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Effects of different substrates on growth and yield of black ginger (*Kaempferia parviflora*) cultivated using soilless culture

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Abstract

Kaempferia parviflora or black ginger is a rhizome plant with medicinal value. Domestic demand for black ginger is high and has increased significantly because of its medicinal properties. However, the demand for black ginger rhizomes in Malaysia can hardly be fulfilled due to the low production yield. Soilless culture system could be an alternative method for increasing black ginger rhizome yields to overcome the supply shortage problem. The effects of soilless substrates on the growth and yield of black ginger were studied. The main objective of the study was to determine the most suitable growth substrate for cultivation of black ginger using soilless culture system. The study was conducted under the side-netted rain shelter equipped with an irrigation system to supply fertiliser solution at a regulated schedule. Eight months black ginger rhizomes were used as seed with 2 – 3 point buds attached to each seed rhizome. Five combinations of growth substrates were evaluated: 100% coir dust; 100% burnt paddy husks; 70% coir dust + 30% burnt paddy husks; 30% coir dust + 70% burnt paddy husks; and 50% coir dust + 50% burnt paddy husks. The black ginger rhizomes were harvested 8 months after sowing. Plants grown in 50% coir dust + 50% burnt paddy husks mixtures gave the best growth performance and yield compared to the other treatments. They produced the highest vegetative fresh weight shoot height (678 g) and rhizome yield (582 g per plant). The lowest rhizome yield (154 g) was obtained from plants planted in 100% coir dust. Hence, it can be concluded that the black ginger plants cultivated in 50% coir dust + 50% burnt paddy husks mixtures substrate using soilless culture system gave the best plant growth and yields.

Keywords: *black ginger, soilless culture system, soilless substrate, coir dust, burnt paddy husks*

Introduction

Soilless culture system is a method of growing plants that provides the same functions as the soil by supporting the plant physically while providing a rooting environment that gives access to optimum levels of water and nutrients. The yields of chillies, rock melons and tomatoes cultivated in soilless system increased 3 – 5 times compared to those using conventional method (Frezza et al. 2005; Fussy and Papenrock 2022). In soilless production system, many types of growing media or substrates such as rockwool, perlite, vermiculite and peat have been used to grow many kinds of crops (Caron et al. 2002; Caron and Nkongolo 2004). Media such as rockwool, perlite and vermiculite are expensive because they have to be imported. Hence, alternative substrates that are cheaper and locally available such as coconut fibers and burnt paddy husks should be used as alternative media (Almeida et al. 2020). One of the most important factors influencing plant fertility, besides water and nutrient content, is soil aeration (Li at al. 2019). Different plant species have different rooting systems which enable them to grow under different oxygen requirements (Striker 2012).

Several studies have been conducted to analyse the physical properties of growth media including available water capacity (AWC) and air filled porosity (AFP) (Abad et al. 2001). AWC indicates the water content of substrates and AFP gives the estimation of oxygen availability or level of aeration in the substrates (Wall and Heiskenen 2003). According to Humara et al. (2002), high water content in the growing substrates can reduce both AFP and aeration, which can lead to logging and hypoxia which are detrimental to most plant species. Sufficient amount of water in growing substrates is one of the most critical

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factors for plant growth and development (Khelikuzzaman 2001).

Kaempferia parviflora is a ginger plant belongs to a tropical and sub tropical *Zingiberaceae* family, which originated from Southeast Asia. This perennial plant with thick dark purple tuberous roots or rhizomes has been cultivated for use as a spice and for herbal medicine. The leaves of black ginger is approximately 6 – 8 cm long, oblong in shape and the plant produces purple and white flowers (Labrooy et al. 2020). Black ginger is widely used as an alternative medicine in treating various types of diseases including fungal infections, gastrointestinal disorders, decreased vitality, reduced allergies, promoting health, relieving body pains, leucorrhea, oral disease, gastrointestinal disorders and rectifying male impotence (Yenjai et al. 2004; Trisomboon 2009). Phytochemical studies revealed that black ginger's rhizomes contains phenolic and flavonoids compound including flavones, flavanones and chalcones (Sutthanut et al. 2007; Azuma et al. 2008). Domestic demand for black ginger is high and has increased significantly as people become more interested in its medicinal properties. However, the demand for black ginger rhizomes in Malaysia can hardly be fulfilled due to the low production yield and planting materials (Labrooy et al. 2013). Therefore, cultivating ginger using soilless culture system could be an alternative method for increasing rhizome yields to overcome the supply shortage problem.

