRF-Bio Phonska Plus effectively enhanced nutrient use efficiency and maize productivity on degraded soils. The optimal dosage of 7.5 g provided synchronized nutrient release aligned with plant demand, supporting both vegetative generative growth. This formulation demonstrates strong potential as an environmentally friendly and sustainable fertilizer strategy for tropical agricultural systems.

Keywords: biochar, corn, nanochitosan, plant growth, SRF-Bio Phonska Plus

Paper Type: Research Paper.

Citation: Lukum, A., Paramata, A. R., Kunusa, W. R., & Litaay, L. (2026). Transformation of shrimp shell waste into biochar-nanochitosan slow-release fertilizer gor enchanced maize productivity. *Agricultural Biotechnology Journal,* 18(2), 449-466.

Agricultural Biotechnology Journal, 18(2), 449-466. DOI: 10.22103/jab.2026.26447.1814

Received: Decembre 23, 2025. Received in revised form: February 16, 2026.

Accepted: February 17, 2026. Published online: February 28, 2026.

Publisher: Shahid Bahonar University of Kerman & Iranian Biotechnology Society.

Introduction

Gorontalo Province is one of the provinces in Indonesia facing land critical challenges. Spread unevenly across districts, degraded areas add up to 217,178 hectares out of a total regional expanse of 1,203,350 hectares. Gorontalo Regency accounts for 75,351 hectares of this damaged land. North Gorontalo follows, showing 39,107 hectares in decline. In Boalemo, the number climbs slightly higher at 50,154 hectares. Pohuwato reports less severe but still notable damage, 22,922 hectares classified as critical. Another 27,998 hectares face deterioration in Bone Bolango. The capical city of Gorontalo Province which is Gorontalo City also shows signs, recording 1,646 hectares under threat (Nurdin, 2022). Overuse of fertilizers stands among leading causes behind farmland deterioration (Rahman & Zhang, 2018). Belief persists among farmers that more fertilizer leads to stronger plants; however, standard formulations rarely deliver nutrients effectively. Efficiency rates for core elements - nitrogen (N), phosphorus (P), potassium (K) - commonly fall within the narrow window of 30-40%. At the same time, most of the nutrients wasted into the environment via rainwater washing, irrigation or surface run off (Oladeji et al., 2022; X. Wang et al., 2022). Loss of nutrients through fertilizer runoff leads to financial strain on farms alongside harm to natural systems such as polluted drinking water sources, overloaded rivers and lakes, along with degraded air quality. When fertilizers are applied without care, the land may grow more acidic; this shift hampers plant roots from absorbing essential elements (Hu et al., 2023). A move to more refined techniques in fertilizer use appears essential should consistent crop yields remain achievable, pairing effectiveness with care for natural systems. Into this effort step tiny engineered particles blended within compounds designed to dissolve gradually, introducing a methodical way to feed crops across weeks. These extended-duration fertilizers dispense their contents slowly, outperforming traditional types by maintaining presence in earth. Across months of growth, green life draws support minus abrupt peaks or shortages. With delivery under control, risks tied to root injury from surplus doses fall sharply (Chen et al., 2023; C. Wang et al., 2021). Stable feeding supports stronger development, leading to higher harvest output. Efficiency rises since less product goes unused, cutting expenses over time. The unused elements escape into environment at lower rates limiting ecological harm. A new approach introduces fertilizers coated with chitosan, sourced from waste shrimp shells, using biochar for slow-release fertilizer. Although this biopolymer is gaining interest due to low environmental impact, challenges persist in how well plants absorb nutrients and control their gradual discharge into earth. Converting the material into nano-sized particles may address such issues - shrinking dimensions intensifies performance in farming contexts. At atomic scales, these tiny structures show distinct behaviors, allowing deeper integration with plant physiology. With capacity to transport essential elements, engineered materials at this level influence root absorption, adjust ground composition, and support greater access to nourishment (Quintarelli et al., 2024; Zaman et al., 2025). Root development receives a boost when nanomaterials are applied, while plant resilience improves under tough conditions like high salt levels or heat waves (Singi et al., 2024). With biochar-based slow-release fertilizers, these materials allow nutrients to move into soil at steadier rates - this balance aids long-term farming success (Singh et al., 2024). With biochar-based slow-release fertilizers, these materials allow nutrients to move into soil at steadier rates and this balance aids sustainability farming success (Zaman et al., 2025). Adding biochar to SRF mixes brings benefits through improved soil health, moisture holding, nutrient supply, microbe function, and texture - factors that collectively aid crop development. Still, controlled delivery methods are needed so nutrients from biochar enter the ground steadily. This method aligns with the 6R fertilizer strategy: correct amount, location, kind, cost, timing, and standard. A new system combines biochar with Phonska SRF coated in nanochitosan, named SRF-Bio Phonska Plus. Initial studies examined slow-release fertilizers incorporating materials such as biochar, zeoline, or natural polymers including chitosan. Nitrogen retention appears improved when biochar is present, reducing leaching caused by water flow in soil (Sharma et al., 2025), meanwhile, nutrient particles coated with nanochitosan release more gradually, aiding plant absorption while subtly influencing soil structure (Hu et al., 2023). Despite such findings, current investigations mostly focus on one substance alone - rarely combining both materials to work together within one unified method meant for farming areas under warm climate patterns like those across Indonesian regions. In contrast to earlier studies that relied on single materials or focused on a single nutrient release control mechanism, the present research introduces a novel approach by simultaneously combining two functional materials: (1) corn cob biochar as a porous matrix that contributes to water retention, nutrient storage, and improvement of soil physicochemical properties; and (2) nanochitosan derived from shrimp shell waste as a nano-encapsulating agent that regulates nutrient diffusion and gradual release. The novelty of this study lies in the formulation of SRF-Bio Phonska Plus as an applicative fertilizer, as it utilizes Phonska fertilizer commonly used by farmers as the base material and enhances its performance through nano- and biochar-based technologies. This innovation is therefore not merely conceptual but holds strong potential for direct adoption in practical agricultural systems, particularly in critical land areas under tropical climatic conditions. This study aimed to evaluate the advantages of the biochar-based, nanochitosan-coated SRF-Bio Phonska Plus composite fertilizer compared with conventional fertilizers in terms of maize growth and yield in Gorontalo Province. Specifically, the objectives were to: (1) determine the optimal dosage of SRF-Bio Phonska Plus for improving vegetative growth of maize, including plant height, number of leaves, and stem diameter; and (2) analyze the effects of SRF-Bio Phonska Plus on maize generative growth as indicated by ear weight.

