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THE EFFECT OF GREEN MUSSEL SHELLS ON THE GROWTH AND PRODUCTION OF EDAMAME SOYBEANS

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ABSTRACT— Edamame is a soybean type with a high potential to be developed because it has a high commercial value and great opportunities in the domestic and export markets. Efforts to increase Edamame production must be carried out to meet the market demand. One of the efforts that can be made is to manage soil fertility by utilizing organic waste as fertilizer and ameliorant. Green mussel shells (GMS) are organic waste that is abundantly available and has the potential to be used as organic material to improve soil fertility and increase soil pH. This research aimed to study the effect of GMS powder on the growth and production of Edamame. The research was conducted in two locations from October 2020 to April 2021. The study used Randomized Complete Block Design (RCBD) with a treatment factor of GMS which consisted of five levels, namely inorganic fertilizer (control), 5 g GMS powder (1 ton ha^{-1}) + urea, 10 g GMS powder (2 tons ha^{-1}) + urea, 15 g GMS powder (3 tons ha^{-1}) + urea, and 20 g GMS powder (4 tons ha^{-1}) + urea. The results showed that various doses of GMS powder with urea had the same effect as inorganic fertilizers on the growth and production of Edamame plants on both Oxisol and Ultisol soils. Edamame plants grown on Oxisol soil had better yields than plants grown on Ultisol soil. Results also indicated that GMS can be used as an ameliorant due to its ability to increase soil pH.

KEYWORDS: Ameliorant; Oxisol; Ultisol; Vegetable Soybean.

1. INTRODUCTION

Edamame (*Glycine max* L. Merr.) is a type of soybean introduced in Japan. It is very popular with Indonesians because it has a delicious taste and high nutritional content [1]. Edamame is rich in protein, fiber, vitamin A, vitamin K, folic acid, omega 3, omega 6, iron (Fe), zinc (Zn), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), copper (Cu), manganese (Mn), and anti-cholesterol substances [2], [3]. Furthermore, Takahashi and Ohyama (2011) stated that Edamame has higher protein and vitamin A than regular soybeans and higher iron than mung beans [2].

Edamame is a vegetable soybean harvested at the stage of full seed development with larger seeds and a sweet taste [4]. Edamame has a higher selling value because of the larger size of the beans compared to ordinary soybeans. The weight of 100 pods of Edamame soybean is about 30 g, with the number of seeds per pod of 2-4 seeds [5]. Edamame has high productivity, which can produce 10-12 tons ha^{-1} or more in one hectare. This product can be higher than ordinary soybean production, which is around 1.5-3 tons ha^{-1} [6]. The selling price of fresh Edamame in the domestic market is around Rp. 17,000-22,000 per kg, while at the farm level, it is around Rp. 3,000-10,000 per kg depending on grade [7]. Meanwhile, the price of Edamame in the export market is around Rp. 20,000-22,000 per kg [6].

The demand for Edamame will continue to increase, along with increasing public awareness of carrying out a healthy lifestyle so that the level of consumption of Edamame in the country will be higher. In addition to meeting domestic demand, the demand for Edamame abroad is also relatively high. Japan is one of the biggest consumers and primary markets of Edamame. Export demand from Japan is 100,000 tons per year and from the United States is 7,000 tons per year. Meanwhile, Indonesia has only been able to meet 3% of the Japanese market needs, while the other 97% are met by China and Taiwan [8]. Edamame has a high potential to be developed because it has high commercial value and substantial market opportunities in domestic and export markets. Therefore, it is necessary to increase the production of Edamame with good quality and quantity to meet market demands.

Efforts to increase crop production must pay attention to the growing environment needed by these plants, including soil type and soil fertility. Edamame can grow well on Entisol, Inceptisol, Vertisol, Oxisol, and Andisol soils. Soil acidity tolerance as a condition for optimal growth for Edamame is pH 5.5-7.5. At a pH of less than 5.5, growth will be stunted due to aluminum poisoning [9]. Soil fertility is an essential factor in efforts to increase crop production, including Edamame, so it is important to increase soil fertility to meet the nutrient needs of Edamame plants. In certain soils with low acidity, increasing soil pH is necessary to support Edamame plants to grow optimally. One of the efforts that can be done is fertilization using organic material, which also functions as an ameliorant.