There is potential to increase the growth and yield of black ginger rhizomes using soilless system based on significant increase in yields of chillies, rock melons, tomatoes and other leafy and fruity vegetables grown on various media (Frezza et al. 2005; Fussy and Papenrock 2022). Thus, this study was conducted to determine the effects of soilless substrates such as coir dust and burnt paddy husks on growth and yield of black ginger. The main objective was to determine the optimum growth substrate for black ginger cultivation using soilless culture system.

Materials and method

Plant materials

The black ginger is vegetatively propagated through rhizomes and the shoot appears 2 – 3 weeks after sowing. Prior to sowing, eight month old black ginger rhizomes were bought from a plantation in Kuala Krai, Kelantan, Malaysia. Each of the rhizomes were cut into smaller pieces of about 4 cm long and 30 g in weight. Each of the seed rhizomes contained 2 – 3 point buds. The seed rhizomes were treated with previcur-N prior to planting. Black ginger can be harvested at 8 months as mature rhizomes.

Rain shelter structure

A side netted rain shelter of 30 m long x 10 m wide x 4.5 m high located in MARDI Serdang, Selangor, Malaysia was used in the study. All structures were made of galvanised steel frame with transparent polyethene film (180 µm thick) roofing and insect repellent net (0.1 x 0.1 mm^2) side cladding. Entrance into the shelter was viable through double doors to reduce the chance of insect entry.

Experimental design and growth media

The treatments were arranged in a randomised complete block design (RCBD) with five levels of treatment with three replicates and 30 plants per treatment. The coir dust and burnt paddy husks were weighed in accordance to the quantity required for each treatment. There were five coir dusts and burnt paddy husks mixtures used as treatments in this study. These treatments were as follows: T1 = 100% coir dust; T2 = 100% burnt paddy husks; T3 = 70% coir dust and 30% burnt paddy husks; T4 = 30% coir dust and 70% burnt paddy husks; and T5 = 50% coir dust and 50% burnt paddy husks. Each mixture was thoroughly mixed in a 10 litre pail before filling into 16 cm x 16 cm black polyethene bags. The seed rhizomes were sown into the media according to the treatments. Each polyethene bag was placed randomly on four irrigation lines under the side netted rain shelter and individually irrigated with nutrient solution via a dripper on the surface of the medium.

Irrigation system

The irrigation system, which was built in the side netted rain shelter, consisted of a 1,500-litre tank, 1.5 horsepower water pump, water filter, pressure metre and four lateral lines (28 m each) which looped to each other. Each of the lateral lines was equipped with 100 drippers that were placed into 100 polyethylene bags, side by side. The distance between each line was 1.5 m and the distance between each dripper point in the lateral line was 0.3 m. A valve was attached to an inlet to control the amount of the irrigated solution to be pumped in. A small valve was also attached to each lateral line to maintain the flow through the drip line. The nutrient solutions were supplied through 0.3 m micro tubes and arrow drippers.

Nutrient concentrations and irrigation frequencies

The fertiliser was formulated by MARDI based on the nutrient requirements of the plant rhizomes. All the fertiliser components were water soluble. The fertiliser stocks were prepared according to Suhaimi et al. (2011). The macro and micro nutrients were prepared separately as A and B stock solutions respectively, at 100x dilution. Solution A contained calcium nitrate and iron, while solution B contained all other components. All components were added one by one to ensure that they dissolved completely in the water. In preparing stock A solution, calcium nitrate was added into the container containing tap water (pH 5.5 – 6.5) and stirred until it dissolved, then the solution was poured into a 100-litre vessel. Iron powder was added into another container that contained tap water, stirred until it dissolved completely, and then added into the vessel. The same procedure was applied in preparing stock B solution.