Materials and methods

Research location: This research is conducted in Chemistry Laboratory of Faculty Mathematics and Natural Sciences, Universitas Negeri Gorontalo between June and September 2025.

Nanochitosan synthesis: Using ionic gelation, nanochitosan was prepared during this research. One hundred milliliters of 1% glacial acetic acid mixed with one gram of chitosan from discarded shrimp shells spun on a magnetic stirrer for two hours. Afterward, 10 mL of 0.1% sodium tripolyphosphate - acting as a crosslinker - entered the blend, along with 0.1% Tween 80 added slowly to stabilize the system; stirring continued at 1,200 revolutions per minute under ambient conditions. When uniformity appeared in the liquid, it moved into a spray dryer set at 90 degrees Celsius to form powdered nanoparticles. Analysis followed: particle dimensions checked via PSA while surface structure examined through SEM imaging. The process concluded once both instruments delivered measurable output.

Production of biochar from corn cob waste: Biochar emerged through pyrolysis by using corn cobs waste. The cobs were collected and dried to reduce the moisture content. Once dry, the material broke into smaller fragments before entering the reactor. Inside, heat climbed to 500 °C - held there for twenty minutes - with little oxygen present, breaking the biomass apart slowly. Thermal change took place: solid residue formed alongside gaseous outputs. When heating stopped, cooling began immediately to avoid accidental flare-ups once air returned. Retrieval happened after temperature dropped. Preparation for later applications finished the sequence.

Granulation of biochar-based SRF fertilizer using nanochitosan as an encapsulant: The fertilizer granulation process was carried out by gradually mixing Phonska fertilizer and finely ground biochar in a granulator at a ratio of 3:7. During granulation, the mixture was sprayed with a 30% molasses binder solution until granules with a particle size of 3-5 mm were formed. After the granules reached a semi-dry condition, the encapsulation process was performed by spraying a 1% nanochitosan solution using the spraying method to uniformly coat the entire surface of the granules. The resulting fertilizer granules were packaged and designated as Bio-Phonska Plus. Subsequently, analyses of macronutrient contents, including nitrogen (N), phosphorus (P), and potassium (K), were conducted to ensure product quality and compliance with the nutritional composition standards of biochar-based slow-release fertilizers formulated with Phonska.

Results and discussion

Synthesis of nanochitosan: This study employed commercial chiosan derived from tiger shrimp (Paneus monodon) shells as the base material. Nanochitosan formed through ionic gelation, a technique relying on attraction between positively and negatively charged particles to build tiny structures (Hoang et al., 2022). Chitosan carried multiple positive charges and interacts with sodium tripolyphosphate (Na-TPP), which bears negative ones. While one actsas a polycation, the other serves as a conterbalancing polyanion. Upon contact, chitosan forms a gel through electrostatic attraction between oppositely charged compnents, leading to the formation of crosslinked structures (Blebea et al., 2025). This method was selected to obtain nanochitosan particles with minimal size, which were subsequently applied as an encapsulant for biochar-based fertilizer derived from corn cobs. The synthesis process involved particle size reduction using a magnetic stirrer operated at a speed of 1.200 rpm. Measuring particles through a Particle Size Analyzer showed an average diameter of 552 nm. This aligns with earlier work fromAli et al. (2011) where chitosan nanoparticles were noted as solid colloids between 10 and 1.000 nm wide. When particles are smaller, they expose more surface per unit mass and this boosts how well they can adsorb susbtances while increasing their practical effectiveness (Choudhary et al., 2017). The sample's Polydispersity Index reached 1,67, revealing uneven particle sizes across the mixture. Such spread likely arises due to elevated levels of tripolyphosphate introduced during synthesis - a factor that raises the count of NH_3^+ groups on chitosan chains involved in forming bonds. As a result, stronger chitosan-TPP crosslinking interactions are formed, leading to heterogeneous nanoparticle complexes (Biernat et al., 2023). Scanning Electron Microscope (SEM) observartions revealed the presence of pores and particles with relatively spherical or near-spherical morphology on the surface of the nanochitosan. These findings are supported by previous studies reporting that chitosan-SiO_2 nanoparticles exhibit sphere-like shapes with slightly coarse surfaces and relatively uniform distribution (Khudhair et al., 2017). The result of SEM analysis of nanochitosan is presented in Figure 1. Based on the physicochemical characteristics obtained in this study, the stynthesized nanochitosan demonstrates strong potential for application as an effective encapsulant.

Looking closely under SEM using 10.000 times magnification with a 1 μm scale, the morphology sample revealed a rough and irregular surface. Folds and creases marked the particle surface, regions varied widely in texture, separated by scattered voids and exposed cavitis. What emerges is a network, tiny units clumped together, linked into a tangled 3D framework. Similar textures frequently appear in substances built from nanochitosan, according to Kubavat et al. (2020a), chitosan-based nanoparticles and biochar-based composites tend to develop uneven surfaces as a result of the ionic gelation process and electrostatic interactions among particles. This kind of surface structure contributes to the increasing of surface area effectiveness, which takes a crucial role in nutrient adsorption and retention process.

