PREPARATION OF BORON-INTEGRATED POLYMER MATERIALS AS COATING FOR SLOW-RELEASE UREA FERTILIZERS CONTAINING MICRONUTRIENT

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Abstract. Micronutrients play an important role in plant growth, quality and productivity. Therefore, many multi-nutrient inorganic fertilizers combined with micronutrient supplements have been researched and commercialized in recent years. This study aims to develop new urea fertilizers that are both slow-release and provide essential micronutrients. These products are manufactured using particle coating technology with polymer materials incorporating micronutrient boron. The polymer materials are synthesized from starch, modified starch, sodium alginate, polyvinyl alcohol, and solubor, possessing good mechanical properties, film-forming ability, and biodegradability. The products were analyzed using modern methods such as SEM, FTIR, XRD, and ICP. The results of study show that the products have a nutrient release time more than 5 times longer than conventional urea fertilizer while simultaneously providing appropriate amounts of micronutrients.

Keywords. Boron-integrated polymer, micronutrients, particle coating technology, slow-release urea release.

1 INTRODUCTION

Micronutrients are substances required by plants in significantly smaller amounts than macronutrients but play a crucial role in plant growth and yield improvement. These elements are indispensable for many metabolic functions, enzyme activities, and the development of internal plant parts, supporting processes such as photosynthesis, respiration, and the synthesis of essential compounds [1]. Essential micronutrients used for crops include boron (B), sulfur (S), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). These substances are provided naturally by minerals and organic matter in the soil or can be supplemented through organic or inorganic fertilizers [2].

Most agricultural land in Vietnam consists of sandy, humus, basaltic red, and grey soils, which have low micronutrient content and unsuitable pH levels, reducing the ability of plants to absorb the micronutrients. Furthermore, continuous cultivation, multiple cropping seasons per year, and excessive use of inorganic fertilizers have depleted nutrient sources and reduced the soil's capacity for recovery. Soil properties and structure have also changed due to unreasonable cultivation and irrigation practices, along with the heavy use of pesticides, growth stimulants, and soil contamination by heavy metals, which further exacerbate this situation. Additionally, the increasing impact of climate change (such as drought, flooding, acidification, saltwater intrusion, and the lack of alluvial deposits) has significantly affected the ability to maintain sufficient micronutrients for plants. Therefore, supplementing micronutrients through fertilizers is essential in modern agricultural production. However, effective management of micronutrient application plays a critical role in optimizing plant health, yield, and the sustainability of farming systems.

Many micronutrient fertilizer products have been researched and commercialized in recent years, such as metal sulfate salts, metal oxides, metal chelate complexes, borates, boric acid, and organic fertilizers, which are applied to the soil or sprayed on leaves [3]. However, due to direct application, the nutrient absorption efficiency of crops is relatively low, and most of the excess is leached or lost to the environment, which can cause toxicity and water pollution [4]. In addition, applying micronutrient fertilizers separately from conventional fertilizers changes farming practices, increases labor days, raises production costs, and makes it difficult to control nutrient uniformity [5]. Therefore, single and multi-nutrient inorganic fertilizers (N, P, K) combined with micronutrient components with dual properties have become more popular in modern agricultural production. These products provide both micronutrients and macronutrients simultaneously in proportions suitable for specific crops and agricultural production conditions, helping to reduce cultivation costs, labor, and raw material usage.

A series of slow-release micronutrient fertilizers based on zinc and copper compounds were introduced by Ray et al. [6,7]. The products were formed from reactions of short-chain polyphosphates of metal ions,

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which are capable of reducing solubility and hygroscopicity. Subsequently, Bandyopadhyay et al. (2014) [8] described a production process for a slow-release micronutrient fertilizer based on the polymerization reaction of substances such as phosphoric acid, zinc oxide, hematite, pyrolusite, copper sulfate, and magnesium oxide, followed by neutralization of the polyphosphate chain with ammonium hydroxide. This fertilizer is a crystalline polyphosphate of Zn-Fe-Mn-Cu-Mg-NH_4 with low water solubility and demonstrates good crop uptake. In 2021, Chiaregato and Faez developed a starch-based material for coating fertilizer granules to increase fertilizer efficiency and minimize losses and environmental issues [9]. Simultaneously, they incorporated micronutrients (Fe, Cu, Mn) with a gelatinized starch mixture to provide micronutrients to crops. The coating consists of microparticles produced by spray drying, which have improved release times but irregular shapes and high swelling potential. Shortly thereafter, research on developing alkyd coatings containing micronutrients (Zn and B) to create controlled-release urea fertilizers was published by Boonying et al. [10]. The production methods for these products are costly, the granulation process is complex, the production conditions are difficult to apply in practice, and it is difficult to adjust the release time and micronutrient composition to suit specific crops.

