Magnesium Fertilizer Increased Growth, Rhizome Yield, and Essential Oil Content of Ginger (*Zingiber officinale*) in Organic Field

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ABSTRACT

Ginger (*Zingiber officinale*) is the main biopharmaceutical export commodity of Indonesia. However, its productivity and quality are low because it is not cultivated using optimal techniques. This study aimed to examine the effect of magnesium (Mg) fertilizer on the growth, rhizome yield, and essential oil content of two ginger varieties in the organic field. The two factors tested were the rate of Mg fertilizer application (0, 50, 100, and 150 kg MgO ha^{-1}) and the variety of ginger (elephant ginger [*Zingiber officinale* var. *officinarum*] and red ginger [*Zingiber officinale* var. *rubrum*]). The variables measured were plant height, number of leaves, number of tillers, rhizome weight, and essential oil content. Mg fertilizer application rate and ginger variety significantly affected growth, yield, and essential oil content. No interaction effects were found between the two factors. Mg fertilizer applied at 150 kg MgO ha^{-1} resulted in the highest rhizome yield and essential oil content, with an increase of 21.74% and 15.38%, respectively, compared to the control (0 kg MgO ha^{-1}). The yield of elephant ginger was 29.41% higher than that of red ginger, whereas the essential oil content of the red ginger was 16.67% higher than that of the elephant ginger.

Keywords: Optimal Cultivation, Productivity, Quality, Variety

ABSTRAK

Jahe (Zingiber officinale) merupakan komoditas ekspor biofarmasi utama Indonesia. Namun, produktivitas dan kualitasnya rendah karena tidak dibudidayakan dengan teknik yang optimal. Penelitian ini bertujuan untuk mengetahui pengaruh pemupukan magnesium (Mg) terhadap pertumbuhan, hasil rimpang, dan kandungan minyak atsiri dua varietas jahe pada lahan organik. Dua faktor yang diuji adalah takaran pemupukan Mg (0, 50, 100, dan 150 kg MgO ha-1) dan varietas jahe (jahe gajah [Zingiber officinale var. officinarum] dan jahe merah [Zingiber officinale var. rubrum.]). Variabel yang diukur adalah tinggi tanaman, jumlah daun, jumlah anakan, bobot rimpang, dan kandungan minyak atsiri. Pemberian pupuk Mg dan varietas jahe berpengaruh nyata terhadap pertumbuhan, hasil, dan kandungan minyak atsiri. Tidak ada efek interaksi yang ditemukan antara kedua faktor. Pemberian pupuk Mg pada 150 kg MgO ha-1 menghasilkan hasil rimpang dan kandungan minyak atsiri tertinggi, masing-masing meningkat 21,74% dan 15,38% dibandingkan kontrol (0 kg MgO ha-1). Hasil jahe gajah lebih tinggi 29,41% dibandingkan jahe merah, sedangkan kandungan minyak atsiri jahe merah 16,67% lebih tinggi dibandingkan jahe gajah.

***Kata kunci:** Budidaya Optimal, Produktivitas, Kualitas, Varietas*

INTRODUCTION

Ginger (*Zingiber officinale*) is a high-value crop that is widely used, especially for its medicinal and flavoring potential. This rhizomatous plant has the highest harvest area in Indonesia, amounting to 10,205.03 hectares in 2018 (BPS, 2018). Although exports of ginger exceed those of other biopharmaceutical crops, it is not grown using optimal cultivation techniques, resulting in low productivity and quality (Bermawie, 2002). Several factors contribute to a crop's chemical composition, including plant genotype, growing conditions, and crop management to modify edible organs to improve the quality of the final products (Akula & Ravishankar, 2011; Dordas, 2009; Stagnari et al., 2018). In this regard, fertilization has an important role because plant metabolite accumulation is closely

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related to the mineral elements available in the growing substrate (Botella et al., 2017; Michalska et al., 2016). Magnesium (Mg) fertilization can be used to improve the yield and quality of crops (D'Egidio et al., 2019).