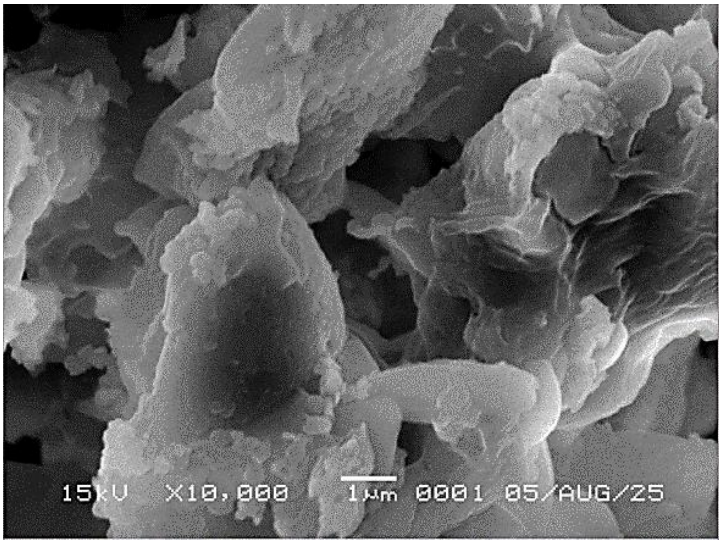

Figure 1. Nanochitosan morphology

Production of biochar from corn cob waste: Biochar emerges from dried corn cobs when heat transforms organic matter without open flame. This transformation happens in sealed units where temperature climbs high between 300-700ºC with low oxygens. Under this condition, the biomass breaks down into three distinct outputs: a carbon-rich residue, liquid byproduct and gaseos compounds. The starting point matters which are removing water beforehand ensures efficiency during heating. Instead of steam taking most energy, breakdown of structure gains priority if raw materials enter dry. Smaller corn cob pieces allow heat to move more efficiently through the material when heated without oxygen. This change often leads to higher amounts of solid residue remaining after decomposition. Temperature during heating, along with how wet biosmass is before processing, strongly shapes what kind of end product forms. Properties like resistence of carbon to breakdown, etent of porous structure and types of minerals present depend heavily on these two conditions, evidence from recent analysis clearly supports this relation (L. Wang et al., 2022). The characterization analysis revealed that the corn cobs-based biochar has a moisture content of 4,24% and an ash content of 3,51%. The low moisture level indicated that drying procedure and pyrolysis conditions effectively minimized residual water, which helps reduce the loss of energy during production. The moisture value obtained in this study compares to other earlier research that reported moisture contents of specific type of biomass biochar have a value of 6,90% (Afshar & Mofatteh, 2024) and it indicated that this study result of moisture content (4,24%) is on the good range for a high-quality biochar. The result of ash content (3,51%) indicated a low fraction of inorganic minerals and showed that most of those things are in the form of fixed carbon. This is a crucial characteristic as Puri et al. (2024) noted that ash content and composition significantly influence the pyrolysis process and the final properties of the resulting biochar, with that result that the low of ash content supports the properties of adsorption and biochar structural stability (Boero et al., 2023).

Granulation of biochar-based SRF fertilizr encapsulated with nanochitosan: The production of this fertilizer consists of 2 main stages: granulation and encapsulation. During the granulation stage, Phonska powder was mixed with biochar by the 3:7 ratioing granulator, then 30% molasse was sprayed until it granules with a size of 3-5 mm. Granulation techniques by using biochar as a part of matrix has been applied in the research of biochar-based fertilizer optimization which is showed that granulation increases the physical and mechanical of fertilizer and also decrease the loss of nutrient during the application (N. Wang et al., 2025). On the encapsulation step, the semi-dried fertilizer granules were sprayed with the 1% nanochitosan solution until all the surface of granules were coated. Polymer coatings such as chitosan and its derivatives have been extensively discussed in slow-release fertilizer formulations due to their ability to act as diffusion barriers, thereby limiting rapid nutrient release into the soil (Vejan et al., 2021; N. Wang et al., 2025). After the coating process, the granules were dried to stabilize the structure and minimize the internal moisture which produced more compact granules with relatively smooth but still porous surface. The SEM analysis indicated that nanochitosan particle took the form of spherical-near spherical morphology and this allowing them to form uniform protective layers on the granules surface. This directly implicated to the granules stability and its ability to control the nutrient diffusion. The research from Kubavat et al. (2020b) reported that spherical morphology nanochitosan supports the formulation of uniform protective layer. The final product was packaged and named as SRF Bio-Phonska Plus Fertilizer. The SRF evaluation was conducted by using static water immersion method where the fertilizer samples were placed in the water. The released of nitrogen (N), Phosphorus (P) and Kalium (K) concentrations were measured periodically for 72 hours. The results showed the nanochitosan fertilizer had more controlled and gradual nutrient release compared to conventional fertilizer (NPK 15-15-15). The percentage data of N, P, and K cumulatif release are presented in the Table below as the average of standard deviation = ±3. The tables above show the cumulative release percentages of N, P and K from SRF Bio-Phonska Plus and conventional fertilizer in various time of incubation. It can be seen quantitatively that SRF Bio-Phonska Plus gradually released N, P and K with low release values in the initial phase and followed by gradual increased up to 72 hours. On the other hand, the conventional fertilizer cumulative released of N, P and K were much more rapid and getting closer to 100% at the same incubation time. These numeric patterns is specifically visualized in macro nutrients release curves in Figure 2.

Table 1. Percentage of nitrogen (N) cumulative release

Time (hours)	SRF Bio-Phonska Plus	Conventional fertilizer
0	5 ± 0,8	15 ± 1,5
12	12 ± 1,2	40 ± 2,0
24	28 ± 1,0	60 ± 2,3
36	35 ± 1,5	75 ± 2,6
48	45 ± 1,8	85 ± 2,8
60	55 ± 2,0	95 ± 3,0
72	88 ± 2,5	100 ± 0,0

Table 2. Percentage of phosphorus (P) cumulative release

Time (hours)	SRF Bio-Phonska Plus	Conventional fertilizer
0	4 ± 0,6	10 ± 1,2
12	10 ± 1,0	35 ± 1,8
24	22 ± 1,3	55 ± 2,1
36	33 ± 1,6	70 ± 2,4
48	42 ± 1,9	85 ± 2,7
60	50 ± 2,1	92 ± 2,9
72	85 ± 2,4	100 ± 0,0

Table 3. Percentage of kalium (K) cumulative release

Time (hours)	SRF Bio-Phonska Plus	Conventional fertilizer
0	6 ± 0,7	8 ± 1,0
12	15 ± 1,1	30 ± 1,6
24	30 ± 1,4	60 ± 2,2
36	38 ± 1,7	80 ± 2,6
48	50 ± 2,0	90 ± 2,8
60	60 ± 2,3	95 ± 3,0
72	90 ± 2,6	100 ± 0,0

