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*Research Article*

# Novel Integrated Nanofertilizers for Improving the Growth of *Polyscias fruticosa* and *Asparagus officinalis*

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The study of nanotechnology has been focused in recent years on the application in various fields including agriculture. Nanofertilizers were suggested to have the ability to supply plants with nutrients more effectively and thus significantly improve crop productivity. Previous studies reported the fabrication of nanofertilizers that contained only one or two essential elements. The addition of other nutrients is necessary for promoting plant development. Therefore, in this study, a novel integrated nanofertilizer containing both macro- and micronutritional elements was synthesized and characterized. The results showed that the prepared fertilizer had the rod shape and nanosize of 20-30 nm in width and 80 nm in length. Treatment of *Polyscias fruticosa* and *Asparagus officinalis* crops with the integrated nanofertilizer increased the number of branches, leaf area, dry matter production, and total biomass up to 50% at using level of 5% compared to nontreatment groups.

## 1. Introduction

For decades, the use of fertilizers in agriculture has doubled the world food production. However, the common drawback of using fertilizers is that a major part of the nutrient contents, such as nitrogen, phosphorus, and potassium, are often dissolved in soil that is over the amount of plant requirement. These contents are then washed away from the soil (50-70%) before being used [1]. Consequently, fertilizers must be applied many times throughout the plant development process. The overuse of these chemicals resulted in residue in agricultural products and serious environmental pollution as well as the disruption of the agricultural ecosystem and soil quality depression [2].

Many studies have proven the effectiveness and cost savings of nanotechnology in providing nutrients to plants. The nanofertilizer allows incorporating nutrients onto a nanodimensional adsorbent. Therefore, this approach leads to the controlled release of active ingredients for a long time and prevents the leaching of nutrients into groundwater, thus reducing the amount of fertilizer used. It is estimated that the amount of nanoformulations needed for plants is only equivalent to 20% of conventional fertilizers [3]. For example, urea (N fertilizer) was incorporated into slow release nanohybrids, and the nanohybrids demonstrated a higher rice crop yield at a 50% lower concentration of urea [4]. Research by Tarafdar et al. [5] showed that soybean growth rate increased by 33% and grain yield improved by 20%

when used nano-P fertilizer instead of conventional phosphate fertilizer [5]. Another study showed the effect of nanozeolite/nanohydroxyapatite as nanofertilizer to increase the P availability in the soil and chamomile yield compared to natural zeolite/hydroxyapatite or normal fertilizer [6].

Besides the need for NPK, a lot of other nutritional elements with less quantity such as Fe, B, and Zn are important factors to ensure the productivity and quality of agricultural products [7]. They serve as a cofactor for various enzymes associated with carbohydrates, nucleic acids, proteins, and lipids. The concentration requirement of these traces is narrow in the ranges from 0.1 mg/kg dry mass (e.g., Mo and Ni) to 100 mg/kg (e.g., Cl and Fe) (Plant [8]). The insufficient amount of micronutrients can slow down the plant growth rate and force the plant to switch to alternative metabolic pathways that less depend on the limiting micronutrients. In those cases, these elements can be supplied in the soil or sprayed onto leaves in the form of fertilizer solution [9]. However, the dynamics and transformation of these elements are greatly affected by even small changes in environmental factors such as pH and organic composition as well as microbial activity in the soil. Therefore, investigating an alternative way to effectively provide these elements to plants is necessary [3].

A study reported that the addition of Zn micronutrients containing foliar fertilizer in the form of ZnO nanoparticles at the concentration of 20 mg/l increased 42%, 41%, 98%, and 76% of root length, root biomass, stem length, and stem mass of soybean, respectively [10]. These superior characteristics make nanofertilizers be an outstanding choice compared to traditional fertilizers. Despite their potential, studies on the application of nutrient nanoformulation are generally at a small scale of testing [4, 11]. Therefore, the research and development of commercially integrated nanoformulations is an urgent requirement.

There are several types of nanofertilizers in terms of their compositions. First, nanofertilizers can be particles in nanosize of elements such as Fe [12], Cu, Ag [13] and nano ZnO [14]. Second, nanofertilizers can also be in the slow release formulations formed by various polymers. For example, hydroxypropyl methylcellulose modified with xanthan or chitosan was used for fabrication of $KNO_3$ nanofertilizer [15]. Chitosan and poly(vinyl alcohol) were the coated material for NPK fertilizer. The hydrophilic coating layer provided the fertilizer with slow-release activity [16]. Third, several minerals can act as nutrient sources or nutrient carriers. Nanohydroxyapatite and nanozeolite were used as nano-phosphorous sources [6, 17] or as urea carrier [4]. Some nanofertiliezers were reported to be the hybrids of the minerals and polymers such as montmorillonite clay-polycaprolacton/polyacrylamine [18] or nanohydroxyapatite encapsulated wood [19]. While some studies showed only the material properties of the nanofertilizer without their effects on any crops [15, 16, 18, 19], some others only provided the influences of the fertilizers on plants without details on the fertilizer characteristics [20–22].

