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Research article

Improving the Quality of Lunar Regolith Simulant Soil for Future Food Security

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nanocapsule;

coir;

humic

Abstract

This research explores the possibilities of using lunar soil resources in agriculture. The effectiveness of humic micro-encapsulated was investigated for physical and chemical quality improvement for lunar culture applications by using TLS-01 (Thailand artificial lunar regolith Simulant-01) as a test substance. Sunflower (*Helianthus annuus* L.) was used as the test plant. TLS-01 particles were evenly distributed, uncluttered, and consisted of 54.55% polygons and 45.45% rods, without having high water-holding capacity. The plants were grown in TLS-01, but their physical characteristics were unacceptable. Sunflower seedlings grown in TLS-01 soil showed a lower percentage of germination, and root and stem length compared to those grown in commercial planting material. After an improvement in physical properties and nutrients, from the study of the relationship between the soil used in the trial for planting and the humic acid concentration, no interaction between soil and humic acid was found. Therefore, while the soil types were significantly different, the humic was not. The results showed that a 1:1 mixture of TLS-01: coconut coir with the addition of 2 times the recommended dose of humic acid could enhance sunflower seedling relative to commercial planting material ($p \leq 0.05$). The germination percentage and growth indexes were 85.00% and 6.62, respectively. However, in order to stimulate actual usage for interplanetary application, coconut fiber-like materials and the humic substances were applied as in microcapsules. Additionally, the humic release test showed that after 6 h, the release of humic substance by Fickian diffusion was 73.45% and it then slowed down. The encapsulation efficiency was 90.37%.

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1. Introduction

At present, the world is facing many crises such as global warming, pollution, and emerging diseases. There has also been a growing interest in space exploration. This has led to the asking of the most question important. “If our planet is at the end of its life, what other planets are there in the universe that humans can migrate to?” Space studies are currently proving the prospects and possibilities of human migrating and settling on the moon or other planets. When that day comes, humanity must be prepared for exploring and sustaining life, energy, and food. Moreover, it appears that the main nutritional problems for space exploration are due to the limitations of transportation. Fresh foods are usually eaten in the first week of travel. This means that the astronauts have to continue eating dry food for a long time. As a result, the astronauts lose weight and have health problems [1].

Over the years, numerous experiments related to growing plants on space stations have been conducted. For example, a study by De Pascale *et al*. [2] looked at the challenges and opportunities of crop production in space environments and found that the plants that should be planted in space are “microgreens”, such as plants in the sunflower family which grow rapidly and sprout leaves within 1-2 weeks after planting. Factors affecting the growth of sunflowers include soil planting, fertilizing, and watering. Sunflower, which are an important and commercially significant oil crops are cultivated in the Thai provinces of Lopburi, Saraburi, Phetchabun, and Nakhon Sawan. Statistics from 2020 show that Thailand imported sunflower seeds worth more than 18 million US dollars with a total export value of 233,174 US dollars [3]. The Food and Agriculture Organization of the United Nations reported that Thailand cultivated 193,750 rai of sunflowers in 2019, which was equivalent to the total harvest from 2016 to 2019 and much greater than the 29,906 rai cultivated in 2015. The production of sunflower seeds between 2016 and 2019 was 129 kg per rai, which was lower than the 2015 yield of 303 kg [4]. Additionally, sunflower plants are a type of sapling that is very popular and nutritious. Sunflower sprouts contain substances that have many phytochemical properties, such as phenolic substances, pigments (such as chlorophyll, carotene, and xanthophyll), vitamins (such as vitamin A, vitamin B, vitamin C, vitamin E, and niacin), and trace elements (e.g. calcium, iron, magnesium, phosphorus), which are critical to health care and disease prevention, are often used in folk medicine. These phytochemicals have interesting antioxidant, antimicrobial Anti-inflammatory and wound healing properties. From the above-mentioned nutritional and medical benefits, sunflower seedlings are classified as functional foods and nutraceuticals, and are gaining popularity [5].