Magnesium is a macronutrient essential for plant growth (Cakmak & Yazici, 2010). It is a major element of chlorophyll and is needed for harvesting solar energy; it also plays a crucial role in phloem-loading and photo-assimilate transport to sink organs, such as fruits, roots, and seeds (Cakmak & Kirkby, 2008). Mg is also pivotal in synthesizing oils, and together with sulfur, it increases oil levels in various plants. Therefore, soil amendment with Mg is crucial to increase the levels of essential oils in ginger plants (Marschner, 2012). A lack of Mg will cause the suppression of plant growth as it impacts photosynthesis (Cakmak, 2013; Verbruggen & Hermans, 2013). The deficiency of Mg will reduce the dry matter partitioning between roots and shoots, increase the accumulation of starch, sugar, and amino acid in the leaves, damage the chlorophyll molecules, lead to the over-reduction of the electron transport chain in photosynthesis, and generate highly reactive oxygen species (ROS) (Cakmak & Kirkby, 2008; Verbruggen & Hermans, 2013). Therefore, enhancing the level of Mg nutrition is necessary to maintain the high yield quality. Magnesium sulfate is a mineral that is allowed to be given in limited doses in organic farming (BSN, 2013)

Several studies have investigated the application of Mg to improve soil fertility, crop production, and oil content (Senbayram et al., 2015; Wang et al., 2020). Mg fertilizers generally promote the yields of most crops, essential oil yields (Dordas, 2009), and oil palm (Tang et al., 2001). However, information on the critical Mg^{2+} values for ginger is scanty. The concentration of critical leaf Mg^{2+} in a majority of plants is 2–4 mg g^{1} DW (Bergmann, 1992). Visual symptoms determine the critical value without yielding a response.

Moreover, studies have reported that a number of crops had a deficiency of Mg that impacted yield, despite no vegetative signs of deficiency and despite the adequate range of Mg concentrations (Prasad et al., 2008). Since Mg is highly needed during the reproductive stage of ginger, the application of Mg can possibly lead to high yield productivity and increase the essential oil content. This study aimed to examine the effect of magnesium (Mg) fertilizer on growth, rhizome yield, and essential oil content of two ginger varieties on organic field. This research is important in order to increase the yield and quality of ginger on organic field and to find out which varieties of ginger give better yields and quality.

MATERIALS AND METHODS

Study area

The study was conducted in the village of Tegallalang, Gianyar Regency, Bali Province, Indonesia. The experimental field was located 750 m above sea level at 8°19'40"S and 115°15'18"E in Bali's major ginger-producing area. The climate is tropical, with mean annual temperatures ranging from 21–31 °C; the mean annual precipitation is 1848 mm. The soil type of the experimental field is Alfisol. The laboratories analysis results of soil prior to the experiment showed that the soil pH was 6.07 (neutral), the organic carbon content was 2.18% (moderate), the total nitrogen content was 0.14% (low), the phosphorus available was 44.25 ppm (high), the available potassium was 118.18 ppm (moderate), the available Mg was 0.52% (low), soil moisture content at field capacity was 39.55 %, and the soil texture was silty loam. The experiment was carried out in organic fields. Organic certification was applied for the fields after August 2015, but the result was not received. Farmers use composted