The irrigation solutions were prepared in a 1,500-litre tank. Stock A and stock B were added into the tank at 1:1 ratio until the needed electricity conductivity (EC) was achieved. The EC of the fertigation solution was between 1800 µS and 2400 µS. The EC for the first month of planting was 1800 µS and 2400 µS beginning from the second month until the end of the cultivation periods. The irrigation scheduling was automatically implemented by a digital timer, two times/day in the first three months (0800 h and 1600 h), three times/day in the 4^{th} – 7^{th} month (0800 h, 1000 h and 1600 h), and once/day in the last month (0800 h). The duration of irrigation was 3 min and an identical amount of fertiliser solution was applied to all polyethene bags. The daily irrigation volumes/plant were 500 ml in the first three months, 750 ml in the 4^{th} till 7^{th} month and 250 ml in the last month. Routine horticultural practices for pest, disease and weed control were followed. Insecticide (Malathion) and fungicide (Benlate) were applied once every two weeks.

Parameter measurements

The growth of the black ginger plants was measured monthly by measuring the height and weight of leaves/ shoots and rhizomes. The black ginger rhizomes were harvested after 8 months of sowing to determine the yield and growth of rhizomes. The weight was measured immediately after harvest to prevent desiccation and water loss from the rhizomes.

Air filled porosity (AFP) and container moisture capacity (CMC)

The container moisture capacity (CMC) is the amount of water present after the medium has been saturated and allowed to drain. The CMC of the five different media mixtures were taken at two different time intervals and calculated using the formula: (saturated mass – dry mass)/dry volume. The measurement was taken at one month after planting by weighing the container at 1 h and 5 h after watering. Air filled porosity (AFP) or air capacity can be defined as the proportion of the volume that contains air after it has been saturated with water and allowed to drain. The AFP measurement was done according to Bunt (1988).

Statistical analysis

Data obtained were subjected to statistical analysis using analysis of variance (ANOVA) procedures to test the significant effect of all the variables investigated using SAS version 9.1. Means were separated using Duncan Multiple Range Test (DMRT) as the test of significance at $p \leq 0.05$

Results and discussion

Air filled porosity (AFP) and container moisture capacity (CMC)

The treatment with 100% coir dust had the highest porosity after 1 h and 5 h of irrigation (*Table 1*). Meanwhile, there were no significant differences in the AFP value between 50% coir dust and 50% burnt paddy husks mixture and 70% coir dust and 30% burnt paddy husks mixture. 100% burnt paddy husks (initial: 6.7%/ final: 9.4%) had the second lowest initial and final porosity at both times after irrigation, followed by 30% coir dust and 70% burnt paddy husks mixture (initial: 5.8%/final: 7.8%). The AFP value from 100% coir dust and mixture with higher coir dust (up to 70%) increased compared to 100% burnt paddy husks and mixture with higher burnt paddy husks (up to 70%). Mixtures with high content of burnt paddy husks had lower AFP values due to its compaction and high water retention properties. The volume of air increased when coir dust was mixed into burnt paddy husks. The addition of coir dust increased the air capacity and decreased the water contents of the mixtures. The availability of air in the substrate is an important factor affecting the success of growing plants in containers (Aendekerk 1994). The container moisture capacity (CMC) measures the water availability or content in the growth substrate. The CMC values decreased 5 h after irrigation (*Table 1*). The highest initial and final CMC values were obtained from the mixture of 30% coir dust and 70% burnt paddy husks, followed by 100% burnt paddy husks, mixture of 50% coir dust and 50% burnt paddy husks, mixture of 70% coir dust and 30% burnt paddy husks and the lowest CMC was observed in the 100% coir dust substrates. The differences in CMC values between 100% burnt paddy husks and 100% coir dust were 26.7% and 22.2%, respectively in both times after irrigation. These results showed that addition of burnt paddy husk into coir dust increased the moisture content while lowering the AFP of the substrates. The air retention and moisture in the substrate play important roles for successful plant growth in containers (Schafer and Lerner 2022).