Figure 2 shows that the conventional fertilizer released high nutrient concentration in the initial phase (0-24 hours), while the nanochitosan-coated SRF reveals the slower and gradually distribution up to 72 hours. The relationship between granules morphology with the NPK slow-release test results is obvious by the nanochitosan coating function as a diffusion barrier that controlled the release rate, while the porous biochar as reservoir of nutrient storage and release it slowly to the surroundings These findings related to the research of N. Wang et al. (2025) that reported the ability of biochar to increase the nutrient retention in fertilizer and also a research from Gumelar et al. (2020) that indicated the combination of biochar and chitosan polymer is effective to decrease nutrient release rates. yang menunjukkan bahwa kombinasi biochar dan polimer kitosan efektif menurunkan laju pelepasan hara. Accordingly, the formulation of Nanochitosan-coated of SRF Bio-Phonska Plus not only maintains the balance of NPK concentration as the procedures, but also ensures the more efficient nutrient release and synchronized the plant needed under field conditions.

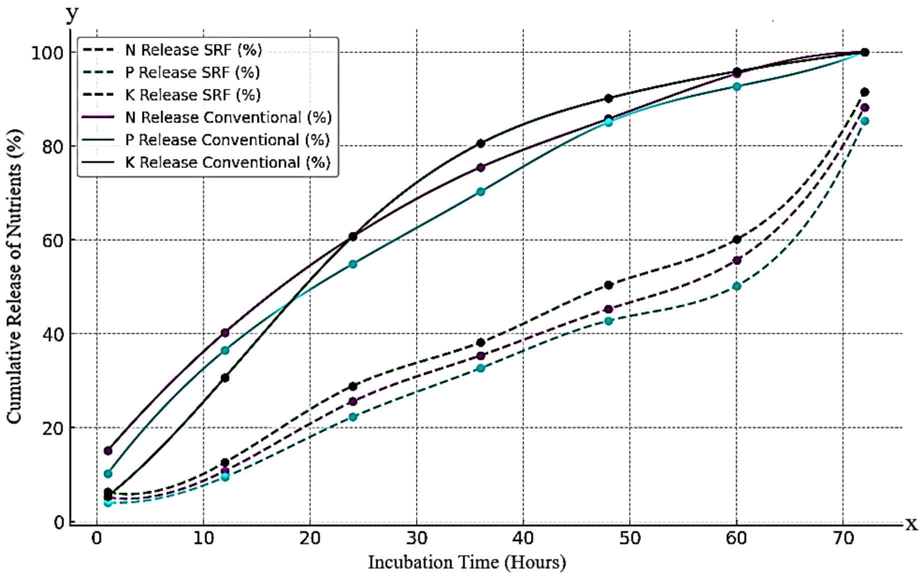

Figure 2. Macronutrients Release (N, P and K) of nanochitosan-coated SRF compared to Conventional Fertilizer (NPK 15-15-15)

Application of SRF Bio-Phonska Plus fertilizer on maize crops: Application of fertilizer was conducted on the degraded tropical soil media with the characteristics of medium to low soil fertility level, limited organic content and in 5,6 - 6,5 soil pH range. The application of SRF Bio-Phonska Plus on maize was intended to evaluate the formulation effectivity to improve the nutrient availability and nutrient use efficiency. Maize was selected as the test crop because its high demand of macro nutrients, while the conventional fertilizers such as NPK 15-15-15 are common to rapidly released and it risks to the lost of nutrients due to washing, volatilization and soil fixation. Fertilizer effectivitty evaluation was conducted by measuring some growth indicators and results including plant height, stem diameter, leaf count and the maize ear weight. The result data then analyzed by using DMRT test (Duncan's Multiple Range Test) with 5% significance level to examine the actual difference between treatments, thus it can be concluded whether the application of SRF Bio-Phonska Plus have a significant effects compares to conventional fertilizer NPK 15-15-15. The experimental design employed in this study was a Completely Randomized Design (CRD) consisting of four treatments with three replications, resulting in a total of 12 experimental units at a 95% confidence level. The CRD was selected because the experimental environment was relatively homogeneous and did not exhibit dominant blocking factors, allowing variation among experimental units to be assumed as random. The treatments consisted of J0 (7.5 g Phonska) as the control, J1 (5 g SRF Bio-Phonska Plus fertilizer), J2 (7.5 g SRF Bio-Phonska Plus fertilizer), and J3 (10 g SRF Bio-Phonska Plus fertilizer). To clarify differences among treatments, data on plant height, number of leaves, stem diameter, and cob weight were presented graphically in Figure 3. These graphs provide a clear visual representation of vegetative growth patterns and generative yield responses of maize under each SRF Bio-Phonska Plus fertilizer treatment.