The space business has enormous transportation costs. Therefore, an idea was raised to use soil from the moon or Mars as a precursor for astroculture. Chang and Ann [6] studied the chemical composition of lunar soil samples collected from the Apollo program and found that although many of the chemical compositions differed, their physical characteristics remained similar. Accordingly, it is conceivable to use artificial lunar soil as a study model to grow plants. Despite the fact that growing crops on the moon is really different from accomplishing this on earth in terms of both internal and external factors, such as endogenous genetic components (genome structure and gene expression, i.e. plant genotype), including plant hormones and phytohormones, activate the growth and differentiation processes of plants. Examples of external factors include environmental stimuli such as composition, salinity, pH, temperature, pollution, humidity (water), radiation in space, photoperiod, and gravitational pull [7]. As a result, space agencies have realized the importance of developing their own country's lunar soil as a model for studying crop cultivation on the moon and other planets. One example is Japan's JSC-1A lunar soil model. Thailand developed an in-house lunar simulant TLS-01 that was used by Space Zap Co. Ltd. [8]. The TLS-01 was found not suitable for growing plants due to poor drainage. Currently, there are many ways of improving simulated lunar soil such as adding gypsum ($CaSO_4$) to simulated lunar soil to grow cherry tomatoes [9] and adding cyanobacteria strain *Synechococcus* sp. PCC 7002 to simulated lunar soil to grow turnips, lettuce, and alfalfa [10], and so on.

Space research authorities have taken many steps to improve the convenience of transportation in the space industry and application. Therefore, humic substances were developed into microcapsules by encapsulation process. Coconut fiber was used in this study because it is an agricultural waste material, lightweight, and can be used as a replacement for planting materials imported from abroad to reduce production costs. Its use was part of our effort to improve the physical and chemical quality of the TLS-01 simulated lunar soil and make it be suitable for growing sunflower seedlings for astronauts. Furthermore, it is a way to create food security for humans in the future if the need to move to the moon or other planets arises, which is consistent with the goal 3 of the national strategic plan titled “Advanced Research in the Earth and Space System” (deep space exploration and space utilization) of the Ministry of Higher Education, Science, Research, and Innovation (MHESI). Together with leading space organizations from countries such as the United States, Japan, and the European Union, the Ministry wants to support humanity’s space exploration plans.

2. Materials and Methods

2.1 A study of the properties of TLS-01 simulated lunar soil and the growth efficiency of sunflower seedlings

2.1.1 Physical properties of TLS-01 soil

The TLS-01 soil sample from Space Zap Co. Ltd. was subjected to a physical examination by 1) shape analysis and particle size comparison with a scanning electron microscope (SEM), HITACHI, model SU8010, Japan. The method used was modified from Neves *et al.* [11], 2) bulk density (BD). The lunar model TLS-01 was used to determine the total density of the soil and its water holding capacity (WHC) [12].

2.1.2 Analysis of some chemical properties of TLS-01 Soil

Soil samples were taken through a 2.0 mm sieve and analyzed for the volume and distribution of the chemical composition of the soil TLS-01 with an energy dispersive X-ray spectrometer (EDX) [13]. The analyzed some chemical properties related to plant growth were as follows: pH measured by pH meter, EC conductivity, organic matter by rapid titration methods, total phosphorus (total P) by the Vanadomolybdate method [14], total potassium (total-K) by the flame photometer method [14], and exchangeable calcium by inductively coupled plasma optical emission spectrometry (ICP-OES).

2.1.3 Efficacy of TLS-01 soil in the germination of sunflower seedlings

The effectiveness of TLS-01 soil in promoting germination of sunflower seedlings was compared with commercial planting material. The experiment was arranged with a completely randomized design (CRD) with 5 replicates of 20 seeds each. The percentages of germination and growth parameters are evaluated according the method described by Siri-Ngam [15].

2.2 Improvement of soil physical and nutritional properties of TLS-01 for cultivating sunflower seedlings

The experimental design was 6x3 Factorial in CRD consisting of factor 1) the planting material type and factor 2) humic content, consisting of 18 treatments (Table 1) with 6 replications of 50 seeds each. The sunflower seeds were sown on various planting materials in nursery trays until a high content of 2/3 of the planting tray was occupied, and the seeds were sprinkled onto the original planting material. Twenty mL of varying amounts of humic matter were added per well, and the seed trays were covered and given 10 mL of water daily. The growth efficiency was assessed by measuring the following: 1) stem length, 2) root length, 3) leaf area (Foliage Area Meter CI 102), and 4) fresh weight of yield after 3 days (or until cotyledons of sunflower seedlings had fully unfolded). Then a score was calculated for sunflower seedlings using the equation: growth parameter = (stem length + root length + leaf area + product fresh weight)/number of indexes.