Recently, we have reported the positive effects of micronutrient nanoformulation on *Asparagus officinalis* seeds [23]. In this study, we synthesized novel integrated nanoformulas of nutrients that contained both the macronutrients of N, P, and K as well as the trace elements of $Zn^{2+}$, $Cu^{2+}$, $Co^{2+}$, $Fe^{3+}$, and $Ag^{+}$ (in nanoparticle form) to stimulate the growth of *Polyscias fruticose* and *Asparagus officinalis*. *Polyscias fruticosa* and *Asparagus officinallis* were chosen for this study because of their high value in nutrition in medicine [24, 25]. To the best of our knowledge, this is the first time such an integrated nanofertilizer has been fully characterized and investigated to apply to these plants. Besides, the second novelty of the manuscript in the required amount of our nanofertilizer was only 5% in comparison with conventional fertilizer to provide up to 50% increase in growth and production parameters on *Polyscias fruticosa* and *Asparagus officinalis*.

## 2. Materials and Methods

### 2.1. Materials and Methods

*2.1.1. Materials.* Hydroxyapatite, alginate, carboxyl methyl cellulose, sodium borohydride ($NaBH_4$), and silver nitrate ($AgNO_3$) were purchased from Merck. Iron(III) chloride hexahydrate ($FeCl_3.6H_2O$), copper sulfate pentahydrate ($CuSO_4.5H_2O$), cobalt (II) sulfate ($CoSO_4$), magnesium sulfate ($MgSO_4$), zinc oxide (ZnO), and commercial NPK fertilizer and commercial NPK + trace element (TE) fertilizer (NPK-15-15-15 and NPK-15-15-15 + TE, provided by Binh Dien Fertilizer Joint Stock Company, composition: total N: 15%, available P ($P_2O_5$): 15%; available potassium ($K_2O$): 15%, $SiO_2$: 1%, Zn: 100 ppm, Cu: 100 ppm, Fe: 100 ppm, B: 200 ppm) were purchased in Vietnam.

*2.1.2. Synthesis of Integrated Nanofertilizer.* The nanofertilizer synthesis consisted of 3 steps. First, the mixture of commercial NPK and hydroxyapatite (at a specified ratio) was used to fabricate the NPK-hydroxyapatite nanohybrid structure by chemical method. Then, microelement solutions containing Ag, Fe, Cu, Co, and Zn in the form of nanoparticles were synthesized by chemical reduction method using $NaBH_4$ as a reducing agent. Finally, the microelement solution and NPK nanostructures were integrated into water-retaining materials like alginate.

In details, 75 g of hydroxyapatite was dispersed in 3 liters of distilled water for 30 min. Then, 1 liter of alginate solution (150 g/l) was slowly added to the above suspension and stirred for 30 minutes. 400 g of commercial NPK fertilizer was suspended in 0.5 liters of distilled water for 30 minutes and then slowly added to the above suspension. Microelements were dissolved or dispersed in distill water as follows: 2 g $AgNO_3$ in 1.18 liters of water, each of $CuSO_4.5H_2O$ (7.20 g), $FeCl_3.6H_2O$ (9.60 g), $CoCl_2.6H_2O$ (8.00 g), and ZnO (2.50 g) in 250 mL of water. The microelement solutions or suspension were slowly added to the above hydroxyapatite solutions in the order of $AgNO_3$, $FeCl_3$, $CuSO_4.5H_2O$, $CoCl_2.6H_2O$, and ZnO suspension into the reaction mixture, while continuously stirring for 30 minutes. 47.5 g of $NaBH_4$ was dissolved in 1 liter of distilled water and then slowly added to the obtained solution and stirred for 30 minutes. Then, 5 g/l carboxylmethyl cellulose solution was slowly added until the viscosity of the reaction mixture reached 20 cP. This polymer helped to

Table 1: Chemical properties of the soil at the start and at the end of the experiment.