In Vietnam, research on fertilizers combining macronutrient and micronutrient components is very limited. Some studies by Tran Quoc Toan et al. on the synthesis of slow-release urea fertilizer with a polyurethane coating and additives were published in 2017 [11], followed by a urea–kaolinite slow-release fertilizer product that had uniform size, met the standards for slow-release fertilizers, and helped supplement micronutrients thanks to kaolinite [12]. Meanwhile, in the domestic fertilizer market, a series of macronutrient fertilizers combined with micronutrients have been produced and commercialized. These products are diverse and come from many large domestic fertilizer manufacturers such as Dam Phu My, Dam Ca Mau, Binh Dien, etc., to meet the requirements of agricultural production [13-17].

Based on the assessment of the current usage, demand, and fertilizer production market, the development of fertilizer products combining macronutrient and micronutrient components is an inevitable requirement in modern agricultural production, suitable for climate change conditions and the degradation of natural resources. The product provides essential nutrients simultaneously so that plants can develop stably and continuously, reducing the time and frequency of fertilization, and saving production costs and raw materials.

The aim of research is to propose new slow-release urea fertilizers (SRUF) that both increase release time and provide the essential micronutrient boron to plants. These products are manufactured using particle coating technology with biodegradable, inexpensive, and easily synthesized polymer coating materials, which help increase fertilizer efficiency, reduce the potential for nutrient release and loss to the environment, thereby helping to reduce production costs, decrease environmental and human health impacts, and avoid resource depletion. These products are not only more effective than traditional inorganic fertilizers but also superior to the micronutrient-supplemented fertilizer products currently on the market.

2 MATERIALS AND METHODS

2.1 Synthesis of boron-integrated polymer materials as coating materials

The materials used include tapioca starch (TS), phosphated starch (PS) provided by Nam Bao Tin Company (Vietnam), and sodium alginate (SA, 98%, Cool Chemistry, China). The materials were dissolved in 100 mL of distilled water according to the ratios in Table 1 at a temperature of 70ºC, with a stirring speed of 200 rpm for 30 minutes. After the mixture reached a homogeneous state, polyvinyl alcohol (PVA, HiMedia, India) was added slowly, and the temperature and stirring speed were stabilized for 40 minutes. Subsequently, Disodium Octaborate Tetrahydrate powder (DOT, Solubor, $Na_2B_8O_{13}.4H_2O$, 99%, Valudor Products, USA) was added slowly at a stirring speed of 300 rpm until the required amount of DOT was completely dissolved. The solutions at each synthesis stage were taken to determine the density using a hydrometer and the viscosity using a Prona RV2 viscometer.

Table 1: Composition of synthesis materials

Hỗn hợp	Mass of TS (g)	Mass of PS (g)	Mass of SA (g)	Volume (mL)	Mass of PVA (g)	Mass of DOT (g)
TS-B	4.0	0	0	100	0.5	25.0

SA-B	0	0	2.5	100	0.5	25.0
PS-B	0	4.0	0	100	0.5	25.0

2.2 Production of slow-release urea fertilizer containing Boron micronutrient

The solution after synthesis is checked and its viscosity adjusted, then fed into a automatic spraying system Prona RA-100RC (Taiwan) to create a coating film. The urea raw material used is commercially available granular urea from Ca Mau petroleum fertilizer company (UF). The raw material is sorted using a sieve system with sizes ranging from 2.83 to 4.76 mm from RETSCH (Germany) before being fed into the coating equipment. The coating process is carried out in a pan coating system with a diameter of 0.5 m. The material weight is 50g, the angle of the pan is 40°, the spray flow rate is 1.5 ml/min, the coating time is 30 minutes, the rotation speed is 60 rpm, the drying agent temperature is 70 °C, and the drying agent flow rate is 45 m^3/h. The coated product was then dried at 70°C for 10 minutes.

2.3 Determining the release rates of urea and Boron

The release rate of nutrients (urea and boron) was determined by adding 0.50 g of the product to 100 mL of deionized water and maintaining it at 25 °C. At each interval, 2 mL of the solution was used to determine the nutrient content. The release rate (g_i) was determined according to Equation (1).

$$g_i = \frac{C_i}{C_*} \quad (1)$$

In which, C_i is the nutrient content of the products at the sampling times, C_* is the total soluble nutrient content determined by cutting 0.50 g of product granules into 100 mL of deionized water, stirring for 30 minutes at 200 rpm.

The soluble urea content was determined by spectrophotometric method [18]. The sample was mixed with the reagent and measured by a GENESYS 20 photometer (Thermo Scientific, USA). The reagent was mixed from the materials p-dimethyl aminobenzaldehyde (p – DMAB, HiMedia, India), ethanol (C_2H_5OH, Xilong, China) and hydrochloric acid (HCl, 36%, Xilong, China).

The acid mixture was used to inorganicize the sample and convert B to ionic form. The sample was treated with 5 mL of concentrated HNO_3 and left for 20 minutes, then 2 mL of H_2O_2 was added to increase oxidation for 10 minutes. The sample was sealed to prevent boron evaporation. The mineralized sample was then passed into an Agilent 7700x ICP-MS system (Agilent, USA) to determine the boron content.