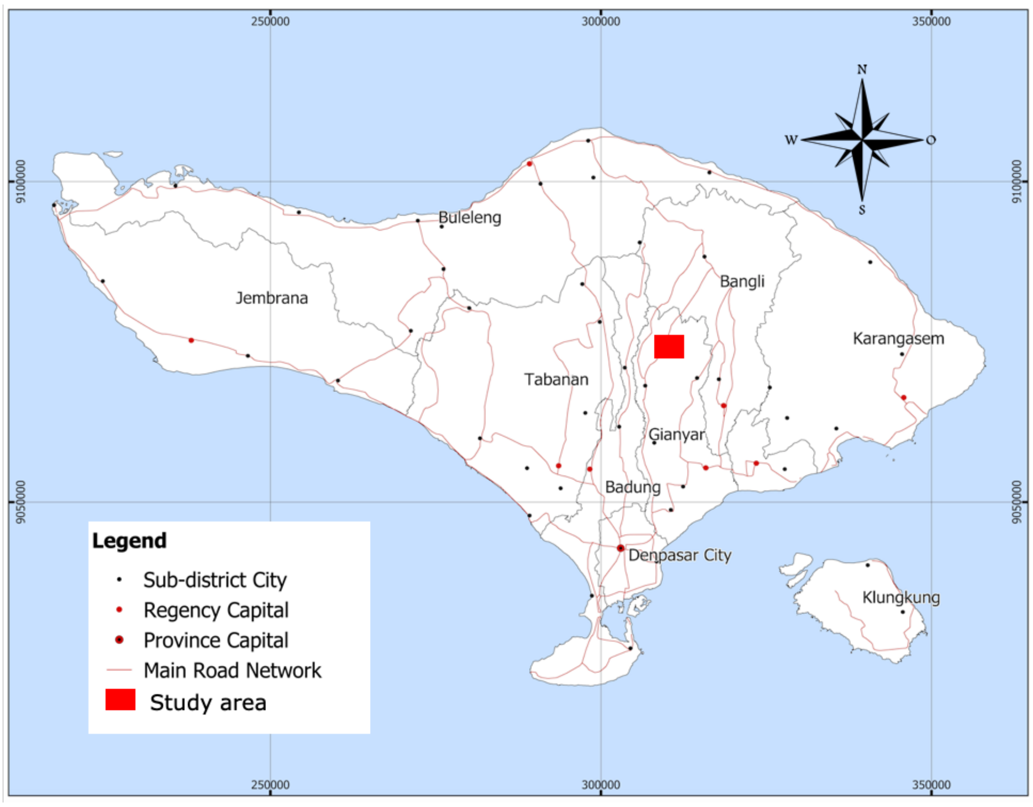

Figure 1. The location of the study site on Bali Island

cow manure for organic ginger production at a rate of 10 tons ha^{-1}. This organic fertilizer's composition of dry matter nutrients includes 17.36% carbon, 1.16% nitrogen, 0.53% phosphorus, and 0.14% potassium.

Experimental design

A randomized block design with two treatment factors was employed in the experiment. The first factor was the rate of Mg fertilizer application with four levels (0, 50, 100, and 150 kg MgO ha^{-1}). The dose of Mg fertilizer refers to the research of Wang et al., (2020), who reported that the agronomic efficiency of Mg fertilizers was correlated with application levels of Mg, at levels (50–120 kg ha^{-1}). The second factor was a variety of ginger, including red ginger (*Zingiber officinale* var. *rubrum*) and elephant ginger (*Zingiber officinale* var. *officinarum*). Both varieties are the dominant varieties cultivated by farmers in this area. These treatments were randomized and replicated four times. Mg was applied in the form of kieserite, a secondary mineral forming solid crystals with the chemical formula $MgSO_4.H_2O$ and containing 26% MgO. Kieserite is used as a fertilizer and is easily soluble in water. The experiment was carried out from April to November 2018 (eight months).

The experiment comprised 32 plots, each 3.5 × 1.5 m in size. Compost was administered at 10 t ha^{-1} one week before planting. In the treatments with fertilizer, MgO was administered two times, one day before planting and 30 days after planting (DAP) at a rate of 50, 100, or 150 kg ha^{-1}. In each plot, three seeds were planted in each of several holes with a dimension of 60 × 40 cm to maintain one healthy seedling per hole or 30 plants per plot (a population of 45,000 plants ha^{-1}). The seedlings were thinned at 14 days after planting (DAP). The plantation was spray-watered two times daily, especially during the beginning of plant growth and harvesting. The plots were weeded once at 14 days after planting (DAP).