| No. | Chemical properties | Unit | Methods | Result | | |
|---|---|---|---|---|---|---|
| | | | | Before experiment | Control | Nanofertilizer |
| 1. | Available P | mg/kg | TCVN 6499 : 1999∗ | 120 | 113 | 172 |
| 2. | Total P | mg/kg | TCVN 8559 : 2010∗ | 242 | 254 | 281 |
| 3. | S | mg/kg | TCVN 175 : 2015∗ | — | 20.16 | 13.28 |
| 4. | Available K | mg/kg | TCVN 8662 : 2011∗ | 59.4 | 73.2 | 81.3 |
| 5. | Si | mg/kg | US EPA method 3051: 2007 + SMEWW 3125 : 2017 | 374896 | 381569 | 400787 |
| 6. | Total organic C | mg/kg | TCVN 6634 : 2000∗ | 8000 | 12000 | 10400 |
| 7. | Total N | mg/kg | TCVN 6498 : 1999∗ | 2487 | 3357 | 2835 |
| 8. | Mg | mg/kg | | 3989 | 3701 | 3208 |
| 9. | Ca | mg/kg | | 13795 | 9522 | 10973 |
| 10. | Cu | mg/kg | | 22.71 | 19.36 | 19.77 |
| 11. | Fe | mg/kg | US EPA method 3051: 2007 + SMEWW 3125 : 2017 | 22576 | 18247 | 17384 |
| 12. | Zn | mg/kg | | 104.7 | 134.7 | 51.15 |
| 13. | Co | mg/kg | | 9.06 | 8.29 | 7.54 |
| 14. | Ag | mg/kg | | 0.66 | 0.32 | 0.42 |

∗TCVN: Vietnam National Standards.

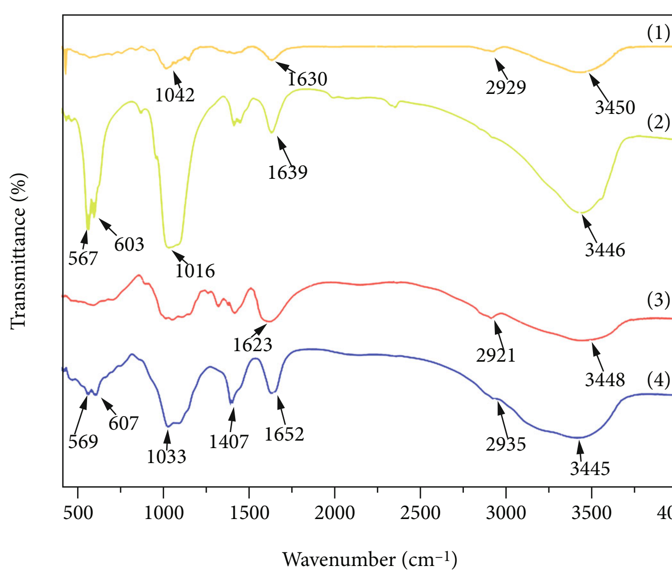


Figure 1: FTIR spectra of alginate (1), hydroxyapatite (2), carboxyl methyl cellulose (3), and the integrated nanofertilizer (4).

stabilize the obtained mixture [26]. The mixture was then further stirred for 24 h to obtain the integrated nanofertilizer.

The liquid nanofertilizer was diluted to use in field experiments. Dry samples of the nanofertilizer were obtained by free-drying method for characterization.

*2.1.3. Characterization.* Physicochemical characteristics of the obtained nanofertilizer were determined using various methods. The field emission scanning electron microscopy (FESEM) images were obtained by a Hitachi S-4800 instrument. The energy dispersive X-ray spectroscopic (EDX) technique was used to validate the elemental compositions and distribution of the samples in the same instrument. The high-resolution transmission (HR-TEM) images were obtained in a JEM 1010 system, while the Fourier Transformation Infrared spectra (FTIR) were recorded on a Shimadzu spectrophotometer using KBr pellets at 400–4000 $cm^{-1}$ wavenumber range. The size distribution and Zeta potential of the fertilizer were measured in a Dynamic Light Scattering (DLS) system (Nano Zetasizer, Malvern UK).

*2.1.4. Evaluation of the Effect of Nanoformulation on Plants.* In this study, the growth indices such as plant height, leaf area, total dry production, and total biomass of *Polyscias fruticose* and *Asparagus officinalis* were used to prove the enhanced effects of nanofertilizer on supporting plant growth in comparison with control groups that were fertilized with commercial NPK and micronutrient fertilizers (NPK-15-15-15 + TE,