Green mussel shell (GMS) is one of the organic wastes that can be used as an alternative organic material for organic fertilizer as well as ameliorant. As an archipelagic country, Indonesia produces green mussels in large quantities and is spread in almost every coastal area in Indonesia. For example, in North Jakarta, in 2014, green mussel production was 28,160 tons [10]. One kilogram of green mussels consists of 457.5 g of mussel meat and 511.9 g of shells [11]. Consequently, the total mussel shell production in North Jakarta in the same year was approximately 14,415.10 tons. This amount will be tremendous if it is accumulated for production throughout Indonesia.

The abundance of shell waste requires special efforts to overcome the potential for pollution and negative environmental impacts. One of the efforts is to utilize GMS as an organic material that can support the productivity of agricultural cultivation. Mussel shells contain calcium carbonate ($CaCO_3$) and other minerals that are beneficial to plants, such as Na, P, and Mg as macronutrients, and Fe, Cu, B, Zn, and Si as micronutrients [12]. GMS contains 0.60% water content and several macronutrients consisting of 0.07% P_2O_5, 0.01% K_2O, 51.83% Ca, and 0.05% Mg. GMS has a fairly high pH of 9.8, which can also be used as an ameliorant for acid soils [11].

Utilization of GMS as organic fertilizer and ameliorant is expected to overcome agro-ecosystem problems due to chemical input. In addition, GMS can also be an alternative fertilizer and ameliorant in household-scale agriculture. The research on green mussel shells on plant growth has not been widely studied so the authors are interested in researching it on edamame soybean plants. This research aimed to study the effect of various doses of GMS powder on the growth and production of Edamame.

2. Materials and Methods

The study was conducted from October 2020 to April 2021 in two locations. The first location is in Kotabaru, Jambi, with an altitude of ± 60 m above sea level (masl) and used the Ultisol soil type. The second location is in South Tangerang, Banten, with an altitude of ± 25 masl and used Oxisol soil type. The study was carried out using a planting model with polybags and arranged according to a Randomized Complete Block Design (RCBD) with GMS treatments consisting of five levels, namely Inorganic Fertilizer (Urea, SP-36, KCl) as control, 5 g GMS powder (1 ton ha^{-1}) + urea, 10 g GMS powder (2 tons ha^{-1}) + urea, 15 g GMS powder (3 tons ha^{-1}) + urea and 20 g GMS powder (4 tons ha^{-1}) + urea. Each treatment was repeated five times so that there were 25 experimental units. Each experimental unit consisted of 3 plants, so the number of plants was 75 observation plants for each location.

GMS powder was made by first cleaning the green mussel shells with water. After cleaning, GMS was dried outdoors to be exposed to direct sunlight for three days. Then the GMS was baked in the oven for about one and a half hours at 200ºC to get a perfectly dry GMS. GMS was then mashed with a mortar until it became flakes and ground with a blender until it became flour. GMS flour was then sieved with a 0.5 mm sieve to get a uniform size and ready to be used [11]. Based on the laboratory analysis results, GMS powder contains macronutrients such as P (0.09%), K (0.02%), Ca (52.50%), Mg (0.07%), and S (0.03%), with a high pH of 9.4. These results are similar to the analysis conducted by [11] with 0.07% P_2O_5, 0.01% K_2O, 51.83% Ca, 0.05% Mg, and a pH of 9.8.

Planting media was prepared by filling each 40 cm x 40 cm polybag with 10 kg of aerated soil and then adding 25 g of manure per polybag or the equivalent of 5 tons ha^{-1} [13]. The Edamame seeds used were Ryoko 75 (R-75) variety. Edamame seeds were then planted in polybags one week after the growing media preparation. GMS application was carried out one week before planting with doses according to the treatments. Inorganic fertilizers were applied eight days after planting (DAP). Harvesting was carried out at 65 DAP [14] when the fresh pods were young and green, and the seed filling was approximately 80-90% full. The observations were done on the growth and yield variables, such as plant height, number of branches, flowering age, number of pods, percentage of filled pods, pod weight, and pH.

Data obtained from the observations were analyzed using the F test (ANOVA), and the difference between treatments was tested using the Honest Significant Difference (HSD) test at the significance level of 5%. Nutrient analysis on GMS powder was carried out at the Laboratory of Soil Research Institute, Bogor.

3. Results and Discussion

3.1 Effect of Green Mussel Shell Powder on Soil pH

In this study, it was found that the application of GMS powder on Oxisol soil increased the soil pH from 6.5 to 7 and Ultisol soil increased the soil pH from 5.18 to 7. The increase in soil pH was caused by the content of Calcium (Ca) and Magnesium (Mg) contained in the clam shells. The elements Ca and Mg are nutrients found in agricultural lime as ameliorant ingredients that can increase soil pH., Ca and Mg are based on that reaction with hydrogen ions in the soil solution to form water. Adding Ca and Mg to the soil not only increases soil pH, but can also improve soil properties, both chemical, physical, and biological properties of the soil [15].