Plant height, number of leaves, number of tillers, fresh rhizome weight, and essential oil content were obtained after harvest. Fresh rhizome weight was measured from a 1.26 m^2 quadrant with 12 plants in each plot, then analyzed and converted to fresh weight per hectare. The essential oil content was measured using the Stahl distillation method (*SNI* 06-2385-2006). A ginger rhizome weighing 150 g was chopped into pieces, placed in a round-bottom flask with 300 ml of distilled water, and then boiled. The water vapor condensed in the condenser (the cooling device), consisting of a mixture of oil and water, was collected and transferred to a separating funnel to which Na_2SO_4 was added. The water and oil will separate after being left for some time, depending on their specific gravity. The essential oil and water can then be partitioned in a separating funnel (Taufiq, 2007). The essential oil was identified using thin layer chromatography (TLC). The TLC plate was dried in the oven ± 3 minutes. Then, the lower and upper border was marked with a distance of 10 cm. The mobile phase in the TLC chamber was benzene and ethyl acetate at a ratio of 90:10. The TLC plate was spotted at the lower boundary line with the essential oil obtained and placed in the chamber with the mobile phase. The TLC plate was dried once the solvent had reached the upper border, and the essential oils were visualized under UV light to calculate Rf.

Statistical analysis

The data were analyzed statistically with ANOVA using Costat and MstatC software. Means comparison was performed using Least Significant Difference analysis with statistical significance at 5 % level (Gomez & Gomez, 2007). Pearson correlation coefficients were calculated between Mg fertilizer application rate and growth, rhizome yield, and essential oil content of ginger. Data transformation was done if necessary.

RESULTS AND DISCUSSION

Plant growth

Higher rates of application of Mg fertilizer, from 50 to 150 kg MgO ha^{-1}, significantly increased the height of ginger plants by 14.76% ($p < 0.05$) compared to the control (0 kg MgO ha^{-1}). However, this effect was not significantly different between 150 kg MgO ha^{-1} and 100 kg MgO ha^{-1} (Table 1). Elephant ginger was taller than red ginger. The application of Mg at 100 and 150 kg MgO ha^{-1} significantly increased ($p < 0.05$) the number of leaves by 24.02% and 8.06%, respectively, compared to the control and the 50 kg MgO ha^{-1} rate (Table 1). Elephant ginger produced 16.75% more leaves

Table 1. The effects of magnesium mineral fertilizer (MgO) application rate on the growth, including plant height, number of leaves, and number of tillers per plant of two ginger varieties

Treatment	Plant height (cm)	Number of leaves plant^{-1}	Number of tillers plant^{-1}
MgO rate (kg ha^{-1})			
0	47.90 ^{b}	56.75 ^{c}	8.88 ^{b}
50	49.85 ^{b}	61.02 ^{bc}	10.5 ^{a}
100	50.87 ^{ab}	65.13 ^{b}	10.5 ^{a}
150	54.97 ^{a}	70.38 ^{a}	10.75 ^{a}
5% LSD	16.571	1.595	0.574
Ginger variety			
Elephant ginger	65.2 ^{d}	72.75 ^{e}	10.97 ^{c}
Red ginger	52.56 ^{c}	62.31 ^{d}	9.06 ^{c}
5% LSD	16.571	1.595	0.574

Notes: Means followed by the same letters in the same column for each factor are not significantly different based on DMRT at α=5%.

Table 2. The effects of four rates of magnesium (Mg) fertilizer application on rhizome weight of two ginger varieties

Treatment	Rhizome weight (g crop-1)	Rhizome weight (t ha-1)
MgO rate (kg ha^{-1})		
0	139.37^{b}	6.27^{b}
50	143.12^{b}	6.89^{b}
100	158.43^{ab}	7.12^{ab}
150	169.67^{a}	7.63^{a}
5% LSD	4.262	0.12
Ginger variety		
Elephant ginger	166.34^{d}	7.49^{d}
Red ginger	128.53^{c}	5.78^{c}
5% LSD	4.262	0.12

Notes: The same letters in the same column for each treatment indicate no significant difference at the 5% level of the LSD test.

than red ginger.

Application of Mg at the rate of 150 kg MgO ha^{-1} significantly increased (p < 0.05) the number of tillers by 21.05% compared to the control. Although elephant ginger had more tillers (2.08%) than red ginger (Table 1), the difference was not statistically significant (p > 0.05).