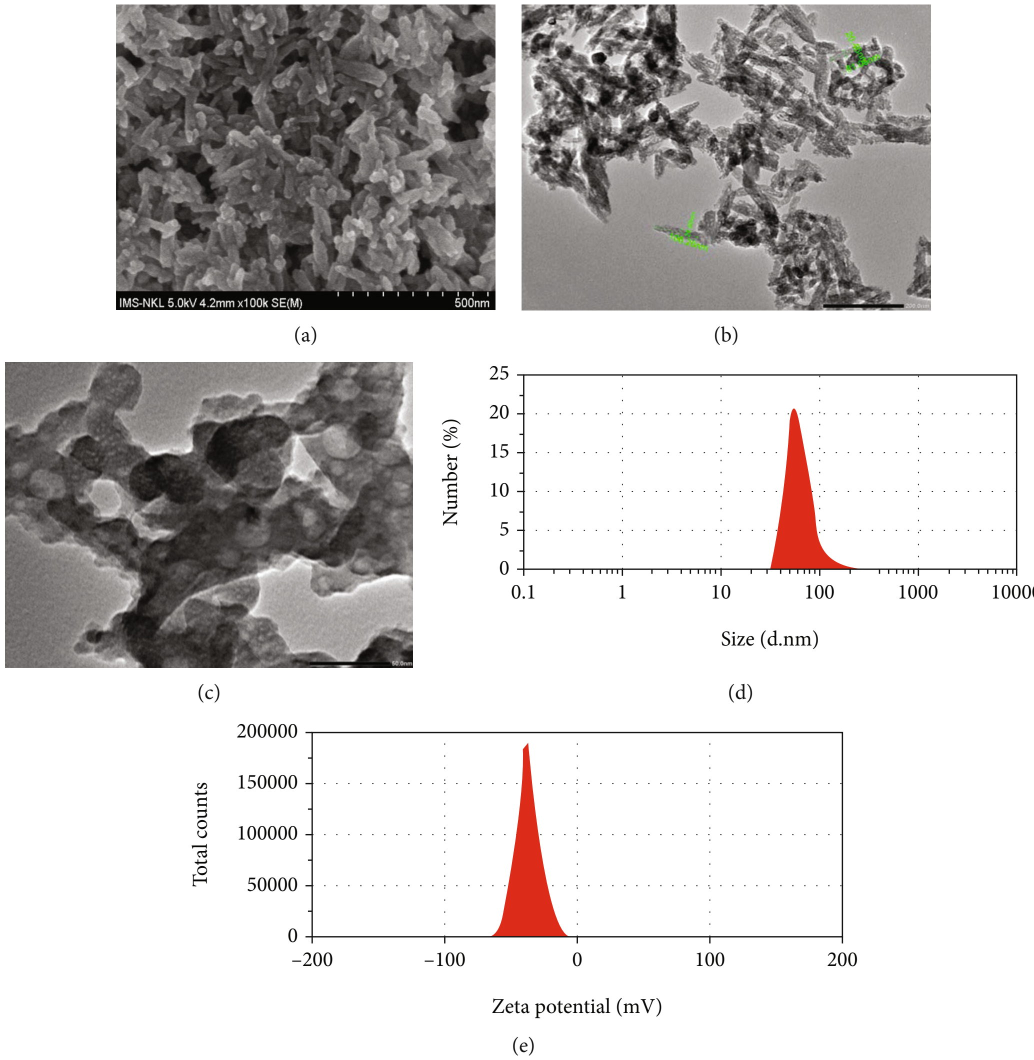


Figure 2: FESEM image (a) and HR-TEM image (scale bar: 200 nm) (b) of hydroxyapatite; HR-TEM image (scale bar: 50 nm) (c), size distribution (d), and Zeta potential (e) of the integrated nanofertilizer.

provided by Binh Dien Fertilizer Joint Stock Company, composition: total N: 15%, available P ($P_2O_5$): 15%; available potassium ($K_2O$): 15%, $SiO_2$: 1%, Zn: 100 ppm, Cu: 100 ppm, Fe: 100 ppm, and B: 200 ppm). The control groups were treated with 160 kg of NPK 15-15-15 + TE commercial fertilizer, 200 kg lime powder/ha twice a month. On the other hand, a diluted suspension (0.2% in irrigation water) of 10 L of the nanofertilizer was sprayed to the leaves and soil around the plant twice a month in nanofertilizer applied group that was approximately equal to only 5% of the NPK amount used in the control group.

The cultivation of *Polyscias fruticosa* and *Asparagus officinalis* was carried out by the Evergreen Agricoop Truong Xuan, Nam Dinh staff, with the assessed area of each experimental group which was 1 ha that were divided into 3 plots for triplicate measurement. The experiment lasted for 12 months for both *Polyscias fruticosa* and *Asparagus officinalis* in 2019-2020.

*2.1.5. Soil Property Determination.* Soil samples before and after the experiments were collected and analyzed for their properties. The analysis methods and obtained results are shown in Table 1.

*2.1.6. Statistical Analysis.* The obtained data are expressed as $mean \pm SD$. The One-way analysis of variance (ANOVA) was performed to determine the statistical difference between the control and nanofertilizer groups.