Table 1. Treatment list details

Code	Treatment details*
T1	TLS-01 soil + humic substance
T2	TLS-01 soil + humic substance 1 time the recommended rate
T3	TLS-01 soil + humic substance 2 times the recommended rate
T4	Coconut coir + humic substance
T5	Coconut coir + humic substances 1 time the recommended rate
T6	Coconut coir + humic substances 2 times the recommended rate
T7	Sandy soil + humic substance
T8	Sandy soil + humic substances 1 time the recommended rate
T9	Sandy soil + humic substances 2 times the recommended rate
T10	Commercial planting material + humic substance
T11	Commercial planting material + humic substances 1 time the recommended rate
T12	Commercial planting material + humic substances 2 times the recommended rate
T13	TLS-01: coconut coir (1:1) + humic substance
T14	TLS-01: coconut coir (1:1) + humic substances 1 time the recommended rate
T15	TLS-01: coconut coir (1:1) + humic substance 2 times the recommended rate
T16	TLS-01: sand (1:1) + humic substance
T17	TLS-01: sand (1:1) + humic substance 1 time of recommended rate
T18	TLS-01: sand (1:1) + humic substance 2 times of recommended rate

*Humic substance (Thong Kwao Brand) recommended rate is humic acid 1 mL/1 L of water.

2.3 Characterization of various forms of humic microcapsules for sunflower seedling cultivation

2.3.1 Physical characteristics of microcapsules

The physical properties of the microcapsules, such as color, smell, and texture were measured. The appearances recorded were as discernible to the naked eye and with a microscope at 4X and 10X magnifications.

2.3.2 Morphology of microcapsules

The microcapsule morphology was examined using a scanning electron microscope (Benchtop SEM), model JCM-6000, Japan, by placing the microcapsules on a carbon tape, plating them with gold, and examining them at a magnification of 200X.

2.3.3 Chemical properties of the microcapsules

1) Release kinetics of humic microcapsules

The clear microcapsules were placed in a cellophane bag, and the bag openings were sealed on both sides. A 0.1 mol concentration of Tween 80 solution was prepared, and put in a 30 mL rose-shaped bottle. The clear microcapsules were placed in the solution, the cap was closed tightly, and immersed in a water bath. The temperature was controlled at 30°C and shaking at 20, 30, 40, 50, 60, 120, 240, 360, 1440, 2880, and 4320 min. After aspirating the solution from an Erlenmeyer flask with a volume of 3 mL, and then adding a volume of Tween 80 solution at 0.1 mol concentration into the flask containing microcapsules, the absorbance of the prepared solution was measured at wavelength 254 nm. The microcapsules were charged, and the values were calculated using the Richter-Peppas equation according to the method described by Pakthongchai [16].

2) Chemical performance test in encapsulation of the microcapsule

The oil on the surface of the microcapsules was extracted. Four grams of microcapsules were added to 25 mL hexane and mixed at 100 rpm for 5 min at 39°C. This was followed by filtering through a No. 1 filter paper, and evaporation of the filtered substance via rotary evaporation [16]. The humic content from the microcapsules was extracted. Microcapsules were mixed with 48 mL dichloromethane and 32 mL methanol and stirred with a magnetic stirring bar at 300 rpm for 15 min, and 16 mL water was added and mixed at 300 rpm for 15 min. A layer of oil mixed with dichloromethane and another layer of encapsulating material mixed with methanol and water were formed by the substance that was put into the funnel. The extraction of essential oil from dichloromethane with a rotary distiller and the encapsulation efficiency of the microcapsules were calculated according to Pakthongchai [16].

2.4 Characterization of various forms of humic microcapsules used to improve the cultivation of sunflower seedlings

The experimental design included 7 treatments in CRD. The factors were various forms of humic substances (Table 2) with a lot of replications, 50 seeds each. The sunflower seeds were sown on various types of planting material in the nursery tray so as to have a high content of 2/3 of the planting tray and the seeds were sprinkled with the original planting material. Twenty mL of varying amounts of humic matter were added per well, the seed trays were covered, and 10 mL of water were added daily. Growth efficiency was measured for: 1) stem length 2) root length 3) leaf area (Foliage Area Meter CI 102), and 4) fresh weight of yield after 3 days (or until cotyledons of sunflower seedlings fully unfolded). Then the scorecard growth parameters were calculated [17].