There was a significant (p <0.05) effect of Magnesium fertilizer application on several plant growth variables. Plant height, number of leaves, and number of tillers significantly increased by 12.5%, 10.6%, and 9.4%, respectively, in the 150 MgO ha^{-1} treatment compared to the control. These growth variables were higher by 12.5%, 10.6%, and 9.4%, respectively, in elephant ginger compared to red ginger. There was no interaction between ginger variety and Mg fertilizer treatment. Ginger responds to Mg application when the soil is deficient in the element (Marschner, 2012), as shown by soil analysis, which indicated a low level (0.42%). These results show that Mg application impacts ginger's growth and productivity, especially when it is planted in soils with low magnesium levels. Under Mg deficiency, the chlorophyll content declines, which may be due to chlorophyll degradation or inhibition of chlorophyll biosynthesis because of a deficiency of Mg and carbohydrates (Marschner, 2012). In addition, a decline in chlorophyll results from interveinal chlorosis of older leaves and the formation of ROS and photooxidation caused by a lack of Mg (Marschner, 2012). Similarly, it was reported that the application of Mg could increase the number of stems in peach and plum (Alcaraz-López et al., 2004). Plants with a low level of Mg become shorter and produce less total biomass than plants with sufficient Mg (Cakmak & Kirkby, 2008; Marschner, 2012). In this study, Mg increased the number of tillers per plant. This may be due to the effect of Mg on carbohydrate transport, which impact components of yield in many plants (Cakmak & Kirkby, 2008; Marschner, 2012). The leaf plays a vital role in photosynthesis by rapidly taking up CO_2, and photosynthetic products can be used to establish rhizomes (Gardner & Pearce, 1991).

Crop yield

Higher rates of application of magnesium fertilizer, which are 100 and 150 kg MgO ha^{-1}, significantly (p <0.05) increased fresh rhizome weight per crop by 21.74% and 10.81%, respectively, compared to the control and the rate of 50 kg ha^{-1} (Table 2). The fresh weight of elephant ginger was 22.72% higher (p < 0.05) than that of red ginger (Table 2). The rhizome yield of ginger had increased significantly due to the application of Mg fertilizer. The rate of 100 kg MgO ha^{-1} increased rhizome yield by 15.12% (or 0.79 t ha^{-1}) compared to the control (Table 2). Elephant ginger had a 29.41% higher

Table 3. The correlation coefficients of the relationships between Mg fertilizer application rate with growth, rhizome yield, and essential oil content of ginger.

	Mg rate	Plant height	Number of leaves	Number of tillers	Rhizome yield
Mg rate	-				
Plant height	0,96	-			
Number of leaves	0.96*	0.99**	-		
Number of tillers	0.96*	0.99**	0,.9**	-	
Rhizome yield	0.99**	0.96*	0.96*	0.96*	-
Essential oil content	0.99**	0.93*	0.93*	0.93*	0.98**

Notes: *p <0.05; **p <0.01

rhizome yield (7.49 t ha^{-1}) than red ginger (Table 2).

The effect of Mg on yield can be attributed to the effects on rhizome weight. This result shows the importance of Mg in increasing the yield of ginger. Mg is essential for ginger; the reproductive phase has higher Mg requirements, and Mg application can directly impact on yield (Cakmak & Kirkby, 2008).

Essential oil content in rhizomes

The Mg fertilizer application could also increase the essential oil content in rhizomes. The 150 kg MgO ha^{-1} rate gave the highest essential oil content (0.42%), an increase of 15.38% compared to the control (Figure 2). The essential oil content of red ginger was 16.67% higher than that of elephant ginger (Figure 2).