3 RESULTS AND DISCUSION

3.1 Characteristics of boron-integrated polymer materials

The density and viscosity of boron-integrated polymer solutions at various synthesis stages are presented in Table 2. In Stage 1, the densities of solutions prepared with SA and TS were lower than that of water, while their viscosities increased, indicating swelling of the molecules following gelatinization. In contrast, the density and viscosity of the PS solution showed negligible changes due to its low swelling capacity. Upon addition of PVA in Stage 2, the solution characteristics remained largely unchanged compared to Stage 1, as the small amount of PVA added had minimal impact. In Stage 3, both density and viscosity increased significantly due to the incorporation of DOT, which formed linkages with other components in the solution.

Table 2: Characteristics of polymer solutions

Polymer solutions	Density (kg/m^3)			Viscosity (mPa.s)		
	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
TS-B	990.5 ± 3.7	989.7 ± 4.3	1403.3 ± 2.3	84.43 ± 3.03	83.64 ± 2.64	94.46 ± 3.41
SA-B	991.2 ± 3.8	896.1 ± 1.5	1272.4 ± 5.1	84.99 ± 1.77	83.44 ± 2.34	115.51 ± 3.52
PS-B	995.1 ± 2.5	985.7 ± 4.5	1433.6 ± 4.8	58.78 ± 0.92	58.14 ± 2.59	108.44 ± 0.99

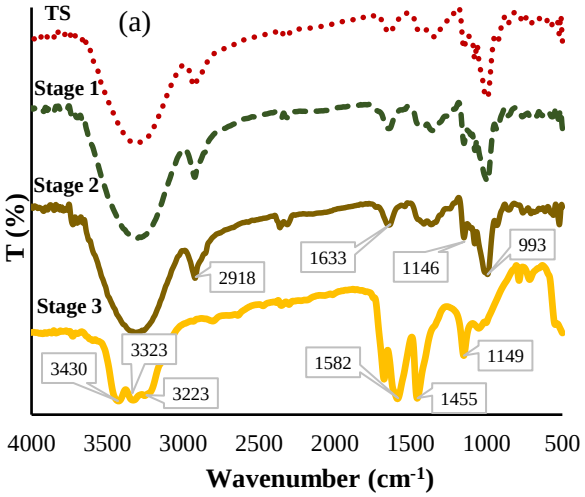
FTIR spectra of the raw materials and solutions at different stages were recorded using a FT/IR-6X spectrometer (JASCO, Japan) to evaluate changes in properties and bond formation (see Figure 1). The FTIR spectra of solutions in Stage 1 were similar to those of the initial raw materials, indicating no new bond formation. In this stage, molecules dispersed and swelled under the influence of -OH groups. Stage 2

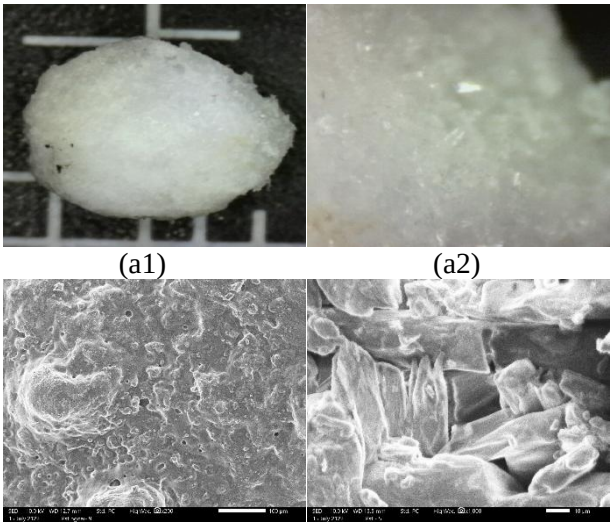
showed no significant spectral changes due to the limited PVA addition. In Stage 3, substantial changes occurred: characteristic peaks of TS, SA, and PS in the 3200–3300 cm^{-1} region split into peaks around 3170 and above 3350 cm^{-1}; peaks at 2918–2940 cm^{-1} disappeared; and new intense peaks appeared in the 1100–1450 cm^{-1} region. These observations confirm the formation of linkages between TS, SA, PS, and DOT molecules, resulting in a homogeneous system with altered physical properties suitable for seed coating applications. The XRD patterns of the PS-B polymer material in Figure 3 also show the appearance of a prominent peak at 28.24°, proving the presence of B_2O_3 crystals in the polymer composition.

3.2 Slow-release urea products containing micronutrients

The morphology of the slow-release urea granules produced using the boron-integrated polymer coatings is shown in Figure 2. Microscopic images reveal uniform surfaces (Figure 2a1, 2b1, 2c1) without air bubbles, indicating a smooth and homogeneous coating. SEM images of the granule surface (Figure 2a3, 2b3, 2c3) further confirm that the polymer particles are tightly bound and uniformly distributed across the coating layer. Cross-sectional images (Figure 2a2, 2b2, 2c2) clearly distinguish two distinct structures: the urea granule core and the outer polymer layer. The SEM cross-section images (Figure 2a4, 2b4, 2c4) provide more detailed insight into the interfacial bonding between the core and the coating layer.

