The effect of varying concentrations of liquid organic fertilizer on the growth and yield of Granola Kembang potato (*Solanum tuberosum* L.) G0 seed tubers

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Abstract. Farmers typically resort to using seeds obtained from their previous harvests, as the high price of tuber seeds makes them inaccessible. To address this challenge, cultivating quality potato cuttings can be a viable solution. This research aims to evaluate the effect of different concentrations of liquid organic fertilizer on the growth and yield of Granola Kembang potato G0 seed tubers. This study was conducted in Pujon Kidul Village, Malang. The research was carried out from February to June 2023 and involved two stages. In the first stage, four treatments were tested: a control (A0) without the application of LOF, and three treatments with LOF for vegetative phase at concentrations of 1 ml/L (A1), 2 ml/L (A2), and 3 ml/L (A3), each with a dose of 13.88 ml/plant. The second stage involved similar treatments but with LOF for the generative phase. The experiment used a non-factorial completely randomized design (CRD) with four treatments and six replications, resulting in 144 plant samples. The results showed that the application of LOF, particularly at a concentration of 3 ml/L, significantly positively impacted various parameters, such as shoot number, diameter, tuber number, weight, and grading.

1 Introduction

Potato (*Solanum tuberosum* L.) is one of the agricultural commodities produced in Indonesia. Potatoes play an essential role in food development in Indonesia. The potato crop commodity has a significant role that can be utilized as a small-scale business, and it is also used as a household food as well as for national and international industries to be processed into various products such as potato snacks. Potatoes hold a crucial role in ensuring food security in developing nations. Food security is achieved when everyone has reliable physical, social, and economic access to nutritious, safe food that fulfills their dietary needs and preferences, promoting an active, healthy lifestyle. When applied to households, this concept focuses on ensuring food availability at the family level, with the well-being of each household member as a priority [1]. The productivity and level of potato consumption in this country have been

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experiencing instability every year. In 2017, potato production was 1,164.74 thousand tons, with a consumption level of 587.20 thousand tons. Potato production 2018 increased with productivity of 1,284.76 thousand tons and a consumption level of 608.02 thousand tons. In 2019, potato production experienced an increase, with a productivity value of 1,314.65 thousand tons and a consumption level of 726.87 thousand tons. Potato production 2020 experienced a decrease, with productivity of 1,282.77 thousand tons and a consumption level of 690.37 thousand tons. Potato production 2021 experienced another increase, with a productivity value of 1,361.061 thousand tons and a consumption level of 771.46 thousand tons. The productivity and consumption of potatoes in 2021 are the highest in the last five years.

The limited number of quality potato seed tubers available to farmers influences the fluctuation in potato production in Indonesia. Farmers often use seed tubers from the previous harvest and replant them as seeds. This is due to the high price of quality potato seed tubers, while the selling price of consumption potatoes is relatively low. Providing high-quality seed potatoes to producers is crucial. In many regions, small-scale farmers compensate for their inability to afford certified seed potatoes by replanting tubers from their previous harvests, exposing them to degeneration and reduced yields.

Meanwhile, larger farms typically address this challenge by importing certified seed potatoes, often from temperate regions. However, importing seeds can introduce additional complications [2]. Pre-basic seed potatoes, also known as mini tubers, are generated from in vitro plantlets and microtubes. Typically, mini tubers are produced using solid substrates in controlled environments. This method is a traditional approach for multiplying and acclimatizing in vitro material before planting it in open fields. Among the quality potato varieties, the Granola and Atlantic varieties are the most preferred by consumers in Indonesia. The Atlantic cultivar is regarded as more challenging for Indonesian farmers to cultivate compared to granola, necessitating more precise technical management, such as careful irrigation and fertilization practices [3].

Seed availability can be improved through quality potato stem cuttings and a relatively short planting season, allowing farmers to not wait long for harvest. The potato stem cuttings for seed propagation are taken from the plant's apical parts. The propagation of potatoes using these cuttings can be assisted by applying auxin (plant growth regulator) concentrations, which is expected to meet the need for healthy and quality potato seed in a shorter time. Potato seed production starts from the G0 seed, obtained from plantlets produced through in vitro techniques. Studies on applying different growing media in forest nurseries and potato cultivation emphasize optimizing factors such as water retention, aeration, and nutrient balance. Cocopeat, renowned for its excellent water retention and porosity, when mixed with manure and topsoil, provides an optimal environment for cultivating G0 potato tubers. This combination promotes healthy root development and plant growth by ensuring adequate drainage, moisture regulation, and nutrient availability [4]. The cuttings used in potato seed propagation are taken from the apical parts of the parent plant, which have undergone an acclimatization stage. The success of these in vitro-derived cuttings is influenced by a good combination of temperature, sunlight, humidity, and the growing media.

Inorganic fertilizers are commonly used to boost crop yields and increase productivity. However, their continuous application can have negative consequences, particularly by contributing to soil compaction. Over time, repeated use of these fertilizers decreases soil porosity and increases bulk density, which results in the hardening of the soil. This compaction restricts root growth, reduces water infiltration, and limits air circulation in the soil, ultimately impacting plant growth and overall soil health. While inorganic fertilizers can improve crop yields, prolonged use may degrade soil structure, reducing fertility and greater susceptibility to erosion. Sustainable practices are being recommended to counter these effects, such as combining organic matter with inorganic fertilizers to enhance soil structure and reduce the risk of compaction [5]. This is due to the accumulation of residues from the inorganic fertilizers, which results in the soil becoming more challenging to decompose properly. Hardened soil will cause plant roots to have difficulty absorbing water and nutrients. More inorganic fertilizers need to be applied to achieve the exact yield as before, and the root growth process and air circulation in the soil become disrupted, causing the roots to not function properly and ultimately hindering potatoes' growth and production process.