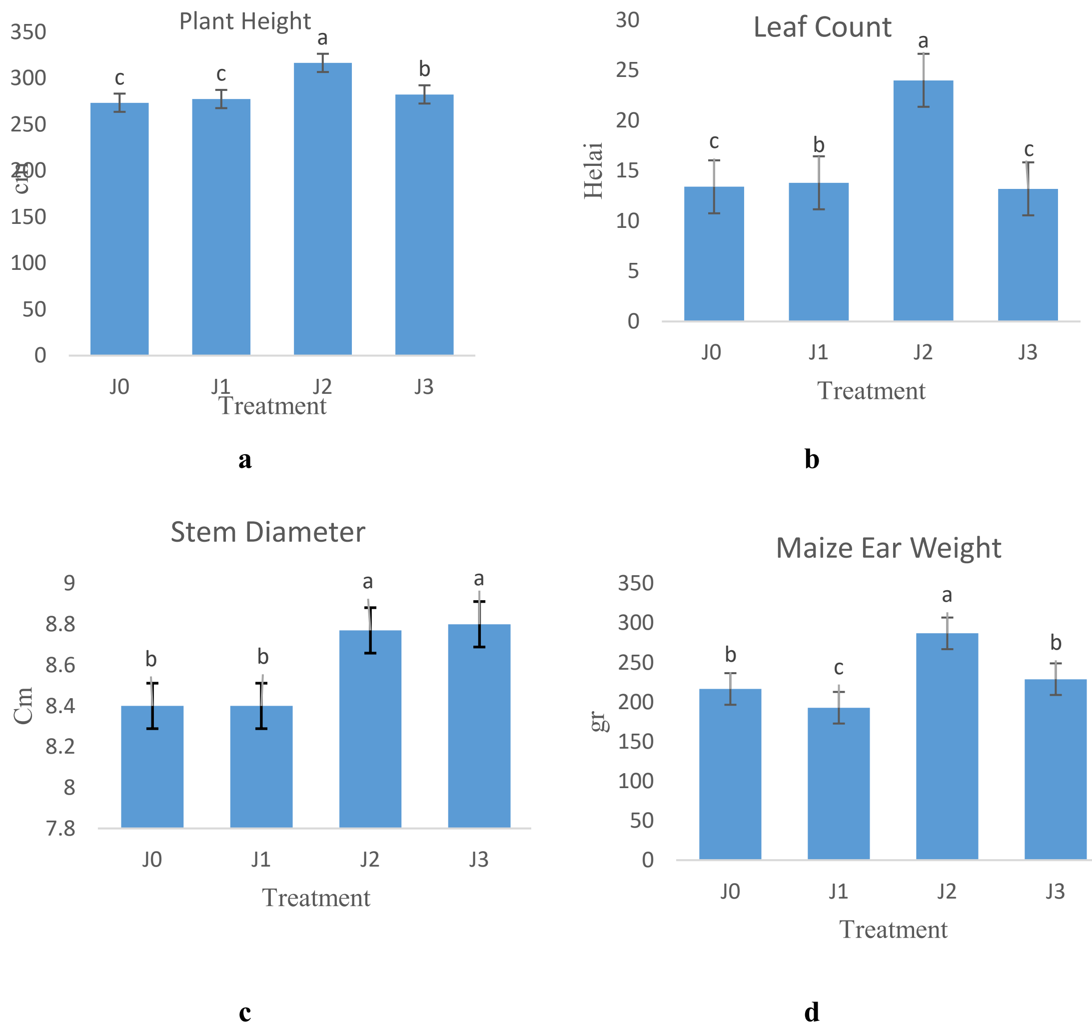

Figure 3. The effect of fertilizer treatment on (a) plant height, (b) leaf count, (c) stem diameter at 100 days after planting, and (d) maize ear weight. Data is presented as average values with SD = ±3. Difference alphabeth above diagram indicates the actual differences between treatment based on 5% DMRT test

The graph illustrates the growth dynamics and result of maize crop in various parameter (plant height, leaf count, stem diameter and maize ear weight) as a response to the SRF Bio-Phonska Plus treatment. Generally, the graph demonstrates the difference between treatment indicating fertilizer combination have a strong impact to the improvement of vegetative growth and crop generative result compares to control. Generally, the J2 treatment (SRF-Bio Phonska Plus 7,5 g) consistently offered the best results along all growth and harvest parameter. During the initial vegetative phase (28 days after planting), J2 indicates the highest value oh plant height, leaf count and stem diameter compares to conventional fertilizer (J0) and any other treatment. This trend continued until 100 days after planting where J2 remained superior in plant height (316,57 cm), leaf count (24 leaves) and maize ear weight (286,87 g). The J1 (5 g) and J3 (10 g) treatments showed better results compares to control, but not as optimal as J2. This concludes that the dosage of 7,5 g was the optimum dose. If the dose was too low, the nutrient is not yet able to meet the plant nutrient demand to the maximum while the excessive dose has potential to decrease nutrient use efficiency due to the imbalance nutrient and the rows of nutrient losses. Statistically, the significance differences of the treatment were examined by ANOVA and followed by post hoc testing ($p<0,05$). Most of the parameter revealed that the used research design was statistically strong (post hoc statistical power). Consistency of J2 superiority for all parameters and followed by low data variability between repetitions. These findings support the role of biochar for improving water retention and nutrient availability and also nanochitosan as encapsulant that gradually regulates the nutrient release. The synchronized release of nutrient and physiological demand of plants was proven capable to support the plant vegetative growth (height, leaves, stem) and generative (maize weight) to the optimum conditions. This is in line with the findings from Park et al. (2021) that reported biochar application improved the maize growth for a long term specifically in its height and biomass. This improvement is also supported by Gaurav et al. (2025) that reported biochar fixed the fine root system and corn grain yield by using the changes in microbial community at Rhizosphere that led to the nutrient use efficiency. Furthermore, the field study in Ghana found that the appropriate biochar dosage significantly increased up to 100% the maize harvest compares to control (Abdul-Aziz et al., 2025), and this is in line with the result of J2 treatment. The synergistic effect of biochar application with inorganic fertilizer was also proven by Faloye et al. (2019) that reported the improvement of stem diameter, leaf count and maize yield. On the other hand, the aspect of nitrogen use efficiency is also contributed, Preza Fontes et al. (2024) stated that biochar reduces the nitrogen losses while increasing nitrogen use efficiency of the maize. Thus, it can be concluded that the findings of this research further reinforce that SRF Bio-Phonska Plus fertilizer is the most effective formulation to improve the maize growth and yield due to its relevance with the other researches that stated the role of biochar in fixing the plant growth, nutrient availability and nitrogen use efficiency (Masulili et al., 2025).

Conclusions: SRF Bio-Phonska Plus fertilizer was proven to be effective to improve the maize growth and yield. The dosage of 7,5 g produces the highest value of vegetative growth (height, leaves, stem) and generative (maize weight) by using 5% DMRT test. This success is supported by the role of biochar in retinting water, nutrient availability and also nanochitosan as fertilizer encapsulant regulating the nutrient release according to plant demands. Generally, these findings demonstrate the potential of nanochitosan-coated SRF application to the sustainability agricultural system by using the reduction of nutrient losses and fertilization frequency which has implication to the cost efficiency and farmer adoption. The result of this research also provides a scientific basis for environmentally friendly fertilization policy development. The limitation of this research is on the relatively small scale, short duration of the experiment and the involvement of only a single crop species without economical and soil microbial analysis. Therefore, further studies are required by using long term field experiments involving multiple crop types, and economical-ecological assessments to strengthen the nanochitosan-coated SRF field application.