## 3. Results and Discussions

*3.1. Characteristics of the Integrated Nanofertilizer.* In the Fourier–transform infrared (FTIR) spectrum (Figure 1) of hydroxyapatite, the strong band at 3446 $cm^{-1}$ belonged to the valence vibration of the –OH group, while the weak absorption band at 1639 $cm^{-1}$ represented the vibration of the $CO_3^{2-}$ group. The strong absorption band at 1016 $cm^{-1}$ belonged to the valence vibrations of the $PO_4^{3-}$ group. The two bands at 567 $cm^{-1}$ and 603 $cm^{-1}$ could be assigned to the oscillations of the P-O bond. There were several shifts in the infrared spectrum of hydroxyapatite compared to that of the integrated nanofertilizer. These shifts included the changes in wave

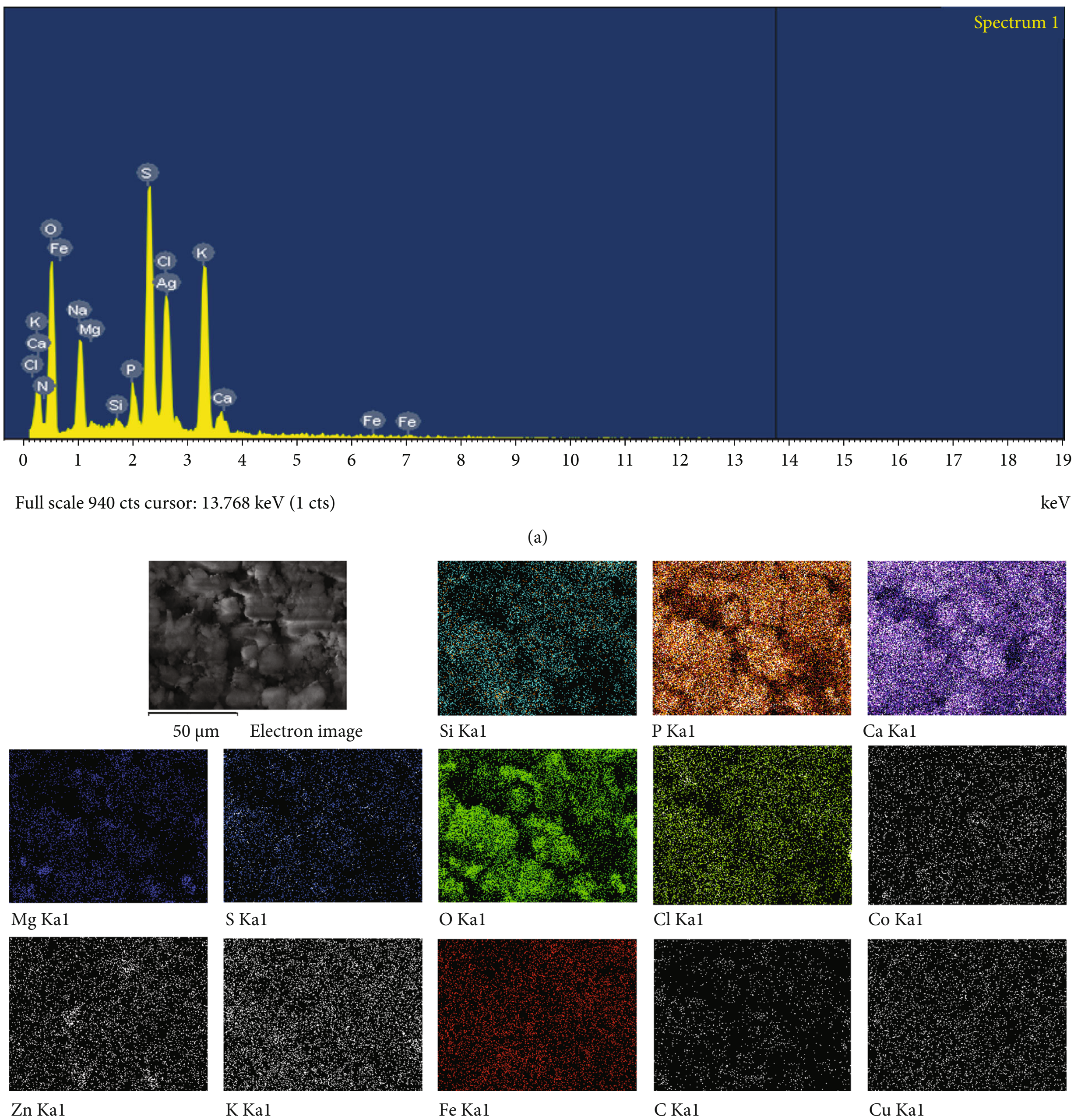


Figure 3: EDX spectrum (a) and EDX mapping (b) of the integrated nanofertilizer.