Applying organic fertilizers as an alternative to inorganic fertilizers is believed to be one of the best solutions for reducing the use of inorganic fertilizers. Organic fertilizers are readily available in nature and do not negatively impact the soil and the surrounding environment. Organic fertilizers come in two forms, solid and liquid, and each type has advantages and disadvantages. Liquid organic fertilizers (LOF) can be made from livestock manure, fermentation of natural microorganisms, or plant residues in the surrounding environment. LOFs optimize plant growth, improve soil organic matter, increase cation exchange capacity, and enhance microbial activity [6] [7]. Moreover, they help reduce the reliance on inorganic fertilizers, often linked to adverse environmental impacts and health concerns. Integrating organic fertilizers into agricultural practices makes it possible to minimize chemical fertilizer usage by up to 50%, thereby promoting a more sustainable approach to crop production [8].

Based on the above, this research is intended to increase the production of G0 class potato tubers by applying various concentrations of liquid organic fertilizer (LOF). The use of LOF is expected to help enlarge the tubers, improve the quality and quantity of the harvest, ensure uniformity of the tubers, and increase the weight and durability during transportation (post-harvest).

2 Materials and methods

2.1 Plant materials and experimental conditions

This research was carried out in Pujon Kidul Village, Malang Regency, where using the Google Earth application, the geographic coordinates were found to be 7°51'30.4" S and 112°27'51.2" E, with an elevation of around 1100-1200 meters above sea level. The research was conducted from February to June 2023. The materials used in this research were Granola Kembang (G.K.) variety potato plantlets, 70% alcohol, plant growth regulator powder, water, rice husk charcoal, manure, insecticide, fungicide, NPK (15:15:15) fertilizer, and liquid organic fertilizer (LOF). The equipment used in this research included a seedbox, U.V. plastic, tire rubber, tissue, plastic trays, watering cans, trays, hoes, medical scissors, a 1-liter hand sprayer, calipers, rulers, digital scales, 5 ml syringes, label paper, stationery, and documentation equipment. This research used a Non-Factorial Completely Randomized Design (CRD) with four treatments and six replications. The total plant sample consisted of 288 populations, 144 samples, 12 plants per seedbed, six randomly selected samples, and 24 seedbeds. The plants were placed inside a screen.

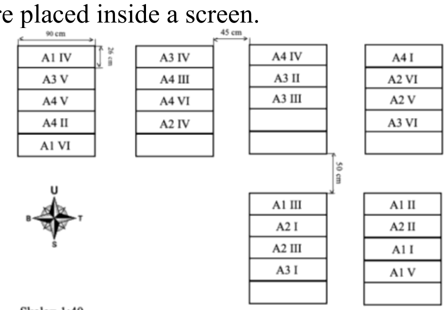

Fig. 1. Research stages.

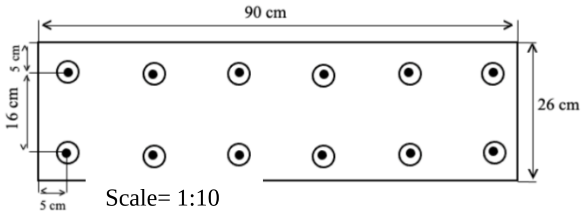

Fig. 2. Research plan.

The preparation of the planting media began by mixing all the ingredients, including cocopeat, manure, and compost, in a 1/2:1:1 ratio to create a homogeneous mixture. After thoroughly mixing the planting media, it was placed into the seeding trays, ensuring it was not too densely packed. This was done to allow the plants to grow optimally. An excellent growing medium should be lightweight, inexpensive, readily available, porous (loose), and fertile (rich in nutrients). Using the appropriate growing medium will determine the optimal growth of the propagated seedlings. The preparation of the shoot cuttings included the planting medium and the 30-day-old acclimatized potato mother plants. The next step was to harvest the shoot tips from the potato mother plants. This was done by using sterilized medical scissors that had been disinfected with 70% alcohol, and then cutting the shoot tips to a length of 2 nodes or three leaves. The harvested shoot tips from the potato mother plants were then collected in a bucket containing a nutrient solution to keep them fresh.

The process of planting the potato shoot cuttings began by creating 3 cm deep holes in the planting medium within the trays. The bottom portion of the potato shoot cuttings was then treated with plant growth regulator powder to help accelerate root formation. The care of the potato shoot cuttings involved watering to maintain moisture, then spraying a complete NPK foliar fertilizer once every seven days at a rate of 1 gram per liter. The planting medium must meet various requirements, including serving as a sturdy support for the plant, being able to retain water and the necessary nutrients for plant growth, having good drainage and aeration, maintaining adequate moisture around the roots, not becoming a source of plant disease, not easily decomposing, being readily available, and being relatively inexpensive.

The planting media used in this study were rice husk charcoal, cocopeat, and manure. These media were mixed in a 1/2:1:1 ratio, placed into the seedbed and watered as needed. The cuttings were planted when the seedlings were 2-3 weeks old after propagation. The cuttings were transplanted into the seedbed containing the prepared media mix. Each seedbed contained 18 plant samples, with a planting distance of 16 cm x 16 cm. After planting, the seedbed was then watered. Watering was done twice daily, as the initial period is critical for the seedlings to adapt. After the plants were approximately one week old, the watering frequency could be adjusted based on the moisture conditions.