Author contributions

A. L. is fully responsible for conceptualizing the study, designing the methodology, collecting primary and secondary data, and writing the initial draft of the manuscript. A. R. P. conducts in-depth analysis of the data, interprets the results, and contributes to the analysis and discussion sections. W. R. K. provides critical input, reviews the methodology, results, and conclusions, and edits the manuscript for clarity and coherence. M. L. performs the final editing, ensuring technical compliance and writing style, and provides final approval. All authors have read and approved the final version of the manuscript.

Data availability statement

Data supporting the findings of this research can be obtained from correspondence upon reasonable request.

Acknowledgements

The authors sincerely acknowledge the financial support provided by the Ministry of Education, Culture, Research, and Technology through the Directorate of Research, Technology, and Community Service (DRTPM). The authors also appreciate the Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Negeri Gorontalo, for providing laboratory facilities and research infrastructure. Sincere gratitude is extended to all individuals who have contributed, directly or indirectly, to the completion of this study.

Ethical considerations

This research does not involve human or animal subjects, thus it does not require formal ethical approval.

Funding

This research is supported by the Ministry of Education, Culture, Research, and Technology through the Directorate of Research, Technology, and Community Service (DRTPM).

Conflict of interest

The authors declare that there is no conflict of interest related to this research.

References

Abdul-Aziz, A.-L., Abukari, I. A., Galadima, M. M., Haruna, A., Abubakari, M., & Abdulai, R. (2025). Biochar effects on soil properties and yield of maize in Northern region, Ghana. *Discover Agriculture*, *3*(1), Article 271. https://doi.org/10.1007/s44279-025-00271-y

Afshar, M., & Mofatteh, S. (2024). Biochar for a sustainable future: Environmentally friendly production and diverse applications. *Results in Engineering*, *23*, Article 102433. https://doi.org/10.1016/j.rineng.2024.102433

Ali, S. W., Joshi, M., & Rajendran, S. (2011). Synthesis and characterization of chitosan nanoparticles with enhanced antimicrobial activity. *International Journal of Nanoscience*, *10*(4-5). https://doi.org/10.1142/S0219581X1100868X

Biernat, M., Woźniak, A., Chraniuk, M., Panasiuk, M., Tymowicz-Grzyb, P., Pagacz, J., Antosik, A., Ciołek, L., Gromadzka, B., & Jaegermann, Z. (2023). Effect of selected crosslinking and stabilization methods on the properties of porous chitosan composites dedicated for medical applications. *Polymers*, *15*(11), Article 2507. https://doi.org/10.3390/polym15112507

Blebea, N. M., Pușcașu, C., Vlad, R. A., & Hancu, G. (2025). Chitosan-based gel development: Extraction, gelation mechanisms, and biomedical applications. *Gels*, *11*(4), Article 275. https://doi.org/10.3390/gels11040275

Boero, A., Mercier, A., Mounaïm-Rousselle, C., Valera-Medina, A., & Ramirez, A. D. (2023). Environmental assessment of road transport fueled by ammonia from a life cycle perspective. *Journal of Cleaner Production*, *390*, Article 136150. https://doi.org/10.1016/j.jclepro.2023.136150

Chen, Y., Xu, M., Yang, L., Jing, H., Mao, W., Liu, J., Zou, Y., Wu, Y., Zhou, H., Yang, W., & Wu, P. (2023). A critical review of biochar application for the remediation of greenhouse gas emissions and nutrient loss in rice paddies: Characteristics, mechanisms, and future recommendations. *Agronomy*, *13*(3), Article 893. https://doi.org/10.3390/agronomy13030893

Choudhary, R. C., Kumaraswamy, R. V., Kumari, S., Pal, A., Raliya, R., Biswas, P., & Saharan, V. (2017). Synthesis, characterization, and application of chitosan nanomaterials loaded with zinc and copper for plant growth and protection. In *Nanotechnology: An agricultural paradigm* (pp. 167-184). Springer. https://doi.org/10.1007/978-981-10-4573-8_10

Faloye, O. T., Alatise, M. O., Ajayi, A. E., & Ewulo, B. S. (2019). Effects of biochar and inorganic fertiliser applications on growth, yield and water use efficiency of maize under deficit irrigation. *Agricultural Water Management*, *217*, 181-193. https://doi.org/10.1016/j.agwat.2019.02.044

Gaurav, S., Diptanu, B., Mehta, C. M., Prasann, K., Nishihara, E., Inubushi, K., Sudo, S., Hayashida, S., Patra, P. K., Minkina, T., & Rajput, V. D. (2025). Effects of biochar amendment at various soil depths on maize roots and growth indices. *Scientific Reports*, *15*(1), Article 9218. https://doi.org/10.1038/s41598-025-09218-1

Gumelar, M. D., Hamzah, M., Hidayat, A. S., Saputra, D. A., & Idvan. (2020). Utilization of chitosan as coating material in making NPK slow release fertilizer. *Macromolecular Symposia*, *391*(1), Article 1900188. https://doi.org/10.1002/masy.201900188

Hoang, N. H., Thanh, T. Le, Sangpueak, R., Treekoon, J., Saengchan, C., Thepbandit, W., Papathoti, N. K., Kamkaew, A., & Buensanteai, N. (2022). Chitosan nanoparticles-based ionic gelation method: A promising candidate for plant disease management. *Polymers*, *14*(4), Article 662. https://doi.org/10.3390/polym14040662

Hu, J., Yang, Y., Zhang, H., Li, Y., Zhang, S., He, X., Huang, Y., Ye, Y., Zhao, Y., & Yan, J. (2023). Reduction in nitrogen rate and improvement of nitrogen use efficiency without loss of peanut yield by regional mean optimal rate of chemical fertilizer based on a multi-site field experiment in the North China Plain. *Plants*, *12*(6), Article 1326. https://doi.org/10.3390/plants12061326