Table 2. Treatment list details

Code	Treatment details*
T1	TLS-01: coconut coir (1:1) + humic substance 2 times the recommended rate
T2	TLS-01: coconut coir (1:1) + GA humic encapsulation at recommended rate
T3	TLS-01: coconut coir (1:1) + WPI humic encapsulation 1 times the recommended rate
T4	TLS-01: coconut coir (1:1) + WPI humic encapsulation2 times the recommended rate
T5	TLS-01: coconut coir (1:1) + GA humic encapsulation at recommended rate
T6	TLS-01: coconut coir (1:1) + GA humic encapsulation 1 times the recommended rate
T7	TLS-01: coconut coir (1:1) + GA humic encapsulation 2 times the recommended rate

*WPI is whey protein isolate, and GA is gum arabic.

3. Results and Discussion

3.1 A study of the properties of simulated lunar soil TLS-01 and the growth efficiency of sunflower seedlings

3.1.1 Physical properties of TLS-01 soil

From the shape analysis and comparison of TLS-01 soil particle size using scanning electron microscopy (HITACHI SU8010, Japan), 2 types of particles were found: 54.55% polygonal shape of width between 9.706 and 20.006 µm, and of length between 12.941 and 35.212 µm, and 45.45% bar shape, of width between 8.451 and 15.991 µm, and of length between 10.183 and 29.985 µm. The particles were evenly distributed (Figure 1), as were the particle sizes of the simulated moon JSC-1A soil and lunar soil from the Apollo and Luna projects [11, 18]. Particle size depends on soil density [19]. The TLS-01 simulated lunar soil had pre- and post-crushed soil densities of 1.72 and 2.30 g/cm^3, respectively and poor or zero water holding capacity. From the above characteristics, the physical properties of the TLS-01 soil made it unsuitable for growing plants. Additionally, Huang *et al.* [20] found that soil particle size significantly affects sunflower seedling growth and can greatly affect both the minerals and the physical characteristics of the soil.

3.1.2 Analysis of some chemical properties of the soil TLS-01

The analysis of the chemical composition of the TLS-01 soil revealed that it contained 15 types of elements, two of elements (K and P) which are essential for plant growth were found to be at 2.20 and 1.09%, respectively. The micro-nutrients (Ca and Mg) were analyzed at 7.55 and 2.63%, respectively, and the other 11 elements, namely O, Si, Fe, Al, Cu, Ti, Na, Mn, Co, Cr, and Zn, were at 39.96, 21.64, 10.46, 8.39, 3.00, 1.74, 0.54, 0.31, 0.25, 0.23, and 0.02%, respectively (Figure 2). Additionally, the TLS-01 soil was found to have a pH of 5.6, a conductivity of 0.09 dS/m. The amount of organic matter in terms of total nitrogen, useful phosphorus, and exchangeable calcium are indicators of moderate fertility in TLS-01 soil. However, TLS-01 soil has very high levels of exchangeable potassium. Thus, increasing the nutrient and soil fertility of TLS-01 is necessary for higher agricultural efficiency. Potassium helps to speed up the growth of tissues. It increases the strength of cell walls, controls the closing and opening of stomata, regulates water balance in plant cells, and affects the synthesis of antioxidants in plants [21]. The soil pH value that the seedlings need is neutral, 5.5-6.5. The measured pH indicates that the TLS-01 soil can be used for cultivating sunflower seedlings [1].

3.1.3 Efficacy of TLS-01 soil on germination of sunflower seedlings

The effectiveness of TLS-01 soil on the germination of sunflower seeds compared to commercial planting material showed that the TLS-01 soil had a germination percentage of 50.66%, which was lower than commercial planting material (68.00%), although the TLS-01 soil was able to support plant growth to some extent. However, due to the physical properties of the soil, it was not suitable for plant growth as it hindered the release of nutrients necessary for the growth of sunflower seedlings. As a result, sunflower seedlings had low stem heights, root lengths, and fresh weights (11.05±2.41, 3.11±1.19 cm, and 0.707 g, respectively), compared to commercial planting material (Figure 3). Some of the soil chemistry showed that the TLS-01 soil had a moderate level of soil fertility for crop growing [22]. However, some physical properties were not suitable for growing crops. The evenly distribution of soil particles when exposed to moisture coagulate into solid cementitious clumps and prevent plant roots from finding food for growth. As a result, the roots are short, the roots are brown to black, and the root hairs are few in numbers (Figure 3A). Both the experimental and control samples were tested under the same conditions of light, temperature, water content, and the number of seedlings. The result showed that humic substances increased soil water absorption and soil porosity. Humic substances also helped improve the biological properties of the soil. They functioned as a source of nutrients and microorganisms (Tables 3 and 4).