Watering was done by thoroughly wetting the entire plant surface using a sprayer. Recent studies on irrigation practices in potato cultivation emphasize the importance of watering frequency, especially during the initial seedling growth stages. In these early stages, the seedlings are susceptible, and maintaining adequate moisture is critical for their adaptation. Research suggests that using a sprayer to wet the entire plant surface twice a day ensures uniform moisture distribution. After the plants are around one week old, the watering schedule can be adjusted based on soil moisture levels to prevent overwatering, which can negatively impact growth. For instance, experiments have shown that regulating irrigation levels based on soil humidity can significantly improve water use efficiency and tuber quality. These practices, combined with modern irrigation techniques, such as drip irrigation under film mulching, are highly effective in maintaining optimal water conditions for potato seedlings and beyond, promoting growth and yield [9]. Hilling was done in the second week by raising the planting medium around the plants to below the leaf axils. This stimulates root growth and prevents the tubers from being exposed to sunlight. Fertilization was done in several stages. The first stage was when the plants were seven days after transplanting, using NPK 15:15:15 fertilizer at a concentration of 5 grams per plant (4-5 pellets).

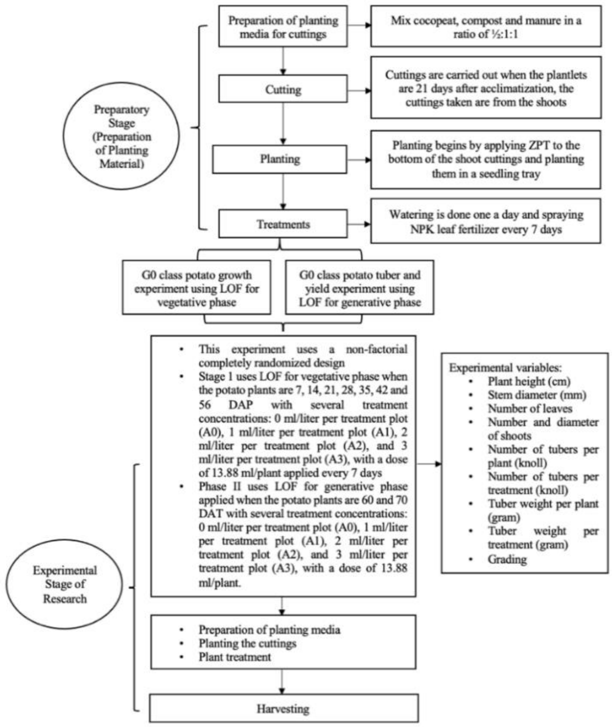

Fig. 3. Research stages.

Fertilizer was applied by broadcasting it along the hilled rows without directly contacting the plants. Subsequent fertilizer applications were done at 14 DAT, 32 DAT, 62 DAT, and 80 DAT at 8 grams per plant concentration. For efficiency, foliar fertilizer and Atonik plant growth regulator sprays were done concurrently with pesticide applications. The concentration of the foliar fertilizer used was 1 gram per liter, and the Atonik PGR was 1 ml per liter [4]. Pesticide application began when the plants were 5-7 days after transplanting and was repeated twice a week until the plants were 60 days old. The insecticide with the active ingredient abamectin was used at a concentration of 1 ml per liter, and the fungicide with the active ingredient mancozeb was used at 1 gram per liter, both applied by spraying underneath the leaves in a sideways motion [4]. Weeding or removing weeds was done when weeds were present around the growing plants by pulling the weeds out by the roots. This was to prevent competition for nutrients between the weeds and the potato plants.

The application of liquid organic fertilizer (LOF) consisted of 2 stages. Stage 1 used the LOF for vegetative phase when the potato plants were 7, 14, 21, 28, 35, 42, and 56 days after transplanting (DAT), with several concentration treatments: 0 ml/liter per plot (A0), 1 ml/liter per plot (A1), 2 ml/liter per plot (A2), and 3 ml/liter per plot (A3), applied at a dose of 13.88 ml/plant every seven days. Stage II used the LOF for the generative phase, applied when the potato plants were 60 and 70 DAT, with the same concentration treatments: 0 ml/liter per plot (A0), 1 ml/liter per plot (A1), 2 ml/liter per plot (A2), and 3 ml/liter per plot (A3), at a dose of 13.88 ml/plant. The fertilizer was applied by injecting the LOF of the appropriate concentration into a 1-liter hand sprayer filled with water, homogenizing the mixture, and then spraying it onto the plants according to the treatment. The treatment plots were isolated with thin wooden boards to prevent spray drift from affecting plants with different LOF concentrations. Stage I was done five times over five weeks, and Stage II was done two times over ten days.

Table 1. LOF for vegetative and generative phase content.

LOF for Vegetative Phase Content	LOF for Generative Phase Content
C-Organic 16.52%	K_2O (K_2SO_4) 46%
N-Organic 1.22%	P 25%
N 2.02%	NO_3 6%
P_2O_5 0.98%	B 15%
K_2O 0.92%	Mg 10%
Mn 33.9 ppm	Mn 2%
Mo 2.4 ppm	S 2%
Cu 76.4 ppm	SI 0.8%
Zn 50 ppm	

The harvesting process was carried out when the potatoes were 90-100 days after planting. There are two methods for harvesting the potato tubers: cutting the plants or using a small concentration of herbicide. The purpose of the latter method is to allow the tubers to remain in the growing medium for one week so that the skin becomes more robust and more resistant to abrasion. After one week, the potato tubers are ready to be harvested. The tubers are then cleaned of any remaining growing medium that is attached and collected into crates.