Table 2: Composition of the integrated nanofertilizer.

| Element | N | P | K | Mg | S | Si | Ca | Fe | Cu | Zn | Co | Ag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % w/w | 12.00 | 3.46 | 5.50 | 1.36 | 6.30 | 2.82 | 10.8 | 0.69 | 0.34 | 0.56 | 0.23 | 0.22 |

number from 3446 $cm^{-1}$ to 3445 $cm^{-1}$; 1639 $cm^{-1}$ to 1652 $cm^{-1}$; 567 $cm^{-1}$ and 603 $cm^{-1}$ to 569 and 607 $cm^{-1}$; and 1016 $cm^{-1}$ to 1033 $cm^{-1}$. Besides, the moderate absorption bands at 2935 $cm^{-1}$ in the integrated nanofertilizer corresponded to C-H ($sp^3$) valence vibration of alginate (2929 $cm^{-1}$) and carboxyl methyl cellulose (2921 $cm^{-1}$). For the synthesized nanofertilizer, a strong peak at 3445 $cm^{-1}$ was assigned to the presence of -OH stretching vibration, while this absorption band also appeared at 3448, 3446, and 3450 $cm^{-1}$ in the spectrum of carboxyl methyl cellulose, hydroxyapatite, and alginate polymer. In detail, the carbonyl bands (-C=O ester stretch) of alginate and carboxyl methyl cellulose appeared at 1630 and 1623 $cm^{-}$

Table 3: Effect of the integrated nanofertilizer on the number of secondary shoots, shoot length, dry matter production, leaf area, and leaf length of *Polyscias fruticosa*.

| Sample | Number of branches/plant | Branch length (cm) | Dry matter production (g/plant) | Leaf area ($m^2$/plant) | Leaf length (cm) |
|---|---|---|---|---|---|
| Integrated nanofertilizer | $7.8 \pm 0.08^a$ | $18.4 \pm 0.2^a$ | $126.48 \pm 0.35^a$ | $0.32 \pm 0.05^a$ | $23.2 \pm 0.15^a$ |
| Control | $5.2 \pm 0.1^b$ | $13.6 \pm 0.4^b$ | $88.57 \pm 0.5^b$ | $0.21 \pm 0.07^b$ | $18.5 \pm 0.2^b$ |

[a,b]Means in each column with the different letter are significantly different at $P = 0.05$.

Table 4: Effect of the integrated nanofertilizer on the number of roots, the total mass of roots, primary root length, and total biomass of *Polyscias fruticosa*.

| Sample | Number of root branches | Total root mass (g/plant) | Primary root length (mm) | Total biomass (g/plant) |
|---|---|---|---|---|
| Integrated nanofertilizer | $21.35 \pm 0.12^a$ | $23.5 \pm 0.4^a$ | $18.5 \pm 0.2^a$ | $149.8 \pm 0.5^a$ |
| Control | $14.44 \pm 0.35^b$ | $15.8 \pm 0.5^b$ | $13.2 \pm 0.1^b$ | $103.45 \pm 0.65^b$ |

[a,b]Means in each column with the different letter are significantly different at $P = 0.05$.

$^1$, respectively, while these bands were shifted to 1652 $cm^{-1}$ in the FTIR spectrum of the integrated nanofertilizer. These results suggested that the new structure had been established based on hydroxyapatite.

The FESEM and TEM images of hydroxyapatite (Figures 2(a) and 2(b)) revealed the rod shape of the hydroxyapatite with the diameter ranging from 20 to 30 nm and about 80 to 100 nm in length. In TEM image of the nanofertilizer (Figure 2(c)), many round nanoparticles with various sizes from 5 to 20 nm appeared in the hydroxyapatite rods. This confirms the success of the combination of nutrients into the nanostructure of hydroxyapatite. Similar observation was also observed in another hydroxyapatite-based nanofertilizer [4].

In the solution, the particles had an average size of 86 nm and a highly negative zeta potential value of -42.3 mV (Figures 2(d) and 2(e)). The measurement results indicated that the nanofertilizer particles were stable. This colloid was much more stable than a reported organic nano-NPK formula [27]. Alginate and carboxylmethyl cellulose are highly hydrophilic polymers that play the role of stabilizers for the fertilizer [28, 29]. Using these polymers, the fertilizer can be used in the form of a colloidal solution.

The elemental composition of the nanofertilizer was determined by the EDX method (Figure 3(a)), and the results are shown in Table 2. The elemental mapping results (Figure 3(b)) provide a clear observation of the elements in the nanofertilizer. Ca, P, and O are the most abundant elements because they are the main compositions of hydroxyapatite. Other elements are found evenly distributed in the material. The results strongly revealed that the macro- and micronutrient elements were successfully integrated into the hydroxyapatite/alginate nanostructures with the expected ratio.

The effects of the commercial fertilizer and nanofertilizer on the soil parameters are listed in Table 1. The results show that some important parameters of available P, available K, total N, and total organic C of the soil samples after the experiment are higher than those of the sample before the experiment. Compared with the control group, applying nanofertilizer slightly increased the available P and K and slightly decreased the total N and total organic C. The similar effect on soil was observed when applying a slow release nanofertilizer with nitrogen, phosphorus, potassium, magnesium, calcium, and humic acid [22]. The amount of trace elements also varies among the samples and has the tendency to reduce after the experiments. This can be explained by the uptake of these elements from the soil of the plants. The elements can affect much on the growth, crop yield, and product quality of some plants [30, 31].