Particle size distribution of the granule urea and the coated products is presented in Figure 4. The urea granules exhibit a normal distribution with particle diameters ranging from 3.2 to 4.5 mm, which is favorable for achieving uniform coating thickness. The products coated with SA-B (SRUF/SA-B) and TS-B (SRUF/TS-B) show a leftward shift in particle size distribution compared to the normal distribution, resulting in slightly thinner and less uniform coatings due to poorer surface adhesion of these polymer solutions. In contrast, the product coated with PS-B (SRUF/PS-B) maintains a normal distribution, indicating superior uniformity in both particle size and coating thickness, along with a higher coating material ratio.





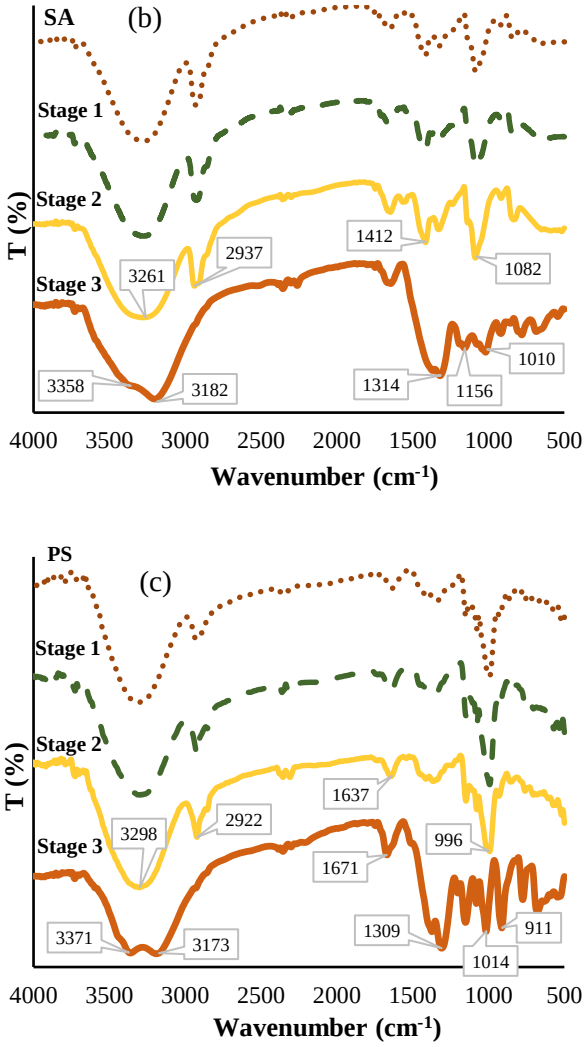


Figure 1. FTIR spectra of the raw material and the stage of the TS-B (a), SA-B (b) and PS-B (c) solutions

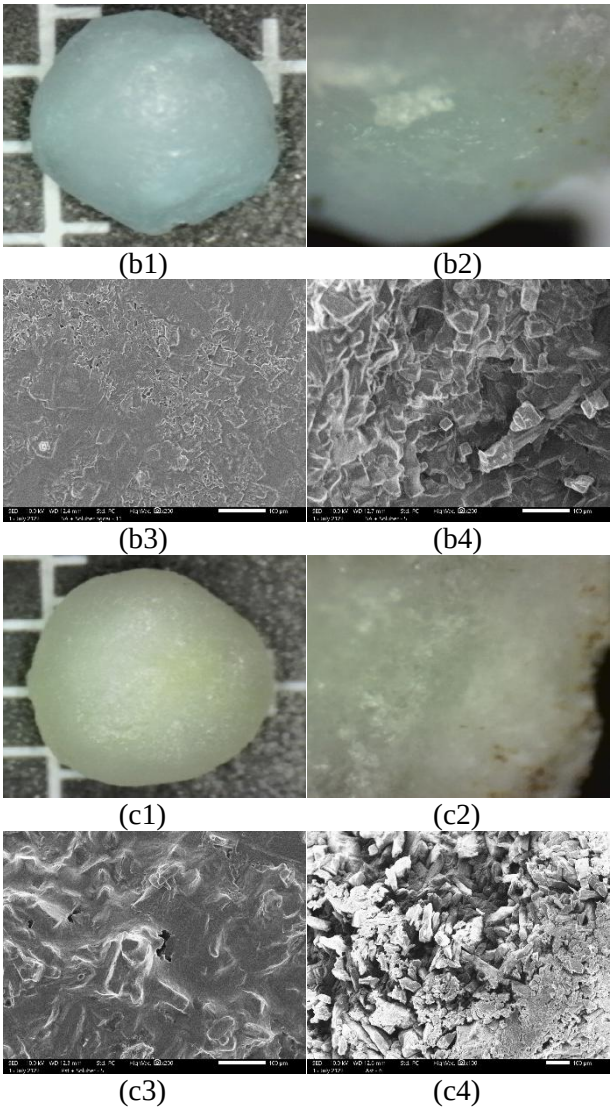


Figure 2. Surface optical, and cross-sectional images of products coated with TS-B (a), SA-B (b), and PS-B (c) polymer, taken with microscope and SEM