2.2 Samples and analysis

The selection of plant samples was carried out using a zig-zag model. Variable measurements on samples were carried out at 7-56 DAP and after being harvested. Plant height was measured from the surface of the growing medium to the topmost point of the plant using a ruler. This observation was conducted once a week, from 7 DAT until the plants were 56 DAT. The plant height was measured from the base of the stem up to the growing point of the plant using a ruler. The observation of stem diameter, number of branches, and number of leaves was conducted by measuring the base of the stem using a caliper. The observations were made every two weeks, from 14 DAT until the plants were 56 DAT. The observation of the number of tubers per plant and per treatment was carried out at the time of potato harvest (91 DAT). The observation was done by uprooting the plants, separating the tubers from the plants, cleaning the tubers, and counting the number of tubers produced per plant and per treatment. The observation of tuber weight per plant and per treatment was conducted after the harvesting process. The weighing was done by separating the tubers from the plant roots, then cleaning them, and weighing the total number of tubers from 1 plant and one treatment to determine the tuber weight per plant and per treatment. The observation of tuber grade was done by separating the tubers based on their weight class using a digital scale. The purpose of sorting the tubers into weight classes was to separate the seed tubers and the tubers for consumption, which would be stored in the warehouse. The tuber weight classes for G0 are divided into three classes: (1) Small (S): < 5 grams, (2) Medium (M): 5-20 grams, and (3) Large (L): > 20 grams [4]

2.3 Statistical analysis

The qualitative character data were analyzed in the form of descriptions and documentation, while the results of the quantitative character observations were analyzed using ANOVA (Analysis of Variance) at a 5% level using the SPSS application. If there were significant differences, then a further Honest Significant Difference (HSD) test at a 5% level was conducted.

3 Results

3.1 Plant height

The research results stated that if the concentration of the liquid organic fertilizer (LOF) sprayed has a higher concentration, then the plant height growth will be more optimal. Spraying LOF with high concentrations of N, P_2O_5, and K_2O stimulates the division of cell walls (Table 1). Spraying LOF containing N, P_2O_5, and K_2O will promote anticlinal cell wall division, leading to faster plant height growth. Higher concentrations of the N-P-K-rich LOF fertilizer resulted in more optimal plant height growth, likely due to the stimulation of anticlinal cell wall division and expansion [10]

Table 2. The average value of plant height (cm) of potato on LOF treatments at 7-56 DAP.

Treatments of LOF for the Vegetative Phase (ml/L)	Average Potato Plant Height Relative to LOF Treatments (DAP)							
	7	14	21	28	35	42	49	56
0	8.73 a	12.33 a	15.47 a	18.52 a	23.88 a	29.60 a	36.07 a	40.52 a
1	9.67 ab	13.30 ab	16.37 ab	20.47 ab	25.22 a	31.68 a	37.02 a	41.33 a
2	10.55 b	14.13 bc	17.57 b	22.40 bc	26.07 a	32.32 a	38.38 a	43.27 b
3	12.12 c	15.37 c	19.42 c	22.82 c	27.42 a	32.87 a	38.75 a	45.55 c
HSD 5%	1.36	1.37	1.68	2.29	3.93	5.43	4.28	1.24

The nutrients in the liquid organic fertilizer (LOF) also act as a catalyst in forming chlorophyll. Proteins are a significant protoplasm component, later used to stimulate cell division and elongation. Spraying LOF is believed to increase the amino acid and protein synthesis rate, which will promote plant growth. Research shows that LOF can significantly enhance the rate of amino acid and protein synthesis in plants, promoting their growth. LOFs, especially those containing amino acids, have been found to improve nutrient uptake and boost plant metabolism, leading to better yield and quality in crops like potatoes. Studies demonstrate that applying amino acid-based foliar sprays increases essential amino acids such as glycine and methionine, which play critical roles in protein synthesis and plant growth regulation.

Additionally, phosphorus is essential for energy transfer within the plant. It is a critical component in storing and transferring energy while synthesizing essential compounds like proteins and carbohydrates. When combined with LOFs, phosphorus can further optimize plant metabolic processes, enhancing crop quality and quantity [10] [11]. The products of the photosynthesis process are stored as organic compounds and then released as ATP, which is used in the formation and division of cells. Plant height is related to the formation of the xylem and cell expansion, causing the cambium to be pushed towards other layers and forming new cells in those layers, resulting in plant growth. The nutrients in the LOF fertilizer, particularly N, P_2O_5, and K_2O, play crucial roles in stimulating chlorophyll formation, protein and amino acid synthesis, and cell division and expansion, ultimately leading to enhanced plant height growth.

The highest peak of the plant height parameter occurred 56 days after planting (DAP), and no further increases were found in the following weeks. The plants then experienced senescence at 70 DAP. The decrease in growth rate and plant death indicate that the potato plants were in the tuber growth phase. Recent research shows that potato plants experience competition between tubers (the generative phase) and the upper parts of the plant (the vegetative phase), which act as simultaneous sinks for resources. This competition affects the plant's overall growth and development, particularly regarding how nutrients and energy are allocated between these two phases. As the vegetative phase matures and peaks, it gradually assumes a supportive role, allowing tuber expansion to become the main focus of resource allocation. This transition is essential for maximizing tuber yield and quality [12]. The potato plants exhibited a peak in height at 56 DAP, after which growth declined as the plants transitioned into the tuber growth phase, where the tubers and the vegetative parts competed for resources, with the tubers eventually becoming the dominant sink.