Khudhair, D., Amani Hamedani, H., Gaburro, J., Shafei, S., Nahavandi, S., Garmestani, H., & Bhatti, A. (2017). Enhancement of electro-chemical properties of TiO_2 nanotubes for biological interfacing. *Materials Science and Engineering: C*, *77*, 111-120. https://doi.org/10.1016/j.msec.2017.03.112

Kubavat, D., Trivedi, K., Vaghela, P., Prasad, K., Vijay Anand, G. K., Trivedi, H., Patidar, R., Chaudhari, J., Andhariya, B., & Ghosh, A. (2020). Characterization of a chitosan-based sustained release nanofertilizer formulation used as a soil conditioner while simultaneously improving biomass production of *Zea mays* L. *Land Degradation & Development*, *31*(17), 2734-2746. https://doi.org/10.1002/ldr.3629

Masulili, A., Suryani, R., & Kurniadi, E. (2025). The use of biochar and fertilizer to maximize the growth and yield of ginger on degraded alluvial soil. *Journal of Degraded and Mining Lands Management*, *12*(3), 7523-7532. https://doi.org/10.15243/jdmlm.2025.123.7523

Nurdin, I. (2022). Pemetaan lahan kritis menggunakan sistem informasi geografis di Kecamatan Sumalata Provinsi Gorontalo [Mapping of critical land using geographic information system in Sumalata District, Gorontalo Province]. *Geodika: Jurnal Kajian Ilmu Dan Pendidikan Geografi*, *6*(2), 232-243. https://doi.org/10.29408/geodika.v6i2.6531

Oladeji, O., Tian, G., Cooke, R., Cox, A., Zhang, H., & Podczerwinski, E. (2022). Capture of surface water runoff for irrigation of corn in western Illinois: Implications for nutrient loss reduction. *Journal of Soil and Water Conservation*, *77*(3), 289-298. https://doi.org/10.2489/jswc.2022.00060

Park, J. C., Sp, N., Kim, H. D., Kang, D. Y., Kim, I. H., Bae, S. W., Yang, Y., & Jang, K. J. (2021). The exogenous application of non-toxic sulfur contributes to the growth-promoting effects of leaf lettuce (*Lactuca sativa* L. var. crispa). *Agriculture*, *11*(8), Article 769. https://doi.org/10.3390/agriculture11080769

Preza-Fontes, G., Greer, K. D., & Pittelkow, C. M. (2024). Does biochar improve nitrogen use efficiency in maize? *GCB Bioenergy*, *16*(1), Article e13122. https://doi.org/10.1111/gcbb.13122

Quintarelli, V., Ben Hassine, M., Radicetti, E., Stazi, S. R., Bratti, A., Allevato, E., Mancinelli, R., Jamal, A., Ahsan, M., Mirzaei, M., & Borgatti, D. (2024). Advances in nanotechnology for sustainable agriculture: A review of climate change mitigation. *Sustainability*, *16*(21), Article 9280. https://doi.org/10.3390/su16219280

Rahman, K. M. A., & Zhang, D. (2018). Effects of fertilizer broadcasting on the excessive use of inorganic fertilizers and environmental sustainability. *Sustainability*, *10*(3), Article 759. https://doi.org/10.3390/su10030759

Sharma, S., Mukherjee, S., Bolan, S., de Figueiredo, C. C., Fachini, J., Chang, S. X., Palansooriya, K. N., Zhou, P., Hou, D., Kaya, C., Siddique, K. H. M., & Bolan, N. (2025). Biochar as a potential nutrient carrier for agricultural applications. *Current Pollution Reports*, *11*(1), 1-18. https://doi.org/10.1007/s40726-025-00349-7

Singh, M., Goswami, S. P., Ranjitha, G., Sachan, P., Sahu, D. K., Beese, S., & Pandey, S. K. (2024). Nanotech for fertilizers and nutrients-improving nutrient use efficiency with nano-enabled fertilizers. *Journal of Experimental Agriculture International*, *46*(5), 220-247. https://doi.org/10.9734/jeai/2024/v46i52372

Vejan, P., Khadiran, T., Abdullah, R., & Ahmad, N. (2021). Controlled release fertilizer: A review on developments, applications and potential in agriculture. *Journal of Controlled Release*, *339*, 321-334. https://doi.org/10.1016/j.jconrel.2021.10.003

Wang, C., Lv, J., Xie, J., Yu, J., Li, J., Zhang, J., Tang, C., Niu, T., & Patience, B. E. (2021). Effect of slow-release fertilizer on soil fertility and growth and quality of wintering Chinese chives (*Allium tuberm* Rottler ex Spreng.) in greenhouses. *Scientific Reports*, *11*(1), Article 87593. https://doi.org/10.1038/s41598-021-87593-1

Wang, L., Olsen, M. N. P., Moni, C., Dieguez-Alonso, A., de la Rosa, J. M., Stenrød, M., Liu, X., & Mao, L. (2022). Comparison of properties of biochar produced from different types of lignocellulosic biomass by slow pyrolysis at 600 °C. *Applications in Energy and Combustion Science*, *12*, Article 100090. https://doi.org/10.1016/j.jaecs.2022.100090

Wang, N., Wang, J., Liu, P., Yin, R., Han, Q., Yu, W., Tuo, Y., & Wang, S. (2025). Optimizing biochar-based slow-release fertilizers (BSRFs): Comprehensive impacts of binder types, pyrolysis temperatures, and nutrient formulations on mechanical strength and nutrient release dynamics. *Industrial Crops and Products*, *232*, Article 121277. https://doi.org/10.1016/j.indcrop.2025.121277

Wang, X., Wang, X., Sheng, H., Wang, X., Zhao, H., & Feng, K. (2022). Excessive nitrogen fertilizer application causes rapid degradation of greenhouse soil in China. *Polish Journal of Environmental Studies*, *31*(2), 1527-1534. https://doi.org/10.15244/pjoes/143293

Zaman, W., Ayaz, A., & Park, S. J. (2025). Nanomaterials in agriculture: A pathway to enhanced plant growth and abiotic stress resistance. *Plants*, *14*(5), Article 716. https://doi.org/10.3390/plants14050716