Effects on plant growth

There were significant differences in vegetative fresh weight between treatments at $p \leq 0.05$ (*Table 2*). The highest vegetative fresh weight was produced by black ginger cultivated in 50% coir dust and 50% burnt paddy husks mixtures with an average weight of 678 g and the lowest were those cultivated in 100% coir dust with an average weight of 495 g. This could be due to the moderate porosity of 50% coir dust and 50% burnt paddy husks mixtures that are able to retain suitable moisture in the substrates compared to the other treatments. Coir dust as substrate has a higher porosity compared to burnt paddy husk which has low porosity. Porosity characteristics give the substrate the ability to retain moisture and create

Table 1. Physical properties of growth substrates at two different times after irrigation

Treatment	Air filled porosity (%)		Container moisture capacity (%)	
	1 h	5 h	1 h	5 h
100% CD	9.8[a]	14.0[a]	41.5[e]	36.8[e]
100% BPH	6.7[c]	9.4[c]	68.2[b]	59.0[b]
70% CD + 30% BPH	8.4[b]	10.3[b]	51.0[d]	47.3[d]
30% CD + 70% BPH	5.8[d]	7.8[d]	71.4[a]	67.6[a]
50% CD + 50% BPH	8.8[b]	10.4[b]	55.5[c]	52.5[c]

Mean values in the same column followed by the same letter are not significantly different at p <0.05
CD = Coir dust; BPH = Burnt paddy husks

Table 2. Plant growth and rhizome yield after eight months of cultivation

Treatment	Plant height (cm)	Vegetative fresh weight (g)	Number of tillers	SPAD value	Diameter of tiller (cm)	Average fresh rhizome yield/plant (g)	Rhizome to vegetative fresh weight ratio
100% CD	58[a]	495[e]	24[a]	42[d]	0.12[a]	154[e]	0.32[e]
100% BPH	60[a]	582[c]	22[b]	48[c]	0.14[a]	228[d]	0.39[d]
70% CD + 30% BPH	56[a]	620[b]	18[c]	52[b]	0.12[a]	418[b]	0.68[b]
30% CD + 70% BPH	59[a]	548[d]	25[a]	58[a]	0.14[a]	298[c]	0.55[c]
50% CD + 50% BPH	58[a]	678[a]	22[b]	50[b]	0.13[a]	582[a]	0.86[a]

Mean values in the same column followed by the same letter are not significantly different at p <0.05
CD = Coir dusk; BPH = Burnt paddy husks

air filled space in the substrates. Combining two types of media together alters the media characteristics as seen in the study. This higher porosity property drained out the excess fertiliser solution between the irrigation schedules more quickly. The mixtures between coir dust and burnt paddy husks could have increased the water holding capacity and maintained the moisture that needs for rhizomes growth.

Plant cultivated in 30% coir dust and 70% burnt paddy husks mixtures showed the highest number of tillers and SPAD value compared to other treatments. However, there were no significant differences in plant height and tiller diameter between treatments. These two parameters were not affected by the type of media used to cultivate the black ginger plant. Previous studies showed that higher content of burnt paddy husks in the medium added more moisture content that lowered dissolved oxygen in the media, which consequently reduced height of the ginger plant compared to 100% coir dust (Suhaimi et al. 2012). Other studies also showed that high water holding capacity also reduces the growth and yield of tomato and cucumber (Mahamud and Manisah 2007; Peyvast et al. 2010). The growth requirements of the black ginger plant differ from those of other rhizomatic plant species because the plant does not require a high water content to grow (Maketon et al. 2020). High water content conditions might increase the chances of plant pathogens affecting the rhizomes in container cultivation (Postma et al. 2008; Gina et al. 2021).

Effects on rhizome yield

For commercial purposes, black ginger rhizomes are harvested eight months after sowing. In this study, the rhizomes were harvested after eight months and the fresh weight of the rhizomes were measured. The interior flesh and epidermis were dark purple in colour than the mother seed piece. The rhizomes also produced a rancid odour. There were significant differences in rhizome yield between treatments after eight months of cultivation (*Figure 1*). The highest average fresh rhizome yield was obtained from plants cultivated in 50% coir dust and 50% burnt paddy husks, followed by mixtures of 70% coir dust and 30% burnt paddy husks, 30% coir dust and 70% burnt paddy husks, 100% burnt paddy husks and last, 100% coir dust. These results showed that black ginger cultivated in the equivalent of the amount of coir dust media and burnt paddy husks increased the rhizome yield by up to 3.8 fold compared to those grown in media containing 100% coir dust.

Moderate moisture content between irrigation in the 50% coir dust and 50% burnt paddy husks supported the underground rhizomes for growth. The black ginger plant did not require too much moisture as it is detrimental to rhizome growth. Meanwhile, too low moisture in the root zone created a dry condition that stunted rhizome growth. A 50:50 ratio of coir dust and burnt paddy husks have a strong capillarity that provides more uniform moisture conditions for black ginger roots. For crops grown in containers, it is important to consider the tendency of most root systems to grow gravitropically to form a dense layer at the bottom of the containers (Raviv et al. 2001).