3.2 Stem diameter

The application of liquid organic fertilizer (LOF) containing K_2O affects the stem diameter of potato plants because it plays a role in every metabolic process and maintains turgor pressure, thereby influencing cell elongation in the stems. Recent research emphasizes the essential functions of potassium (K) and oxygen in supporting metabolic activities and maintaining turgor pressure in potato plants. As a critical macronutrient, potassium is vital in regulating several physiological processes, such as enzyme activation, photosynthesis, and cell elongation. Its presence is necessary for sustaining turgor pressure, which is crucial for proper cell expansion, especially in the stems of potato plants [13] [14]. Liquid organic fertilizers (LOF) that are rich in K2O have demonstrated a positive effect on the diameter of potato stems by enhancing metabolic functions and maintaining turgor pressure, thereby promoting cell elongation. This connection highlights the significance of ensuring an adequate supply of potassium to optimize growth and structural development in potato cultivation.

Table 3. The average value of potato stem diameter (mm) on LOF treatments at 14-56 DAP.

Treatments of LOF for the Vegetative Phase (ml/L)	Average Stem Diameter (mm) to LOF Treatments (DAP)			
	14	28	42	56
0	3.49 a	4.33 a	5.18 a	5.96 a
1	3.67 b	4.54 b	5.46 a	6.28 b
2	3.74 bc	4.71 b	5.61 a	6.50 c
3	3.84 c	4.97 c	6.13 b	6.67 d
HSD 5%	0.11	0.20	0.44	0.16

The stem diameter of potato plants is also influenced by temperature. Increased temperatures lead to higher respiration activity, causing photosynthates to be primarily used for plant growth rather than other processes (Table 2). Recent studies have shown that rising temperatures can significantly affect the respiration rates of potato plants, resulting in stress. Elevated respiration rates indicate that photosynthates—products of photosynthesis—are not being fully utilized for the plant's growth and development. Instead, a substantial amount is diverted to increased respiration activities [15] [16]. Research also suggests that high temperatures can interfere with the plant's carbon transport mechanisms, which diminishes the conversion of assimilated carbon into starch within the tubers. This interference is especially harmful during crucial growth stages, such as tuberization, when elevated temperatures can severely reduce photosynthetic efficiency, leading to chlorophyll degradation and a decline in CO_2 fixation [17]. The weekly increase in potato plant stem diameter indicates that the stems are sturdy and can support the growth of the potato plants. Good stem growth suggests that the plants are strong enough to withstand strong winds and are less susceptible to lodging, ensuring that potato plants do not die before harvesting. Potato plants with larger stem diameters are expected to be able to support taller plants, allowing them to continue growing upright and preventing them from lodging. Recent research on potato plant growth highlights the importance of solid stem development for improving plant stability, especially in the face of strong winds, and minimizing the risk of lodging. A larger stem diameter enhances the plant's ability to support taller structures, allowing the plant to remain upright and preventing collapse before harvest. This structural reinforcement ensures that potato plants continue to thrive and produce high-quality tubers, even under challenging environmental conditions. Furthermore, studies suggest that stem strength is influenced by factors such as lignin content, which plays a significant role in lodging resistance. Proper management of plant height and stem diameter through techniques like gibberellin (G.A.) regulation can further enhance the plant's ability to withstand environmental stresses, allowing it to maintain structural integrity and continue its growth without lodging [18]. Temperature plays a crucial role in affecting the stem diameter of potato plants by influencing respiration rates and the allocation of photosynthates. Maintaining adequate stem diameter is essential for providing structural support, preventing lodging, and ensuring the overall growth and development of potato plants.

The research results indicate that the lower the concentration of liquid organic fertilizer (LOF) applied, the less optimal the availability of essential nutrients like P_2O_5 and K_2O for the growth of potato plants, particularly the stem diameter. P_2O_5 and K_2O are critical factors that support plant growth. If the highest concentration of liquid organic fertilizer based on the packaging instructions is applied, it will support the growth of the plant's root system, which will then transport the nutrients from the soil upwards. If the applied macronutrients are less than the recommended concentration, it will result in hindered transport from the roots to the leaves, ultimately preventing the desired expansion of the potato plant's stem. In summary, the concentration of the applied LOF directly impacts the availability of essential nutrients, such as P_2O_5 and K_2O, which are crucial for supporting the growth and development of the potato plant's stem diameter. Applying the recommended higher concentrations of LOF can enhance root growth and facilitate the efficient translocation of nutrients, leading to optimal stem expansion.

3.3 Number of leaves

The research results indicate that the higher the concentration of liquid organic fertilizer (LOF) applied, the faster the rate of the number of leaves. LOF containing organic N, N, and P_2O_5 plays a role in a number of leaves. The increase in the number of potato plant leaves is due to the application of LOF, which is believed to stimulate the cells at the stem tip to undergo cell division activities, particularly in the meristematic regions. The research also explains that number of leaves is influenced by the presence of organic N, N, and P_2O_5 elements in the LOF, which have a role in the formation of new cells, including components of organic compounds such as chlorophyll, amino acids, ADP, nucleic acids, and ATP. Research suggests that LOF containing organic nitrogen (N) and phosphorus (P2O5) significantly enhances leaf development in potato plants. LOF promotes cell division in the meristematic regions, particularly at the stem tip, which facilitates leaf growth. The inclusion of organic N and P2O5 in the fertilizer is essential for generating new cells and aids in the synthesis of important organic compounds such as chlorophyll, amino acids, ATP, and nucleic acids, which are vital for robust leaf development and overall plant health [19].

Studies have demonstrated that using a combination of organic and mineral fertilizers improves nutrient absorption and enhances the productivity and health of potato crops, especially in soils lacking nutrients. Additionally, integrated fertilization approaches that incorporate LOF optimize plant growth by promoting leaf and stem development, ultimately leading to higher tuber yield and quality. This is attributed to the role of organic N, N, and P_2O_5 in stimulating cell division and the formation of new cells, including the components essential for leaf development [20].