Increased Mg fertilizer application led to significantly higher (p <0.05) essential oil content in ginger. The control (without Mg) resulted in the lowest essential oil content, 0.28%, compared to 0.42% (an increase of 15.38%) in the 150 kg MgO ha^{-1} treatment. Insufficient Mg results in a low yield of essential oils because, together with sulfur, Mg increases the synthesis of oils in various plant species. Mg takes part in enzymatic processes, the formation of chlorophyll, and the metabolism of carbohydrates and proteins. All of which can enhance the process of photosynthesis. Photosynthetic carbohydrates are used as a substrate for forming essential oils through glycolysis. Glycolysis produces pyruvic acid, which undergoes a number of reactions to produce geranyl pyrophosphate, a precursor in the formation of essential oils in the

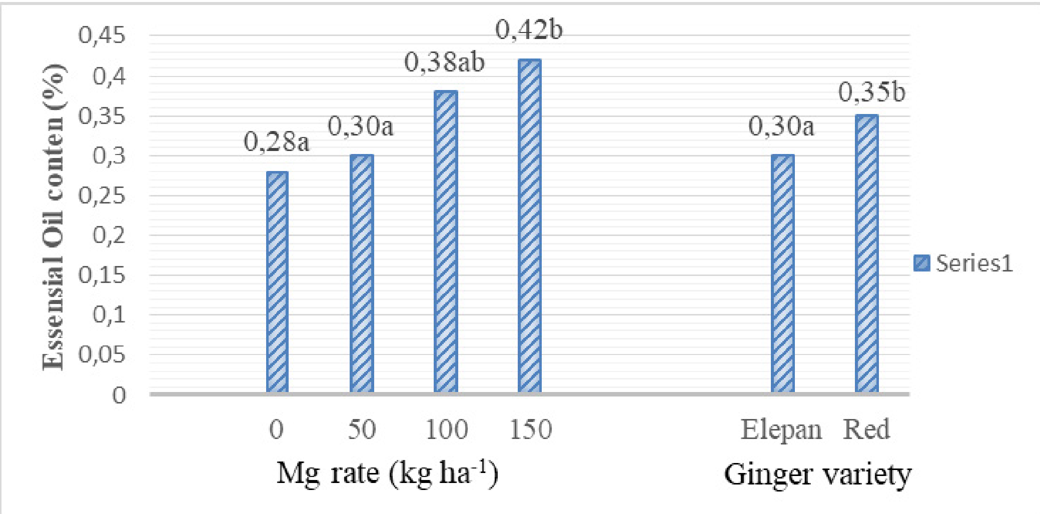

Figure 2. Effects of Mg fertilizers rate and ginger varieties on the essential oil content of ginger plants. The same letters in the same column for each treatment indicate no significant difference at the 5% level of the LSD test.

terpenoid group. The essential oil of ginger includes sesquiterpenes. Sesquiterpene biosynthesis involves photosynthesis. The increased availability of Mg increases the metabolic process of plants, which can further increase the levels of secondary plant metabolites, including essential oil. The effects of Mg fertilizer application in this study are similar to those observed in previous research on other plant species (Prasad et al., 2008). Red ginger produced 16.67% higher essential oil content than elephant ginger. These results may be due to the genetic differences between the two varieties (Rizqullah et al., 2018). It is in line with Jyotsna et al., (2012), who found that different ginger varieties differed significantly in quality.

Correlations

There was a positive correlation between Magnesium concentration with plant height, number of tillers per plant, rhizome weight, and essential oil content (Table 3). Plant height was correlated positively with number of tillers per plant, rhizome weight, and essential oil content (Table 3). A positive correlation was also found between the total number of leaves and number of tillers per plant, rhizome weight, and essential oil content. There was a positive correlation between number of tillers per plant with rhizome weight and essential oil content. Rhizome weight was positively correlated with essential oil content.

CONCLUSION

The growth, yield, and essential oil content of the two ginger varieties significantly increased after the application of Mg mineral fertilizer. No interaction effects were found between the two factors. The Mg fertilizer application rate of 150 kg MgO ha^{-1} resulted in the highest rhizome yield and essential oil content, with an increase of 21.74% and 15.38%, respectively, if compared to the control. The elephant ginger yield was 29.41% higher than that of red ginger. Conversely, the essential oil content of red ginger was 16.67% higher than elephant ginger. We recommend farmers apply Mg fertilizer at the rate of 150 MgO ha^{-1} or plant a red ginger variety to obtain high essential oil yields. Further research on organic fertilizer applications should be undertaken to evaluate the potential benefits for rhizome yield and essential oil production.

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