3.2 Effect of Green Mussel Shell Powder on the Growth of Edamame Plants

The variance analysis showed that the application of GMS powder had no significant effect on plant height, the number of branches, and the flowering age of Edamame plants. This result shows that the application of GMS can match the application of inorganic fertilizer (control) in supporting the growth of Edamame plants but has not been able to increase the growth of Edamame plants more than the control treatment (Table 1). Optimal plant growth is due to the availability of sufficient and balanced nutrients in the growing media to support plant height growth. From planting to harvesting, plants generally grew well in each treatment. Edamame soybeans can grow from 30 cm to more than 50 cm [5].

Table 1. Effect of Green GMS powder on plant height at 7 WAP, number of branches at 7 WAP, and flowering age of edamame plants

Treatment	Plant Height (cm)		Number of Branches		Flowering Age (DAP)	
	Oxisol	Ultisol	Oxisol	Ultisol	Oxisol	Ultisol
Inorganic fertliziers	30.32a	54.49a	5.47a	3.60a	27.33a	26.67a
5 g GMS powder + urea	29.38a	52.01a	5.73a	3.47a	27.40a	26.40a
10 g GMS powder + urea	30.16a	57.98a	5.87a	3.47a	27.47a	26.20a
15 g GMS powder + urea	30.65a	65.03a	5.80a	3.60a	27.80a	26.00a
20 g GMS powder + urea	29.43a	61.14a	5.67a	3.63a	27.67a	26.67a
Average	29.99	58.13	5.71	3.55	27.53	26.39

Note: The numbers followed by the same letter in the same column are not significantly different based on the HSD test at 5%. DAP = Day After Planting

Table 1 shows that the plant height of Edamame on Oxisol soil ranged from 29.38 to 30.60 cm. This result was lower than the plant height based on the seed description, which ranges from 65 to 80 cm. Meanwhile, Edamame plants on Ultisol soils ranged from 52.01 to 65.03 cm. This result was also generally lower than the plant height based on the seed description, except for the 15 g GMS powder + urea treatment with a plant height of 65.03 cm, which was in the range of plant height according to the seed description. The results also showed a significant difference in height between plants grown in Oxisol and Ultisol soil, where on average, the plants in Ultisol soil had almost twice the height of plants grown in Oxisol soil.

Table 1 also shows a significant difference in the number of branches between plants grown in Oxisol soil and plants grown in Ultisol soil. Plants in Oxisol soil produced more branches than plants in Ultisol soil. These results indicate that there were differences in the allocation and utilization of resources and energy for crops grown on different soil types. Plants in Oxisol soil tended to use resources and energy for branch formation, while plants in Ultisol soil tended to use resources and energy to increase plant height.

The results of vegetative growth that were not significantly different between treatments for each type of soil indicated that the nutrients present in each treatment were sufficient to support the growth of Edamame plants. The Vegetative growth of plants, including plant height and the number of branches, is influenced by the availability of nutrients in the soil. Nitrogen (N) is the essential nutrient in the vegetative growth phase of plants. N is a constituent of many important organic compounds in plants, such as amino acids, proteins, enzymes, and nucleic acids, as well as part of the processes involved in synthesizing and transferring energy. N is also the main part of chlorophyll responsible for the photosynthesis process [16].

Other elements in GMS that also support plant growth are Ca and Mg. Ca helps plants in plant metabolism, especially in the vegetative phase. Ca in GMS increases soil pH to help plants absorb N in the soil. Nitrogen and other nutrients are translocated with water in the plant body by Ca as an osmotic regulator of cells [17]. Another benefit of Ca is accelerating nitrate absorption and increasing leaf green matter/chlorophyll [18]. The Mg content in GMS helps plants in early growth. Mg is a constituent component of leaf chlorophyll and is therefore very important in photosynthesis [19].

On the variable of flowering age, the results showed that Edamame plants flowered at relatively the same age on both Oxisol (27.53 DAP) and Ultisol (26.39 DAP) soils. Flowering age of the resulting Edamame plants ranged from 27.17 to 27.61 DAP [20]. This was longer than the description of the seeds, which stated the flowering age of the Edamame R-75 variety is 23 DAP. These results are assumed to occur due to the influence of environmental factors. The reproductive phase of Edamame begins when the flowers form and ends when the seeds ripen. Edamame is sensitive to changes in day length, especially during flower formation [21]. Flowering age is influenced by environmental factors such as photoperiod, temperature [22], nutrients, water, and light, as well as genetic factors [23].