Table 4. The average value of the number of potato leaves on LOF treatments at age 14-56 DAP.

Treatments of LOF for the Vegetative Phase (ml/L)	Average Number of Leaves to LOF Treatments (DAP)			
	14	28	42	56
0	3.49 a	4.33 a	5.18 a	5.96 a
1	3.67 b	4.54 b	5.46 a	6.28 b
2	3.74 bc	4.71 b	5.61 a	6.50 c
3	3.84 c	4.97 c	6.13 b	6.67 d
HSD 5%	0.11	0.20	0.44	0.16

Spraying liquid organic fertilizer containing nitrogen as a component of chlorophyll will increase the formation of photosynthates from the photosynthesis process, thereby enhancing the development of leaf meristematic tissues. Liquid organic fertilizer can increase the rate of the number of leaves if applied at the highest concentration recommended for use and done routinely. This can increase the rate of amino acid and protein synthesis activity (Table 3). Recent research has found that applying liquid organic fertilizer (LOF) to potato plants can enhance amino acid and protein synthesis, leading to faster leaf growth. When LOF is applied at higher concentrations and used regularly, it can accelerate the increase in leaf number and size, which is an indicator of optimal plant development. The presence of larger and more numerous leaves supports healthy growth and ensures the production of larger and more abundant potato tubers [10]. Using amino acid-based foliar sprays, such as glycine and lysine, significantly boosts leaf mass and tuber yields, emphasizing the role of amino acids in stimulating both vegetative growth and overall productivity. The application of nitrogen-containing liquid organic fertilizer can enhance photosynthate production, promoting leaf meristem development. Consistently applying LOF at the highest recommended concentration can accelerate amino acid and protein synthesis, leading to a faster number of leaves. The resulting abundant and large leaves are a sign of the plant's optimal growth, which will translate to the production of large and plentiful tubers.

The rate of the number of leaves increases along with the growth in the height of the potato plant. Taller potato plants will produce more leaves, which will subsequently stimulate the process of photosynthate formation. However, the rate of the number of leaves declines at 56 DAP (days after planting) or the eighth week. This occurs because the potato plant has reached the senescence phase, whereby the plant gradually wilts, drops its leaves, and experiences mortality. One characteristic of the senescence phase is a decrease in the growth rate, which indicates that the potato plant has matured and begun to senesce [21]. The rate of number of leaves in potato plants increases with plant height, as taller plants can produce more leaves and enhance photosynthate production. However, this rate of the number of leaves eventually decreases around 56 DAP as the plant enters the senescence phase and growth slows down, signaling the plant's maturation and the onset of aging.

3.4 Number and diameter of shoots

The research results indicate that the concentration of organic liquid fertilizer (LOF) is directly proportional to the number of shoots. The increasing number of shoots each week suggests that the plant has adequate available nutrients. Shoots are an essential factor for potato plants, as the number of shoots is directly proportional to the number of leaves. Nitrogen (N) plays a role in the photosynthesis process, and if potato plants have many leaves, the photosynthesis process will occur more rapidly, resulting in more optimal energy for cell formation and elongation. The greater the number of primary branches (shoots), the more leaves the plant will produce. The concentration of organic liquid fertilizer positively influences the formation of potato plant shoots. The increased number of shoots indicates adequate nutrient availability, and this is important as the number of shoots is directly linked to leaf production. The quantity of primary branches, or shoots, in potato plants, is vital for their overall productivity. Each shoot has the potential to generate several leaves, enhancing the plant's capacity to absorb light and carry out photosynthesis. Studies have demonstrated that an increased number of shoots not only reflects robust growth but also correlates with more excellent leaf production [13] [22].

The concentration of organic liquid fertilizers has been demonstrated to positively impact the development of shoots in potato plants. By applying organic fertilizers, nutrient availability in the soil is enhanced, which in turn supports shoot growth. Research has shown that using organic liquid fertilizers leads to an increase in the number of shoots, which is associated with improved nutrient absorption and more outstanding leaf production. This connection is crucial, as a sufficient supply of nutrients is essential for the optimal growth and development of potato plants [13]. This interplay between shoots and leaves is critical, as a larger leaf count improves photosynthetic efficiency, ultimately leading to higher tuber yields. More leaves facilitate a faster photosynthesis rate, providing the plant with the necessary energy for growth and development.

Table 5. The average value of the number and diameter of shoots (mm) on LOF treatments at the age of 14-56 DAP.

Treatments of LOF for the Vegetative Phase (ml/L)	Average Number of Shoots to LOF Treatments (DAP)				Average Shoot Diameter (mm) to LOF Treatments (DAP)			
	14	28	42	56	14	28	42	56
0	0.00 a	0.33 a	0.70 a	0.89 a	0.00 a	0.15 a	0.46 a	0.82 a
1	0.00 a	0.53 b	0.89 a	1.28 b	0.00 a	0.30 a	0.79 b	1.40 b
2	0.30 b	0.89 c	1.25 b	1.58 b	0.17 b	0.57 b	1.01 b	1.65 b
3	0.53 c	1.28 d	1.56 c	2.20 c	0.34 c	0.97 c	1.67 c	2.57 c
HSD 5%	0.08	0.14	0.20	0.32	0.07	0.19	0.27	0.30