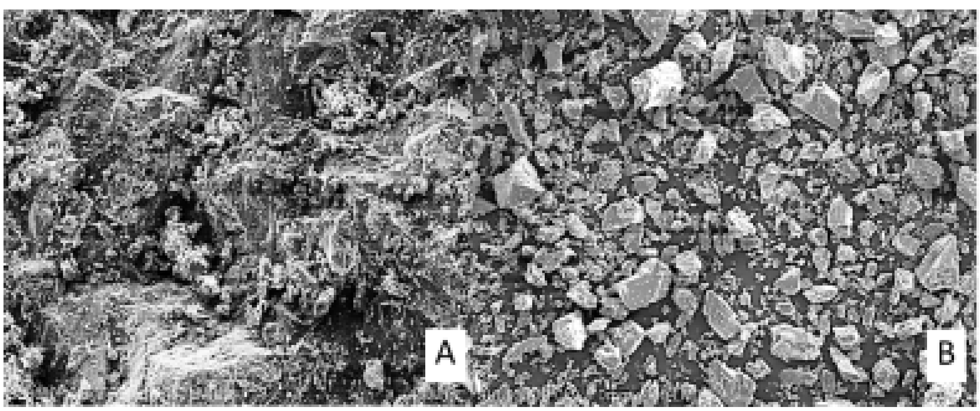

Figure 1. Transmission electron microscope photograph of TLS-01 soil particles at 400X, uncrushed (A) and crushed (B)

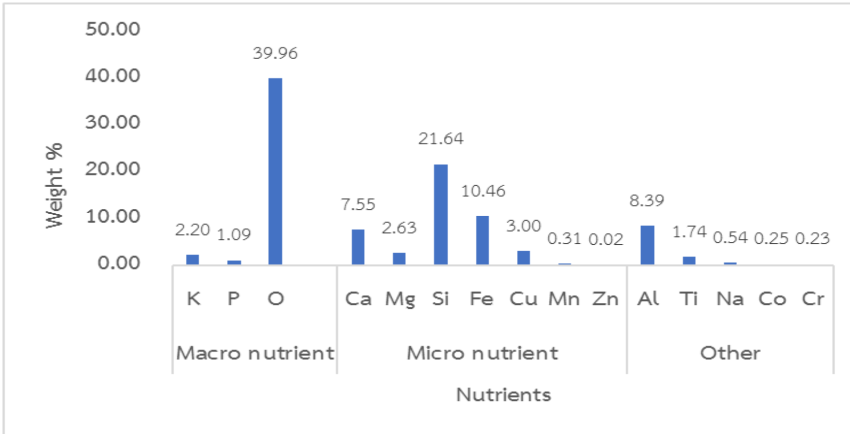

Figure 2. Chemistry analysis of TLS-01 by energy dispersive X-ray spectrometer (EDX)

Figure 3. Growth characteristics of sunflower seedlings grown with TLS-01 soil (A) compared with commercial planting material (B)

3.2 Improving the physical and nutritional properties of the TLS-01 soil for growing sunflower seedlings

The physical properties of the TLS-01 soil such as drainage, loaminess, and anti-coagulant needed to be adjusted. Furthermore, its chemical properties were improved by addition of humic substances. We found that sunflower seedlings grown in TLS-01 soil mixed with coconut coir in a 1:1 ratio and humic substances added at a concentration of 2 times the recommended amount (humic acid 1 mL/ 1 L of water) promoted the growth of sunflower seedlings. The seedlings had a germination percentage and growth parameters of 85.00% and 6.62, respectively. After improving both the physical and chemical properties of the TLS-01 soil, the soil had better properties and was able to promote seedling growth. The results were as good as those for commercial planting material, which gave a growth parameter of 8.29 (Figure 4B). The quality of TLS-01 soil was improved by adding coconut coir to reduce its physical disadvantage such as low water holding capacity and reduced coagulation. The coconut coir increases the percentage of air-filled pores in the planting material [23], produces higher solubility of nutrients in the soil granules, and benefits the plants. It was also found that adding a humic concentration 1 time higher than the recommended rate resulted in better growth of sunflower seedlings. Based on the soil chemistry, TLS-01 had a quite good nutrient