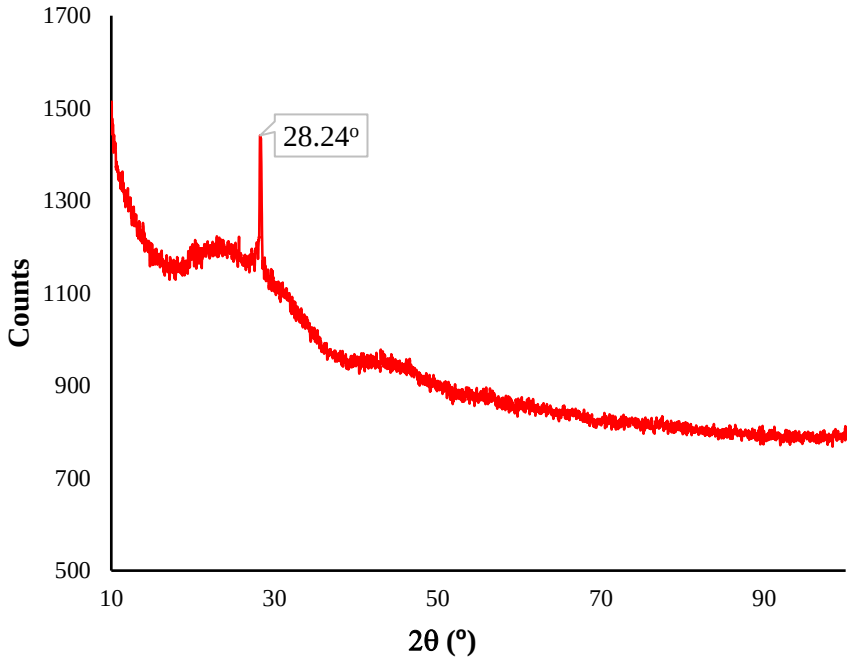


Figure 3. XRD patterns of boron-integrated polymer materials

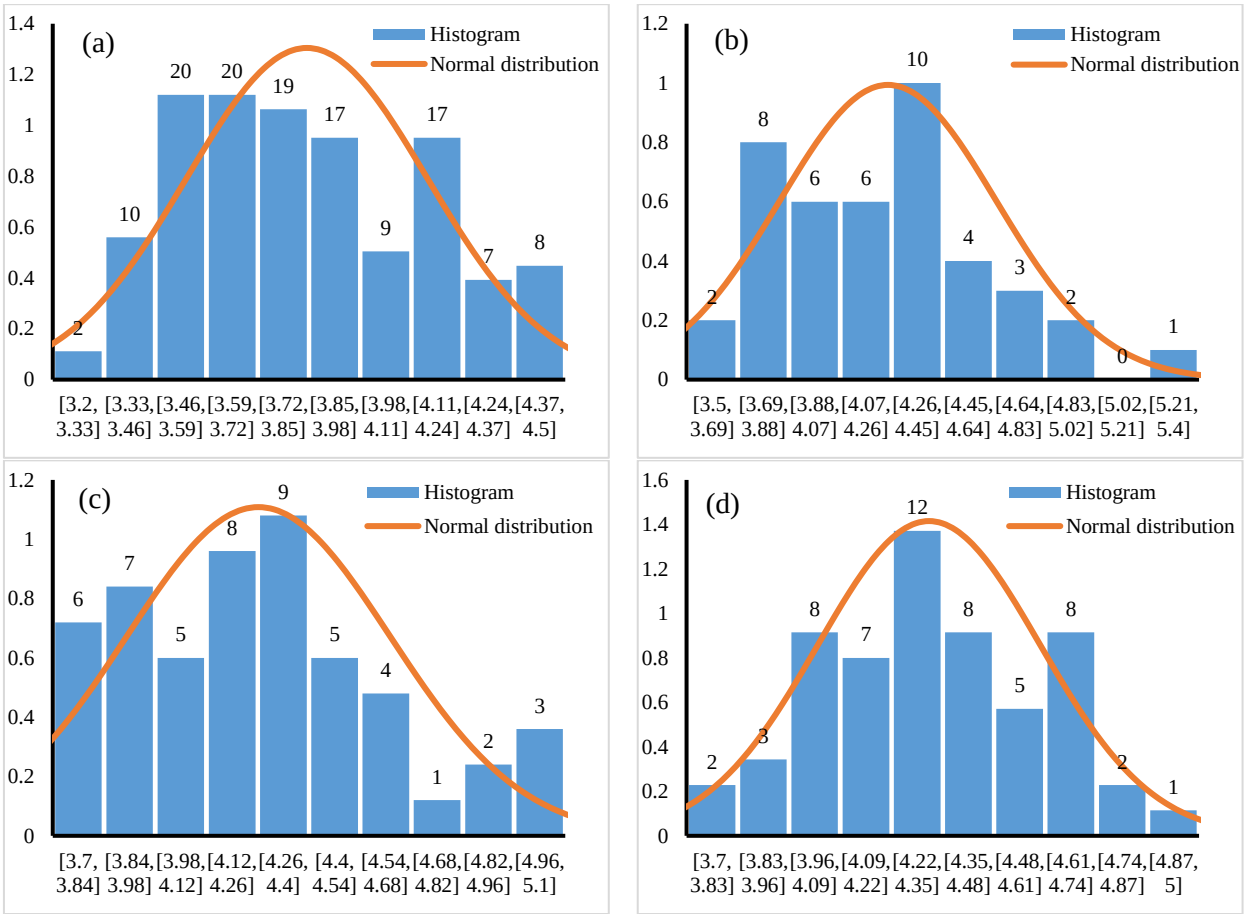


Figure 4. Particle size distribution of UF (a), SRUF/SA-B (b), SRUF/TS-B (c) and SRUF/PS-B (d)

Table 3: Properties of raw granule urea and coated products

Parameter		UF	SRUF/SA-B	SRUF/TS-B	SRUF/PS-B
d (mm)		3.845 ± 0.306	4.247 ± 0.401	4.262 ± 0.360	4.315 ± 0.282
ρ (kg/m^3)		752.78 ± 38.47	578.09 ± 35.50	575.23 ± 44.90	557.85 ± 35.84
δ (mm)		0.000	0.201	0.209	0.253
Nitrogen content	$\%N_{Cal}$ (%)	46.30	44.73	44.48	44.19
	$\%N_{Exp}$ (%)	46.30 ± 1.97	44.95 ± 0.29	45.15 ± 0.25	44.80 ± 1.50
	ε_N (%)	0.0	0.48	1.48	1.36
Boron content	$\%B_{Cal}$ (%)	0.000	0.588	0.682	0.834
	$(C_B)_{Cal}$ (ppm)	0	29.4	34.1	41.7
	$(C_B)_{Exp}$ (ppm)	0	27.1	32.2	38.6
	ε_{C_B} (%)	0	8.5	5.9	8.0

The experimental and calculated parameters of the raw material and coated products are summarized in Table 3. Coating thickness (δ) was calculated using Equation (2):

$$\delta = \frac{d_{SRUF} - d_{UF}}{2} \tag{2}$$

Nitrogen content was determined experimentally ($\%N_{Exp}$) using an FP-258 Nitrogen Determinator (LECO, USA). The calculated nitrogen content ($\%N_{Cal}$) and the relative error (ε_N) were obtained using Equations (3) and (4), respectively. Boron concentration in the coated products ($(C_B)_{Cal}$) was calculated using Equation (5).