Spraying the organic liquid fertilizer (LOF) containing Organic-C, Organic-N, N, P_2O_5, K_2O, Mn, Mo, Cu, Zn, and other nutrients shows a high rate of leaf growth, which means the process of photosynthate formation is increasingly abundant (Table 4). This, in turn, accelerates the growth and development of vegetative organs, as leaves play a role as the site of the photosynthesis process, which converts solar energy into carbohydrates. The shoot diameter is influenced by the nutrient content in the LOF. However, in addition to this factor, other factors, such as the environment, can also affect the shoot diameter of potato plants. Environmental factors such as planting distance and population density have a significant impact on the branching and overall growth of potato plants. Maintaining an optimal planting distance ensures sufficient light penetration and air circulation, both of which are essential for developing branches and leaves. Research indicates that broader spacing between plants can result in an increased number of primary branches, which in turn enhances leaf production and boosts photosynthetic efficiency [23]. Additionally, the availability of nutrients is crucial for cell expansion and elongation. When nutrients are abundant in the soil, they promote cell division and growth, leading to a higher number of branches and broader leaves. Studies have shown that soil fertility and effective fertilization practices are directly related to improved branching and higher yields in potato plants [24]. However, plants require an optimal fertilizer concentration to support good growth. Plants will experience a decline if they receive excessive nutrients. There is a tendency for a decrease in the number of branches when the plants receive too many micronutrients. The use of organic liquid fertilizers that are abundant in essential nutrients has been found to significantly promote leaf growth in potato plants. This enhancement leads to more excellent photosynthate production and accelerates vegetative development. Research suggests that these fertilizers create an optimal environment for nutrient uptake, which is crucial for the healthy development of shoots and leaves. A larger leaf area subsequently improves photosynthetic efficiency, which directly contributes to increased yields [25]. However, it is essential to recognize that while nutrient levels are vital for maximizing shoot diameter and overall growth, environmental factors also play a critical role. A balanced nutrient supply is necessary, as an excess can adversely affect branch formation. Such an imbalance may lead to reduced branching, thereby compromising plant health and productivity. Studies emphasize that implementing a well-managed nutrient strategy, including the appropriate use of organic liquid fertilizers, is essential for attaining optimal growth conditions for potato cultivation [25].

3.5 Number and weight of tubers

The research shows that the different concentrations of organic liquid fertilizer (LOF) applied provide different conditions in each treatment. The number of shoots or side stems influenced by the N, Organic-N, and P_2O_5 elements contained in the LOF for the vegetative phase will affect the leaf number of the plant, which will significantly assist in the photosynthate formation process (Table 5). The number of shoots in potato plants has a significant impact on leaf production and photosynthate generation. An increased shoot count is linked to larger leaves, which serves as a strong indicator of healthy growth and can contribute to greater tuber yields. Studies show that varying concentrations of liquid organic fertilizer (LOF) produce different growth responses in plants. Specifically, the nutrients found in LOF—especially nitrogen (N), organic nitrogen, and phosphorus pentoxide (P_2O_5)—are crucial in determining the number of shoots and lateral stems, which subsequently affects leaf quantity. More leaves lead to enhanced photosynthate production, further supporting plant growth [26]. Potato plants with larger leaf areas and more significant leaf numbers are typically indicative of vigorous growth, resulting in increased tuber yields [27].

Table 6. The average value of potato tuber yield per plant and per treatment for LOF treatments.

Treatments of LOF for Generative Phase (ml/L)	Average Number of Tubers (knolls) per plant	Average Number of Tubers (knolls) per treatment	Average Weight Bulbs (grams) per plant	Average Weight of Bulbs (grams) per Treatment
0	3.49 a	4.33 a	5.18 a	5.96 a
1	3.67 b	4.54 b	5.46 a	6.28 b
2	3.74 bc	4.71 b	5.61 a	6.50 c
3	3.84 c	4.97 c	6.13 b	6.67 d

HSD 5%	0.11	0.20	0.44	0.16

The application LOF containing essential macro and micronutrients, such as nitrogen, phosphorus, sulfur, calcium, magnesium, iron, manganese, molybdenum, and boron, has been shown to positively impact both the number and weight of potato tubers. These nutrients play a crucial role in cell development and overall plant health, promoting tuber formation and enhancing yield. Specifically, nitrogen, phosphorus, and calcium are known to drive processes like cell expansion and elongation, which are essential for the generative phase of potato growth. Research from recent years suggests that applying LOF at optimal concentrations provides potatoes with the necessary nutrients, ensuring balanced growth during both vegetative and generative stages. This not only supports tuber production but also improves tuber quality. However, excess or imbalanced nutrients can lead to issues such as nutrient antagonism, where an excess of one nutrient reduces the availability of others, potentially harming plant growth [28]

The weight of potato tubers is closely linked to the overall growth of the potato plants. As potato plants increase in height and produce more leaves, their capacity for photosynthate production also rises. This photosynthate is crucial as it supports the processes involved in tuber formation and filling. Research indicates that taller potato plants generate more photosynthate, which can be directed toward forming and filling a more significant number of tubers. Additionally, an increase in plant height and leaf number correlates positively with the weight of the tubers produced. This relationship is grounded in the plant's ability to synthesize and allocate photosynthetic products effectively. More leaves contribute to enhanced photosynthetic activity, leading to greater tuber yield and weight . Consequently, optimizing plant growth conditions—such as nutrient availability and light exposure—can significantly influence the final yield and weight of potato tubers. This emphasizes the importance of management practices that support both vegetative growth and tuber development for maximizing potato production [29]