Table 3. Statistical analysis results used to determine the relationship between planting material type (A) and concentration of the humic substance (B)

Planting material type (A)	The concentration of the humic substance (B)[1/]			Average[2/]
	B1	B2	B3	
1) TLS-01	5.31	6.36	5.88	5.85[b]
2) Coconut coir	4.26	3.96	3.94	4.05[c]
3) Sand	6.82	9.81	7.74	8.12[a]
4) Commercial planting material	5.86	6.08	6.01	5.98[b]
5) TLS-01: coconut coir (1:1)	7.45	8.54	6.10	7.36[a]
6) TLS-01: sand (1:1)	4.33	5.59	3.20	4.37[c]
Average	**5.67**	**6.73**	**5.48**	
F-Test				
A		*		
B		ns		
AxB		ns		

ns=not significant, *= significant at 95% confidence level
[1/]B1=humic substances at the recommended rate, B2=humic substances at 1 time the recommended rate, and B3=humic substances at 2 times the recommended rate.
[2/]Mean followed by the same letters are not significantly different at p≤0.05 by DMRT, when comparing the differences between planting material types.

Table 4. Statistical analysis results to determine the germination index of sunflower seedlings in each experiment set

Code	Treatment details *	Germination index **
T1	TLS-01: coconut coir (1:1) + humic substance 2 times the recommended rate	9.49[a]
T2	TLS-01: coconut coir (1:1) + WPI humic encapsulation at recommended rate	8.07[b]
T3	TLS-01: coconut coir (1:1) + WPI humic encapsulation 1 time the recommended rate	8.71[ab]
T4	TLS-01: coconut coir (1:1) + WPI humic encapsulation 2 times the recommended rate	7.67[b]
T5	TLS-01: coconut coir (1:1) + GA humic encapsulation at recommended rate	7.73[b]
T6	TLS-01: coconut coir (1:1) + GA humic encapsulation 1 time the recommended rate	8.59[ab]
T7	TLS-01: coconut coir (1:1) + GA humic encapsulation 2 times the recommended rate	8.15[b]

*WPI is whey protein isolate and GA is gum arabic.
**Means followed by the same letters are not significant difference at p≤0.05 by DMRT, when comparing between planting material types.

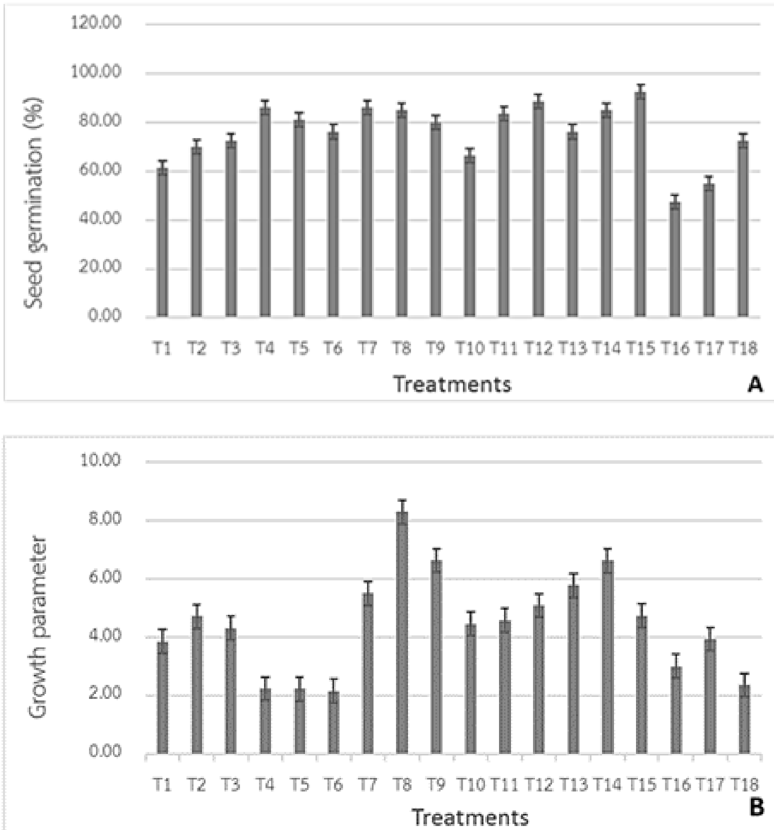

Figure 4. Efficiency of TLS-01 soil after improvement of physical and nutrient characteristics on sunflower seedling growth compared with commercial planting material A) percentage germination and B) growth parameter of sunflower seedlings