$$\%N_{Cal} = \frac{m_{UF}}{m_{SRUF}} \cdot \%N_{UF} = \frac{V_{UF} \cdot \rho_{UF}}{V_{SRUF} \cdot \rho_{SRUF}} \cdot \%N_{UF} = \frac{d_{UF}^3 \cdot \rho_{UF}}{d_{SRUF}^3 \cdot \rho_{SRUF}} \cdot \%N_{UF} \tag{3}$$

$$\varepsilon_N = \frac{\%N_{Cal} - \%N_{Exp}}{\%N_{Exp}} . 100\% \tag{4}$$

$$(C_B)_{Cal} = \frac{0.5 \cdot \%B_{Cal}}{0.1} \cdot 10^3 \tag{5}$$

In which, $\%B_{Cal}$ is the B content in the product determined as Equation (6). $\%B_m$ is the B content in the film material calculated according to Table 1 with the B ratio in DOT being 20.5% and the moisture content in the product being negligible.

$$\%B_{cal} = \frac{m_{SRUF} - m_{UF}}{m_{SRUF}} \cdot \%B_m = \frac{d_{SRUF}^3 \cdot \rho_{SRUF} - d_{UF}^3 \cdot \rho_{UF}}{d_{SRUF}^3 \cdot \rho_{SRUF}} \cdot \%B_m \tag{6}$$

The results of Table 3 show that nitrogen content in all coated products remained above 44%, with only minor changes compared to the UF, ensuring comparable nitrogen supply to conventional fertilizers. The small errors in nitrogen calculation (ε_N) confirm good agreement between theoretical and experimental values. The difference between experimental and calculated concentration B (ε_{C_B}) is relatively high because the calculation process ignores several influencing factors such as moisture content and air bubbles. Boron concentrations in all products exceeded 5000 ppm (0.5%), meeting the requirements for high-boron micronutrient fertilizers.