The LOF has been shown to positively influence both the number and weight of potato tubers. Essential nutrients such as nitrogen (N) and phosphorus (P) in LOF play crucial roles in enhancing tuber growth. Nitrogen is vital for overall plant growth, while phosphorus is essential for energy transfer and photosynthesis, as it is a crucial component of ATP. This facilitates the conversion of carbon dioxide into organic compounds, which is critical for tuber production. Moreover, LOF not only provides essential nutrients but also increases the water content in potato plants, which is beneficial for tuber weight. Optimal water availability enhances cell weight and turgidity, leading to improved tuber development. Research highlights that sufficient water and nutrient availability are crucial to maximizing the size and number of cells, which in turn affects tuber yield [19]

Environmental factors, particularly temperature, significantly influence potato tuber formation. Research has shown that tuberization is optimized at soil temperatures of 15-18°C. When soil temperatures fall below this range, particularly during the night, specific hormonal responses are triggered, particularly involving the inhibitor hormone, which can inhibit tuber growth. This response is crucial as low temperatures stimulate the production of this inhibitor hormone, transmitted to the stolon (the tuber bud), effectively ceasing its growth and initiating tuber formation. Moreover, it has been established that higher soil temperatures can inhibit tuber growth as well, further emphasizing the importance of maintaining ideal temperature conditions. Several studies indicate that both the quantity and weight of tubers per plant are directly affected by the soil temperature [30] [31].

3.6 Grading

The research results state that the concentration of organic liquid fertilizer (LOF) is directly proportional to the tuber size. The higher the concentration of LOF sprayed on the potato plants, the larger the tubers produced due to the presence of K_2O (K_2SO_4) in the LOF of the generative phase. The application of Liquid Organic Fertilizer (LOF) has been shown to significantly influence the yield and size of potato tubers. Specifically, studies have found that spraying LOF can enhance the production of large (L) and medium (M) sized tubers while reducing the quantity of small (S) sized tubers. This effect is primarily attributed to the potassium (K) content in LOF, which is essential for tuber filling throughout the growth stages of the potato plant. Potassium plays a critical role in various physiological processes, including photosynthesis, enzyme activation, and carbohydrate synthesis. Its presence in adequate amounts contributes to a higher number of larger tubers. Additionally, phosphorus (P) is another essential nutrient that aids in the tuber weight of potatoes. As a component of adenosine triphosphate (ATP), phosphorus is crucial for converting carbon dioxide into organic compounds, ultimately enhancing tuber weight. Moreover, potato tubers' overall yield and size depend on sufficient nutrient availability and water content in the soil. The balance of K and P, along with other nutrients in LOF, directly affects the carbohydrate levels in potato plants, further influencing tuber growth. Therefore, applying LOF at optimal concentrations can effectively improve the size and yield of potato tubers, particularly by increasing the proportion of large and medium-sized tubers [32] [33].

Table 7. Average value of grading results for tuber sizes L, M, and S on LOF treatments

Treatments of LOF for Generative Phase (ml/L)	Average Tuber Grading (%) Large (L)	Average Tuber Grading (%) Medium (M)	Average Tuber Grading (%) Small (S)
0	3.49 a	4.33 a	5.18 a
1	3.67 b	4.54 b	5.46 a
2	3.74 bc	4.71 b	5.61 a
3	3.84 c	4.97 c	6.13 b
HSD 5%	0.11	0.20	0.44

Recent studies on potato production, sunlight, and nutrient management, including using organic liquid fertilizers (LOF), have shown that they significantly influence tuber size. Adequate sunlight is essential for optimal photosynthesis, which drives the production and accumulation of photosynthates, the carbohydrates that feed tuber development. Potato plants require consistent exposure to sunlight, as insufficient light reduces photosynthesis, leading to smaller leaves, closer internodes, and diminished tuber size. These plants, classified as long-day species, thrive under prolonged daylight, and this directly supports the growth of larger tubers by ensuring the continuous supply of nutrients and energy. When combined with proper nutrient application, mainly using LOF, the effects on tuber size are enhanced. LOF typically contains potassium (K) and phosphorus (P), crucial to promoting tuber growth. Potassium contributes to tuber filling, increasing the proportion of large- and medium-sized tubers, while phosphorus aids energy transfer during photosynthesis and carbon assimilation, promoting tuber mass. Studies suggest that using LOF helps optimize nutrient availability, ultimately improving the yield and quality of potato tubers. This synergy between sunlight and nutrient management has been extensively discussed in research. For instance, a study on organic potato production emphasizes the critical role of nutrient management, including phosphorus application, in increasing tuber size and overall yield. In contrast, another study highlights the importance of sufficient sunlight in optimizing the photosynthetic process and supporting tuber bulking under different growing conditions [12] [19].

4 Conclusion

The experiment on varying concentrations of liquid organic fertilizer (LOF) on the growth and yield of Granola Kembang potato (*Solanum tuberosum* L.) G0 seed tubers underscores the significant advantages of LOF in enhancing plant performance and tuber quality. By examining different LOF concentrations, the study identified that a concentration of 3 ml/L optimally boosted plant height, stem diameter, leaf count, and tuber yield, offering a superior balance of essential nutrients that directly supports robust vegetative and generative growth stages.The positive effects observed, particularly in tuber size and weight, highlight LOF's role in facilitating more efficient nutrient uptake and metabolic activity, leading to improved marketability of larger tubers. This approach not only supports productivity but also promotes sustainable farming by reducing dependence on chemical fertilizers, which can compromise soil health over time. Integrating LOF into potato farming practices can thus help small-scale farmers increase profitability while maintaining environmental sustainability. The study's findings advocate for further research and practical application of LOF to optimize crop yield and quality in a sustainable, economically viable manner.

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