*3.2. Effect of the Integrated Nanofertilizer on Polyscias Fruticosa.* Observation on the development of *Polyscias fruticosa* was conducted after 150 days. The measurement results presented in Tables 3 and 4 proved the positive effect of nanofertilizer on plant growth, compared to the control group.

As described in Table 3 and Figure 4, the average branches number and their length were also increased from $5.2 \pm 0.1$ to $7.8 \pm 0.08$ and from $13.6 \pm 0.4$ to $18.4 \pm 0.2$ cm, respectively, in response to the nanofertilizer application.

The dry matter production of the plant is an index of the dry matter product accumulated on an area unit and is the result of a series of assimilation and catabolism processes during the growth of the plant. Using nanofertilizer resulted in the dry matter of 126.48 g/plant which was 1.5 times higher than the control of 88.57 g/plant. The ability of the plant to build up dry matter influences the formation of active ingredients in the *Polyscias fruticosa*, thereby affecting the quality of the medicinal plants (roots and leaves) after harvest. Using an integrated nanofertilizer helped to improve the ability to accumulate dry matter of *Polyscias fruticosa*, thereby increasing the value and economic benefits of the plant.

Additionally, the leaf area index (LAI) is defined as the ratio of one-sided leaf area per unit ground area. Under the same amount of light, a higher LAI indicates a larger photosynthetic active area, and thus a higher photosynthetic rate and productivity of the crop are achieved [32]. In the process of growth and development, the nanofertilizer treated *Polyscias fruticosa* reached a higher leaf length of $23.2 \pm 0.15$ cm and LAI of $0.32 \pm 0.05$ $m^2$/plant than that of $18.5 \pm 0.2$ cm and $0.21 \pm 0.07$ $m^2$/plant, respectively, in the control group. Consequently, the nanofertilizer utilization promoted plant


Figure 4: The growth of *Polyscias fruticosa* during the experiment time.

Table 5: Effect of the integrated nanofertilizer on the height, spear number, and average weight of *Asparagus officinalis* after 150 days.

| Sample | Plant height (cm) | Average number of spears/cluster (spears/cluster) | Average weight/cluster (g/cluster) | Average weight of each spear (g) |
|---|---|---|---|---|
| Integrated nanofertilizer | $93.1 \pm 2.3^a$ | $18.2 \pm 3.85^a$ | $193.25 \pm 7.5^a$ | $11.46 \pm 2.33^a$ |
| Control | $62.7 \pm 3.12^b$ | $8.7 \pm 1.6^b$ | $46.67 \pm 3.33^b$ | $6.12 \pm 0.45^b$ |

[a,b]Means in each column with the different letter are significantly different at $P = 0.05$.

photosynthesis capacity, thereby increasing their ability to accumulate higher dry matter and yield. These results were consistent with other reports on the effects of nanoformulas on maize [33]. Interestingly, the improvement in growth parameters achieved by the application of the integrated nanofertilizer was occurred at the nanofertilizer amount of only 5% compared to that of conventional fertilizer. This is an outstanding benefit of the integrated fertilizer. In comparison, a urea-hydroxyapatite nanohybrid leads to better rice crop yield at 50% lower concentration of urea [4]. Nanozeolite and nanohydroxyapatite at the same level of P with conventional fertilizer could increase the measured parameters including the plant height; branch number; sub-branch number; chamazulene amount; flower number; phosphorous content in the soil, root, and shoot; and fresh and dry weight of flower and shoot [6].

The primary function of the root is to absorb water, dissolved nutrients, and conduct to the stem. Plants that are provided adequate nutrients will have longer and deeper root set that reach out in all directions in the soil. When the root system grows well, it will create favorable conditions for the plant to grow and develop. Therefore, the number, weight, and length of the root systems were also monitored in this study. The detailed results are shown in Table 4.

In particular, the nanofertilizer treated group had an average of 21.35 roots per plant and a total root weight of 23.5 g/plant that was about 50% higher compared to the commercial fertilizer treated group. Similar trends were also observed for the average root length and total biomass (including stem and root). The difference of these parameters between the two groups was about 5.3 cm and 46.35 g/plant, respectively. It was confirmed that the roots of *Polyscias fruticosa* grew stronger in quantity, volume, and main root length under the supplement of nanofertilizer. Moreover, *Polyscias fruticosa* is well-known for the accumulation of glucosides, alkaloids, saponins, triterpene, tannins, 13 amino acids, vitamin B1, and many other active ingredients in their roots [34]. When the roots grow well, the content of the ingredients can be increased. Especially the content of saponin, which has a good effect on 5 organs and the ability to detoxify, increase blood and milk production, digest support, reduce inflammation, treat coughs and enhance memory, and prevent fatigue, can be significantly improved when using of nanofertilizer. Hence, further investigation is necessary to evaluate whether the nanofertilizer application would result in higher content of active ingredients when harvesting (3 years since planted). Further research is in progress.