3.3 Nutrient release behavior

Urea release kinetics of the raw material and products were determined using a spectrophotometric method based on the calibration curve presented in Table 4.

Figure 5 illustrates the urea release profiles. Raw urea dissolved completely within approximately 5 minutes, showing a nearly vertical curve indicative of rapid dissolution. In contrast, the coated products exhibited three distinct release phases: (1) an initial slow-release phase due to the diffusion barrier provided by the polymer coating, (2) a rapid release phase once the coating was breached, and (3) a final slowing phase as urea concentration in the solution increased and the driving force decreased. The SRUF/PS-B

product showed the longest release duration (>30 minutes), approximately 5 times longer than conventional urea.

Table 4: Calibration curve parameters for soluble urea determination

Equation	$C_{Urea} = 0.0034 \cdot A$
Range C_{Urea}	0 – 200 ppm
Range Absorbance (A)	0.000 – 0.700
R Square (R^2)	0.9986
LOD	3.984 ppm
LOQ	12.071 ppm

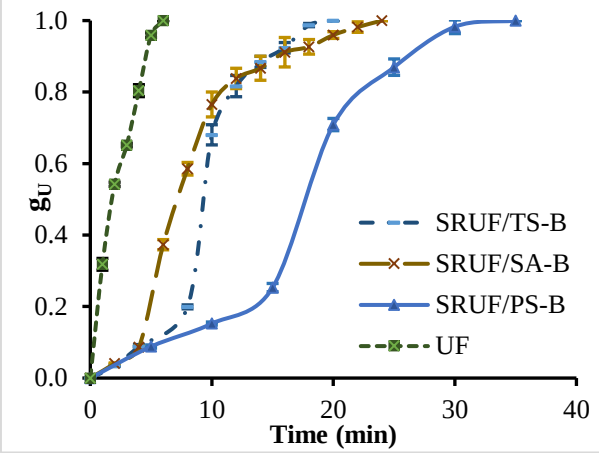


Figure 5. Kinetics of the Urea release

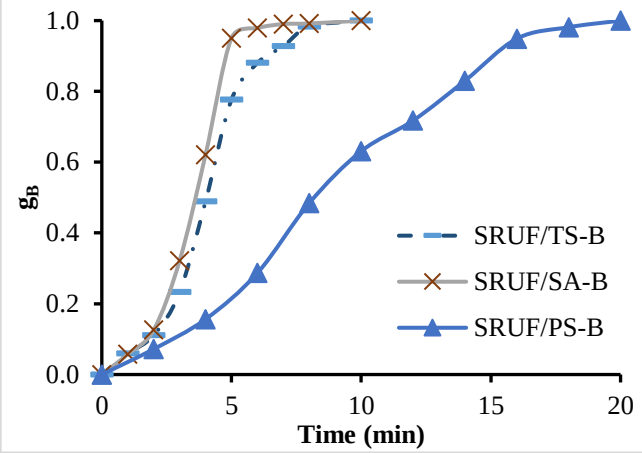


Figure 6. Kinetics of the Boron release

The boron release kinetics (Figure 6) followed an approximately linear pattern. Boron was released through gradual degradation of the polymer coating, occurring simultaneously with urea release. This synchronized release allows plants to absorb both macronutrient (nitrogen) and micronutrient (boron) concurrently.

4 CONCLUSIONS

Sodium alginate, tapioca starch, and phosphated starch combined with polyvinyl alcohol (PVA) successfully formed polymer solutions capable of incorporating DOT. These solutions exhibited appropriate biodegradability, suitable boron content, and physical properties required for effective granule coating. Slow-release urea fertilizers coated with these boron-integrated polymers demonstrated good uniformity, extended urea release time, and simultaneous supply of boron micronutrients. Among the formulations, the PS-based coating exhibited the best overall performance, with a urea release duration exceeding 30 minutes. The release kinetic curves clearly revealed distinct phases of nutrient release, providing valuable information for future optimization of release mechanisms and parameters. However, the release duration is still relatively short; further studies are recommended to fine-tune the coating formulation for longer release times and more controlled boron delivery to better meet crop requirements.

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REFERENCES

[1] H. F. Reetz, *Fertilizers and their efficient use*. Paris, France: IFA, 2016.