3.3 Effect of Green Mussel Shell Powder on Yield Components of Edamame Plants

Analysis of variance showed that the application of GMS powder had no significant effect on the number of pods, the percentage of filled pods, and the weight of Edamame soybean pods. This result shows that the application of GMS powder was able to match the application of inorganic fertilizers (control) in supporting the production of Edamame but has not been able to produce better Edamame yields than the control treatment (Table 2). The number of pods formed by each treatment was not significantly different, indicating that each treatment provided roughly the same resources because pod formation in soybean plants was affected by water, nutrients, and sunlight [24]. Sunlight is an essential component in photosynthesis, and the photosynthesis results will be used to form pods. High availability and translocation of photosynthate are needed in the generative phase of soybean to produce more pods [25].

Table 2 shows a significant difference between the number of pods produced by plants in Oxisol soil and plants in Ultisol soil. Plants grew on Oxisol soil produced significantly more pods (40.21 pods) than plants grown on Ultisol soil (13.74 pods). This is thought to be caused by the difference in the number of branches formed. Soybean flowers appear on every trunk and branch node. The first flower appears on the fifth or sixth node, and the next flower will appear on the node above it towards the end of the main stem and the end of each branch [26]. The more branches formed, the more nodes on the plant, so the number of flowers formed will also increase. The more flowers formed, the more pods can be produced. Plants grown on Oxisol soil produced more branches (Table 1), so the number of pods produced was higher than that of plants grown on Ultisol soil.

Table 2. Effect of GMS powder on yield components of edamame

Treatment	Number of pods (pods plant^{-1})		Percentage of Filled Pod (%)		Pod Weight (g plant^{-1})		Production on Hectare (ton ha^{-1})	
	Oxisol	Ultisol	Oxisol	Ultisol	Oxisol	Ultisol	Oxisol	Ultisol
Inorganic fertilizers	40.93a	14.57a	85.21a	86.38a	79.29a	25.42a	13.22	4.24
5 g GMS powder + urea	38.20a	14.93a	83.00a	86.67a	72.43a	24.52a	12.07	4.09
10 g GMS powder + urea	40.07a	12.07a	84.52a	91.86a	75.14a	22.93a	12.52	3.82
15 g GMS powder + urea	43.00a	13.97a	81.27a	90.17a	78.05a	24.47a	13.01	4.08
20 g GMS powder + urea	38.87a	13.17a	81.27a	90.08a	72.36a	25.38a	12.06	4.23
Average	40.21	13.74	83.05	89.03	75.45	24.54	12.58	4.09

Note: The numbers followed by the same letter in the same column are not significantly different based on the HSD test at 5%.

Table 2 also shows that the percentage of filled pods in Edamame plants grown on Ultisol soils tended to be higher than in plants grown on Oxisol soils. The difference is related to the number of pods on each plant. The plants grown on Ultisol soil produced fewer pods, so the photosynthesized material could be translocated to the pods more efficiently. Meanwhile, the plants grown on Oxisol soil produced more pods, which meant that the photosynthate produced would have to be distributed to more posts, causing a higher number of pods that did not receive maximum photosynthate translocation.

In the process of seed formation and development, the availability and translocation of photosynthate are critical factors [27]. This is influenced by water, nutrients, and sunlight availability during the photosynthesis process [28], [29]. The results of this study indicate that GMS powder can meet the nutrient requirements for plant growth and production. Ca contained in GMS can be utilized for the process of water and nutrient absorption, where Ca has a role in the structure and permeability of cell membranes [16]. Ca contained in the treatment of GMS helped plants translocate nutrients and water [17]. Adequate nutrients and water can help plants fill the pods optimally. In addition, although in small amounts, K and P contents in GMS can support the production process of Edamame plants. K plays an essential role in photosynthesis and the translocation of nutrients and photosynthesis. At the same time, P is an essential part of photosynthesis and carbohydrate metabolism as a regulator of photosynthate translocation between leaves and seeds [16]. The availability of sufficient K and P can facilitate the process of translocation of photosynthate in plants to maximize the formation and development of seeds.