content for plant growth but those elements may not have been released due to the improper physical properties of the soil. The humic addition helps plants get more nutrients. Plants grew better compared to TLS-01 before improvement (Figure 3A). Additionally, the humic substances contributed to the binding of soil particles, making a stronger structure. As a result, the fertilized soil had a positive ion exchange capacity (CEC) value, which increased the number of durable soil grains, and increased the ability to absorb water [23, 24]. The porosity of the soil can reduce the benefits of plant nutrients and microorganisms [25]. This method of prevention and correction effectively improved the soil in the future. However, in actual usage for interplanetary application, coconut fiber-like materials and the humic substances were applied as microcapsules. This is because they must be in a form that is easy to transport and non-hazardous. Thus, this study created the idea of developing and investigating the efficiency of using humic microcapsules [21, 23-25].

3.3 Characterization of various forms of humic microcapsules used to improve the cultivation of sunflower seedlings

3.3.1 Physical characteristics of microcapsules

The physical appearance of various humic microcapsules indicated that GA-encapsulated humic microcapsules were a dark brown fine powder, while WPI-encapsulated microcapsules were a sparkling brown fine powder. Meanwhile, due to poor molding properties, the PVA-encapsulated microcapsules had a brown foam-like appearance that could not be seen and implanted under the electron microscope. When examined at 4X magnification, the WPI and GA-encapsulated microcapsules were plate-like dark brown to black. When spreading apart at the 10X magnification, they looked like multi-layered plates of irregular shape. In benchtop scanning electron microscopy of the WPI, and GA-encapsulated humic microcapsules (Figure 5), it was found that the physical characteristics of microcapsules and humic microcapsules were sheets of smooth surface.

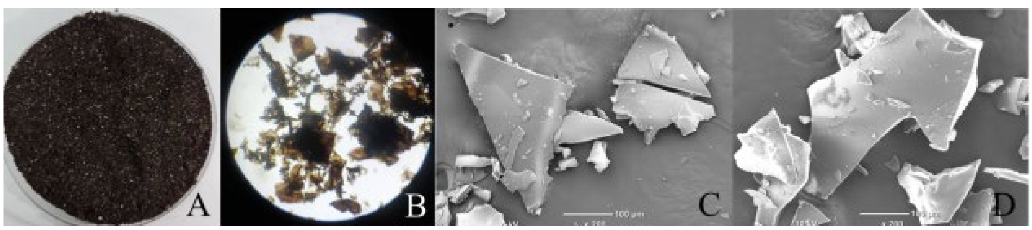

Figure 5. Humic substance encapsulates (A), humic encapsulate microcapsules under 4X (B), and under benchtop SEM camera at 200x magnification WPI (C), and GA (D)

3.3.2 Chemical properties of the microcapsule

1) Release kinetics of humic microcapsules

The release kinetics of the humic microcapsules (WPI and GA) by the Rijger-Peppas equation were plotted between M_t/M_∞, and it was found that the R-squared value of the humic microcapsules with WPI encapsulation was 0.6033, and it had a diffusion exponent of 0.0027 which corresponded to Fickian diffusion, which is diffusion from high to low concentration. In the time before 360 min, a release of 73.45% of the humic content occurred, and after that the release was slow. The GA-encapsulated humic microcapsules had an R-squared of 0.5846 and a diffusion exponent of 0.0214, which also indicated Fickian diffusion. Before the 360 min, a release of 72.03% of the humic content occurred, and after that it was released slowly (Figure 6).