[2] R. Uchida, Essential nutrients for plant growth: nutrient functions and deficiency symptoms, *Plant nutrient management in Hawaii's soils*, vol. 4, pp. 31-55, 2000.
[3] N. K. Fageria, V. C. Baligar, and R. B. Clark. Micronutrients in crop production, *Advances in agronomy*, vol. 77, pp. 185-268, 2002.
[4] A. McCauley, C. Jones, and J. Jacobsen, Plant nutrient functions and deficiency and toxicity symptoms, *Nutrient management module*, vol. 9, pp. 1-16, 2009.
[5] B. J. Alloway, Micronutrients and crop production: An introduction, in *Micronutrient deficiencies in global crop production*, Dordrecht: Springer Netherlands, pp. 1-39, 2008.
[6] S. K. Ray, C. Varadachari, and K. Ghosh, Novel slow-releasing micronutrient fertilizers. 1. Zinc compounds, *Industrial & engineering chemistry research*, vol. 32, no. 6, pp. 1218-1227, 1993.
[7] S. K. Ray, C. Varadachari, and K. Ghosh, Novel slow-releasing micronutrient fertilizers. 2. Copper compounds, *Journal of Agricultural and Food Chemistry*, vol. 45, no. 4, pp. 1447-1453, 1997.
[8] S. Bandyopadhyay, K. Ghosh, and C. Varadachari, Multimicronutrient Slow-Release Fertilizer of Zinc, Iron, Manganese, and Copper, *International Journal of Chemical Engineering*, vol. 2014, no. 1, 2014.
[9] C. G. Chiaregato and R. Faez, Micronutrients encapsulation by starch as an enhanced efficiency fertilizer, *Carbohydrate Polymers*, vol. 271, 2021.
[10] P. Boonying, S. Sottiudom, P. Nontasorn, K. Laohhasurayotin and W. Kangwansupamonkon, Novel coating films containing micronutrients for controlled-release urea fertilizer: release mechanisms and kinetics study, *Polymer Bulletin*, vol. 80, no. 9, pp. 9627-9649, 2023.
[11] Q. T. Trần, T. G. Bùi and T. H. Vũ, Nghiên cứu tổng hợp phân bón ure nhả chậm với vỏ bọc polyme và phụ gia có nguồn gốc thiên nhiên, *TNU Journal of Science and Technology*, vol. 173, no. 13, pp. 141-146, 2017.
[12] Q. T. Trần, T. H. Đỗ, N. T. Dương, T. H. Trần, T. V. Đinh, T. H. T. Phạm, T. T. H. Nguyễn and V. T. Đặng, Tăng cường tính chất nhả chậm của phân bón urea-kaolinit bằng chất kết dính poly (vinyl alcohol), *Tạp chí phân tích Hóa, Lý và Sinh học*, vol. 30, no. 2A, 2024.
[13] Công ty Cổ phần Bình Điền – MEKONG, Sản phẩm phân bón. [Online]. Available: https://binhdienmekong.vn/san-pham (accessed July 9, 2025).
[14] Công ty Cổ Phần Phân Bón Bình Điền, Sản phẩm: NPK Đầu Trâu. [Online]. Available: https://binhdien.com/sanpham/npk-dau-trau (accessed July 9, 2025).
[15] Phú Mỹ, Sản phẩm: Phân bón PVFCCo. [Online]. Available: https://dpm.vn/nhom-san-pham/phan-bon-1 (accessed July 9, 2025).
[16] Phân bón Miền Nam, "Sản phẩm". [Online]. Available: https://phanbonmiennam.com.vn (accessed July 9, 2025).
[17] VietNga Agri, Phân bón Việt Nga: Sản phẩm nổi bật. [Online]. Available: https://vietnga.vn (accessed July 9, 2025).
[18] I. Hussain, Z. Mahmood, R. Yasmeen, M. Jahangir, R. Hammed, and R. Nasir, Assay of urea with p-dimethylaminobenzaldehyde, *Journal-Chemical Society of Pakistan*, vol. 24, no. 2. pp. 122–128, 2002. doi: 10.1016/0026-265X(68)90115-X.

TỔNG HỢP VẬT LIỆU POLYME KẾT HỢP BORON LÀM MÀNG BỌC PHÂN BÓN URÊ GIẢI PHÓNG CHẬM CHỨA VI LƯỢNG

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Tóm tắt. Các chất vi lượng đóng vai trò quan trọng trong sự phát triển, cải thiện năng suất và chất lượng của cây trồng. Vì vậy, nhiều sản phẩm phân bón vô cơ đa lượng kết hợp với bổ sung chất vi lượng đã được nghiên cứu và thương mại hóa trong những năm gần đây. Nghiên cứu nhằm mục đích phát triển các sản phẩm phân bón urê mới vừa giải phóng chậm, vừa cung cấp các vi lượng thiết yếu. Các sản phẩm này được sản xuất bằng công nghệ bọc hạt với vật liệu polymer kết hợp chất vi lượng Boron. Vật liệu polyme được tổng hợp từ tinh bột, tinh bột biến tính, sodium alginate, polyvinyl alcohol và solubor có tính cơ lý tốt, khả năng tạo màng và phân hủy sinh học. Sản phẩm được phân tích bằng các phương pháp hiện đại như SEM, FTIR, XRD và ICP. Kết quả nghiên cứu cho thấy sản phẩm có thời gian giải phóng chất dinh dưỡng lớn hơn 5 lần so với phân urê thông thường và đồng thời cung cấp lượng chất vi lượng phù hợp.

Từ khóa. Chất vi lượng, công nghệ bọc hạt, phân bón urê giải phóng chậm, polyme kết hợp Bo.

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