These conditions can increase aeration in the base mix and reduce drying of the surface by lifting the moisture higher up in the polyethene bags. This increases the volume of the mix that is suitable for root development and improves access to moisture and fertiliser. This moisture redistribution is possibly one of the reasons plants grown in mixtures of 50% coir dust and 50% burnt paddy husks have higher rhizome yield. Aeration in the growing medium is positively related to AFP and negatively to water content (Raviv and Lieth 2008). The 50% coir dust and 50% burnt paddy husks mixtures are less acidic with a pH suitable to facilitate ginger to grow and consequently allows the plant roots to absorb nutrients efficiently.

In the cultivation period between six to eight months, the growth of rhizomes between treatments was similar with an increase in rhizome yield regardless of media mixtures. Rhizomes in 50% coir dust and 50% burnt paddy husks mixtures treatment showed the most rapid growth compared to other treatments (*Figure 2*). Media with high content of coir dust gave lower rhizome yield throughout the cultivation period with a mixture of 100% coir dust exhibited the lowest rhizome yield. These results were similar to the study conducted by Wan Zaliha (2018), who found that the yield of black ginger rhizome decreased significantly when grown using 100% coir dust. Previous study done by Hayden et al. (2004) found that the growth of rhizomes is dependent on the type of medium. The growing medium acts as heat insulator and provides heat that enhances the growth of rhizomes.

Figure 1. Effects of substrates on black ginger rhizomes after eight months of cultivation. (a) 100% coir dust, (b) 100% burnt paddy husk, (c) 70% coir dust + 30% burnt paddy husk, (d) 30% coir dust + 70% burnt paddy husk and (e) 50% coir dust + 50% burnt paddy husk

Rhizomes and vegetative ratio

Overall biomass of black ginger plants can be divided into two parts: aboveground biomass consisting of leaves and stems (shoots) and underground biomass consisting of rhizomes and roots. In this study, there were significant differences between treatments in rhizome to vegetative fresh weight ratio. The ratio of underground biomass to aboveground biomass was highest in plants cultivated in 50% coir dust and 50% burnt paddy husks mixtures with a ratio of 0.86 (*Table 2*). There was higher aboveground biomass compared to underground biomass in all treatments. The high ratio of underground biomass to aboveground biomass reflects that the roots were able to supply the top of the plant with water, nutrients, stored carbohydrates and certain growth regulators (Harris 1992).

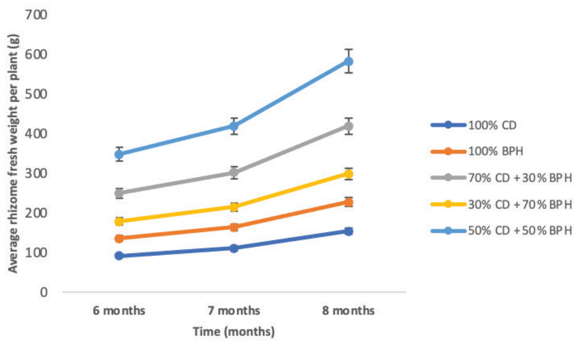

Figure 2. Growth of black ginger rhizomes between six and eight months of cultivation

Conclusion

The mixture of coir dust and burnt paddy husks significantly alters the characteristics of substrates that affected plant height, vegetative fresh weight, number of tillers, SPAD value, diameter of tiller, average fresh rhizome yield/plant and rhizome to vegetative fresh weight ratio. Media containing 50% coir dust and 50% burnt paddy husks mixtures showed good growth and increased the rhizome yield up to 3.8 fold compared to those containing 100% coir dust. It can be concluded that 50% coir dust and 50% burnt paddy husks mixtures are the best substrates for growing black ginger in the soilless culture system. However, studies on burnt paddy husks in combination with other agricultural wastes like sago waste, industrial by-products like polystyrene beads or any other less expensive media such as coarse sand should be continued in order to increase the use of burnt paddy husks as a growing medium for growing black ginger or any other suitable crop in soilless culture production systems.

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