In the variables of pod weight and pod production per hectare, there were also significant differences between Edamame plants grown on Oxisol soil and plants grown on Ultisol soil. The average pod weight and pod production per hectare for plants grown on Oxisol soil (75.45 g plant^{-1} and 12.58 tons ha^{-1}, respectively) were much higher than for plants grown on Ultisol soil (by 24.54 g plant^{-1} and 4.09 tons ha^{-1}, respectively). This is in line with the number of pods produced by plants in each type of soil. Edamame plants grown on Oxisol soil produced more pods, so pod weight and pod production were also higher. The weight of Edamame pods are strongly influenced by the availability of photosynthate in seed filling, the number of pods, and pod skin content [29], [30].

Table 2 shows that the weight of pods in plants grown on Oxisol soil ranged from 72.36 to 79.29 g plant^{-1}. That the weight of pods per plant ranged from 61.08 to 82.98 g [31]. However, this result was greater than the study results with pod weight per plant ranging from 35.09 to 40.73 g [20]. Meanwhile, the weight of pods in plants grown on Ultisol soil ranged from 22.93 to 25.42 g plant^{-1}. This result was almost similar to the study results with the pod weight per plant ranging from 24.03 to 68.30 g but much smaller than that in the studies mentioned above [32].

High yield potential will be achieved maximally influenced by nutrients available in the soil to support plant growth and production [33]. The results above indicate that the nutrients in GMS powder can optimally support Edamame plant production. Each treatment got the same amount of N from the applied urea fertilizer. The amount of N absorbed by plants from the soil would initially be stored in the stems and leaves. Then, after the formation of the pods, N will be stored in the pod shells, which will be translocated to seeds as the podge. Increasing the N absorption of the plant will increase soybean seed production. Therefore, applying sufficient N into the soil can produce good seed filling [34].

P content in GMS can be appropriately utilized by plants even though the amount is small. P has many essential functions for plants, one of the main ones being the source and transfer of energy in plants. ADP and ATP are high-energy phosphate compounds that control many reactions in plants, such as photosynthesis, respiration, protein, amino acid synthesis, and the transport of nutrients and photosynthate through plant cells [35], as well as stimulate the growth of flowers and fruit/seeds [36]. The addition of P fertilizer was able to increase the production (number of pods, number of seeds, and seed weight per plant) of soybean compared to the control treatment (without the addition of P fertilizer) [37].

Yield conversion per hectare with a spacing of 40 cm x 15 cm showed that the Edamame production per hectare on Oxisol soil ranged from 12.07 to 13.22 tons ha^{-1} (Table 2). This result was above the product range in the description of the Edamame R-75 variety, which is 10-12 tons ha^{-1}. This result was also higher using the same soil (Oxisol), with a production per hectare ranging from 5.79 to 6.34 tons ha^{-1} [38]. Meanwhile, on Ultisol soil, the production ranged from 3.82 to 4.24 tons ha^{-1} (Table 2) and was below the product range in the seed description. This result is similar to the study by which obtained yields per hectare of Edamame ranging from 3.45 to 6.31 tons ha^{-1} [32]. The production variation occurred due to yield component variation produced in the study. The yield component is influenced by genetics and the environment. The environment (water, nutrients, temperature, sunlight, and other environmental factors) affects the ability of these plants to express their genetic potential [39]. These results also indicate that Edamame is more suitable for planting on Oxisol soil than on Ultisol soil. Oxisol soil was able to support the growth of Edamame to produce higher yields than the seed description, while Ultisol soils produced lesser yields (up to 68.17%) compared to the seed description.

GMS is mainly composed of calcium phosphate ($Ca_3(PO_4)_2$) and calcium bicarbonate ($Ca(HCO_3)_2$) [40], and calcium carbonate ($CaCO_3$) [41]. The high content of calcium (Ca) makes GMS have the potential to be an ameliorant. This material can comprehensively increase chemical, physical, and biological soil fertility [42]. The $CaCO_3$ content of GMS can increase the pH of acidic soil to become neutral. Plant roots will more easily absorb nutrients in the soil at a neutral pH [12]. This makes soil pH one of the most influential factors in plant cultivation.

4. Conclusion

Based on the results of this study, it can be concluded that the application of various doses of GMS powder with urea gave the same effect as inorganic fertilizers on the growth and production of Edamame plants on both Oxisol and Ultisol soils. Edamame plants grown on Oxisol soil had better yields than plants grown on Ultisol soil. Edamame plants grown on Oxisol soil could produce yields that match the seed description, while plants grown on Ultisol soil produced productions far below the seed descriptions. These results indicate that Edamame plants are better planted on Oxisol soil. In addition, GMS on Oxisol and Ultisol soil increased the soil pH.

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