مجله بیوتکنولوژی کشاورزی
شاپا چاپی: ۲۲۲۸-۶۷۰۵ شاپا الکترونیکی: ۲۲۲۸-۶۵۰۰

تبدیل پسماند پوسته میگو به کود آهسته‌رهش بیوچار-نانوکیتوزان برای افزایش بهره‌وری ذرت

آستین لوکوم

*نویسنده مسئول. دانشکده ریاضیات و علوم طبیعی، دانشگاه دولتی گورونتالو، اندونزی. ایمیل: astin.lukum@ung.ac.id

آرفیانی ریزکی پاراماتا

دانشکده شیلات و علوم دریایی، دانشگاه دولتی گورونتالو، اندونزی. ایمیل: arfiani@ung.ac.id

ویوین روینی کونوسا

دانشکده ریاضیات و علوم طبیعی، دانشگاه دولتی گورونتالو، اندونزی. ایمیل: rewinikunusa2014@gmail.com

مگدالنا لیتای

دانشکده ریاضیات و علوم طبیعی، دانشگاه حسن‌الدین، اندونزی. ایمیل: mlitaay@fmipa.unhas.ac.id

تاریخ دریافت: ۱۴۰۴/۱۰/۰۲ تاریخ دریافت فایل اصلاح شده نهایی: ۱۴۰۴/۱۱/۲۷ تاریخ پذیرش: ۱۴۰۴/۱۱/۲۸

چکیده

هدف: این مطالعه با هدف توسعه و ارزیابی یک کود آهسته‌رهش مبتنی بر بیوچار-نانوکیتوزان (SRF-Bio Phonska Plus) مشتق‌شده از پسماندهای کشاورزی و شیلاتی و تعیین دوز بهینه مصرف آن برای بهبود رشد رویشی و عملکرد ذرت کشت‌شده در خاک‌های تخریب‌شده مناطق گرمسیری انجام شد. به‌طور خاص، اثر مقادیر مختلف این کود بر ارتفاع بوته، تعداد برگ، قطر ساقه و وزن بلال ذرت در مقایسه با کود متداول Phonska بررسی گردید.

مواد و روش‌ها: این پژوهش از ژوئن تا سپتامبر ۲۰۲۵ در آزمایشگاه شیمی دانشکده ریاضیات و علوم طبیعی دانشگاه دولتی گورونتالو انجام شد. نانوکیتوزان از کیتوزان استخراج‌شده از پوسته میگو با استفاده از روش ژلاسیون یونی و سدیم تری‌پلی‌فسفات به‌عنوان عامل پیونددهنده سنتز شد و سپس به روش خشک‌کردن پاششی تهیه گردید. بیوچار از پسماند بلال ذرت از طریق پیرولیز در دمای ۵۰۰ درجه سانتی‌گراد و در شرایط اکسیژن محدود تولید شد. فرمولاسیون کود با دانه‌بندی کود Phonska و بیوچار در نسبت ۳ به ۷ و با استفاده از ملاس به‌عنوان چسب تهیه شد و سپس با محلول ۱٪ نانوکیتوزان پوشش‌دهی سطحی گردید تا گرانول‌های SRF-Bio Phonska Plus تشکیل شود. رفتار آزادسازی عناصر نیتروژن (N)، فسفر (P) و پتاسیم (K) با آزمون

غوطه‌وری ایستا در آب ارزیابی شد. آزمایش مزرعه‌ای بر اساس طرح کاملاً تصادفی با چهار تیمار و سه تکرار اجرا گردید و داده‌ها با آزمون آنالیز واریانس (ANOVA) و سپس آزمون چنددامنه‌ای دانکن (DMRT) در سطح معنی‌داری ۰/۰۵ تحلیل شدند.

نتایج: نتایج مشخصه‌یابی نشان داد نانوکیتوزان سنتزشده دارای اندازه متوسط ذرات حدود ۵۵۲ نانومتر با مورفولوژی متخلخل و تقریباً کروی است که برای کپسوله‌سازی عناصر غذایی مناسب می‌باشد. بیوچار دارای رطوبت و خاکستر پایین بود که نشان‌دهنده پایداری ساختاری و ظرفیت جذب مطلوب آن است. کود SRF-Bio Phonska Plus آزادسازی عناصر N، P و K را به‌صورت آهسته‌تر و کنترل‌شده‌تر نسبت به کود متداول نشان داد. در کاربرد روی ذرت، تیمار ۷/۵ گرم از SRF-Bio Phonska Plus بیشترین ارتفاع بوته، تعداد برگ، قطر ساقه و وزن بلال را تولید کرد و نسبت به دوزهای کمتر و بیشتر و همچنین کود متداول عملکرد بهتری داشت.

نتیجه‌گیری: ادغام بیوچار حاصل از بلال ذرت و نانوکیتوزان مشتق از پسماند پوسته میگو در فرمولاسیون SRF-Bio Phonska Plus به‌طور مؤثری کارایی مصرف عناصر غذایی و بهره‌وری ذرت را در خاک‌های تخریب‌شده افزایش داد. دوز بهینه ۷/۵ گرم موجب همزمانی آزادسازی عناصر غذایی با نیاز گیاه شده و رشد رویشی و زایشی را بهبود بخشید. این فرمولاسیون پتانسیل بالایی به‌عنوان راهبردی پایدار و سازگار با محیط‌زیست برای کشاورزی مناطق گرمسیری دارد.

کلمات کلیدی: بیوچار، ذرت، رشد گیاه، نانوکیتوزان، SRF-Bio Phonska Plus

نوع مقاله: پژوهشی

استناد: آستین لوکوم، آرفیانی ریزکی پاراماتا، ویوین روینی کونوسا، مگدالنا لیتای (۱۴۰۵) تبدیل پسماند پوسته میگو به کود آهسته‌رهش بیوچار–نانوکیتوزان برای افزایش بهره‌وری ذرت. *مجله بیوتکنولوژی کشاورزی*، ۱۸(۲)، ۴۴۹–۴۶۶.

Publisher: Shahid Bahonar University of Kerman & Iranian Biotechnology Society.