2) Chemical performance test in encapsulation of the microcapsules

The encapsulation efficiency of humic microcapsules with WPI and GA encapsulations were compared with the cryopreservation technique. The encapsulation efficiencies were different at 90.37 and 88.36%, respectively. This was consistent with the research of Zhang *et al*. [26]. Additionally, when comparing the results with Zhang *et al*. [27], it was found that the experimental results were consistent in terms of an encapsulation layer that formed around the core material, resulting in a higher encapsulation efficiency with an increasing concentration of GA in the coating material. The encapsulation efficiency of capsaicin microcapsules from capsicum using WPI

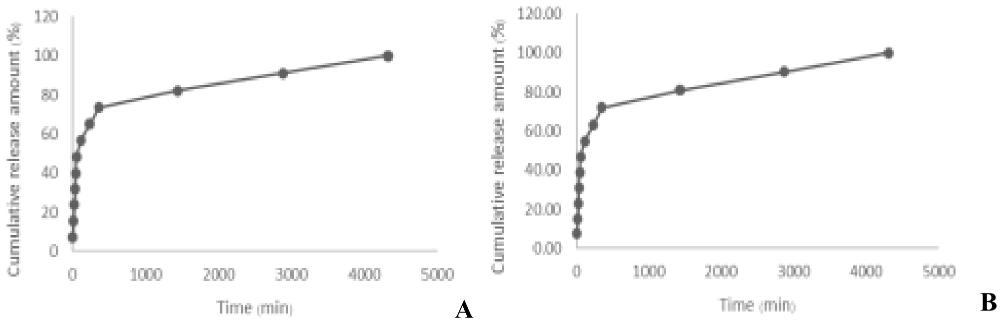

Figure 6. Whey protein isolate (A) and GA (B) encapsulated humic release kinetics

encapsulation ranged from 49.90% to 94.60%, indicating that the samples in the above study with WP and OS mixed at weight ratios of 10:0, 9:1, and 7:3 yielded significant differences. Thus, it indicated that the material has excellent encapsulation capabilities, WP, and OS with 10:0, 9:1, and 7:3 aspect ratios offer good interaction.

3) Characterization of various forms of humic microcapsules used to improve the cultivation of sunflower seedlings

The growth parameters of sunflower seedlings measured after using various forms of humic microcapsules to improve the cultivation of sunflower seedlings showed that the use of 2 times the recommended rate of humic acid added to the simulated lunar soil with coconut fiber at a 1:1 ratio gave the highest germination index of 9.49, followed by the use of microcapsules. The WPI microcapsules had a germination index of 8.71, and the use of humic microcapsules with GA encapsulation had a germination index of 8.59. Because plants with humic substances added to the soil can absorb nutrients immediately after absorption, whereas humic microcapsules showed slower release kinetics than the above method. Therefore, it can be seen from the experimental results that humic microcapsules are released first and released slowly, including some substances that can be lost in the process.

4. Conclusions

The properties of TLS-01 soil were not suitable for plant growth and the soil can store or reduce the nutrient release required for sunflower seedling growth to occur. As a result, the sunflower seedlings had reduced stem height, root length, and fresh weight compared to commercial planting material. In order to improve the physical and nutritional properties of the TLS-01 soil for growing sunflower seedlings, the quality of TLS-01 soil was improved by adding coconut to reduce the physical disadvantage of TLS-01 soil, which included low water storage capacity and reduced coagulation. The addition of coconut coir increased the proportion of air-filled spaces in the planting material, gave higher solubility of nutrients in the soil grains, and thus benefitted the plants. It was found that adding a humic concentration of twice the recommended humic acid dose resulted in better growth of sunflower seedlings. The addition of humic acid helps the plants get more nutrients. The plants grew better compared to those grown in the original TLS-01.

However, humic chemicals and polymers resembling coconut fiber must be used in microcapsule forms for interplanetary purposes. They must be used in a non-hazardous and readily transportable form. Due to this, the concept of creating and analyzing the utility of humic microcapsules for experimental purposes emerged in this work. The study showed that humic microcapsules with WPI encapsulation can improve the germination index of sunflower seedlings close to that of humic substances at a humic concentration of 2 times the acceptable rate. It was found that 73.45% humic chemicals were released from the encapsulation layer. In addition, the experimental results showed that the encapsulation efficiency was 90.37%.

Therefore, suggestions for future research on these issues are as follows: 1) There should be a study on coir storage and transportation for convenience in future cultivation, 2) The release and encapsulation efficiency of microcapsules should also be studied for a longer duration, and 3) The amount of humic substances remaining in the planting material should be further studied.

5. Acknowledgements

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