Figure 5: Asparagus officinalis was grown and monitored at the Evergreen Agricoop Truong Xuan, Nam Dinh.

Table 6: The effect of integrated nanofertilizer on some asparagus growth indicators after 12 months.

| Sample | Plant height (cm) | Length of root (m) | Spear diameter (cm) | Average weight of each spear (g) |
|---|---|---|---|---|
| Integrated nanofertilizer | $205.46 \pm 5.5^a$ | $1.92 \pm 0.27^a$ | $1.2 \pm 0.3^a$ | $16.23 \pm 2.33^a$ |
| Control | $178.12 \pm 4.33^b$ | $0.71 \pm 0.17^b$ | $0.9 \pm 0.2^b$ | $9.74 \pm 1.89^b$ |

[a,b]Means in each column with the different letter are significantly different at $P = 0.05$.

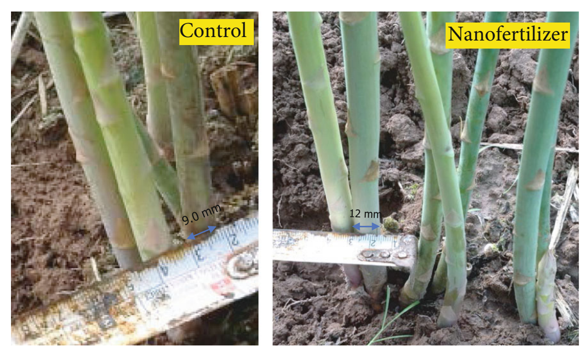


Figure 6: Different in spear diameter of the commercial fertilizer applied group (a) and integrated nanofertilizer applied group (b) after 12 months.

*3.3. Effect of the Integrated Nanofertilizer on Asparagus Officinalis.* Asparagus is a shrub, herbaceous, coniferous plant. Research on the development of asparagus spears of asparagus plants was conducted on the height and weight of the spears. The results of evaluating the effects of integrated nanonutrients on some growth indicators of *Asparagus officinalis* in the first stage of 150 days are presented in Table 5.

After 150 days of cultivation, the height of *Asparagus officinalis* in the group that received the integrated nanofertilizer was $93.1 \pm 2.3\,cm$, which was 1.5 times higher than the control group of $62.7 \pm 3.12\,cm$. The average number of spears/cluster in the nanofertilizer treated group was 18.2 spears/clump, and an average clump weight of 193.25 g/cluster that was also 2 times higher than the NPK treated group with the average number of spears/clump and average clump weight were 8.7 spears/clump and 46.67 g/cluster, respectively. Additionally, the average weight of a young shoot in the nanonutrient group of 11.46 g was almost twice as high as that of 6.12 g in the control group. Thus, in the early stage of asparagus growth (150 days), it could be seen that nanonutrients played an important role in promoting the growth rate compared to the nontreated group (Figure 5).

For a clearer view, the effect of integrated nanofertilizer on the growth and development of Asparagus officinalis was continued to monitor after 12 months. Data are presented in Table 6.

As shown in Table 6, the height of asparagus plants in the group using integrated nanofertilizer increased to 205.46 cm, higher than that of the control group of 178.12 cm. Along with that, the improvement of root length, diameter, and average weight of the spear were also observed when integrated nanofertilizer were used (Table 6 and Figure 6). The root length of asparagus in the experimental group using integrated nanofertilizer was 1.92 m, which was 2.7 times longer than the control group using conventional fertilizers (0.71 m). Spears in the group using the integrated nanofertilizer had a diameter of 1.2 cm and an average weight of each spear of 16.23 g. It was higher than the spears in the control group which had the spear diameter of 0.9 cm and an average weight of each spear of 9.74 g. This proves the effectiveness of applying integrated nanofertilizer to asparagus planting process, and the growth and development of plants and spears are faster than that of conventional fertilizers.

While some nanofertilizers were studied for their properties only [15, 16, 18, 19], some recent reports also suggested that nanofertilizer could improve the crop yield and quality. However, the nanofertilizer levels applied in these investigations were similar to that of conventional fertilizers [12, 35]. Using such a low level of the integrated fertilizer (5% compared to conventional fertilizer) could effectively reduce environmental pollution [36].

## 4. Conclusion

In conclusion, multinutrient contained nanofertilizer was synthesized by a simple method and successfully used to improve the growth indices of *Polyscias fruticosa* and *Asparagus officinalis* with only 5% amount of conventional fertilizer. Thus, this novel nanofertilizer could be a promising approach for the sustainable development of agriculture in terms of enhancing productivity. Further investigation will be carried out to evaluate the interactions of the nanofertilizers and biological systems or food chains before its massive application in agriculture.

## Data Availability

The data used to support the findings of this study are included within the article.

## Conflicts of Interest

The authors declare that there is no conflict of interest.

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