IMPACT OF HARVESTING AGE AND CULTIVATION METHOD ON ANTIOXIDANT CAPACITY OF HALIA BENTONG (*ZINGIBER OFFICINALE ROSCOE*)

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ABSTRACT

This study investigates the influence of harvesting age and cultivation system on the antioxidant capacity of Halia Bentong (Zingiber officinale) rhizomes. Rhizomes were harvested at different maturity stages, ranging from 3 to 8 months, and were cultivated using conventional, hydroponic and fertigation planting systems. Other than that, antioxidant capacity of fresh and dried ginger rhizomes was also compared. The total polyphenol and total flavonoid content were determined using established analytical methods, and antioxidant activity was assessed through in vitro assays such as FRAP (ferric reducing antioxidant capacity), DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity, and TEAC (trolox equivalent antioxidant capacity). Results indicate that both harvesting age and cultivation system significantly impact the antioxidant capacity of Halia Bentong. Distinct maturity stages show variations in antioxidant levels, with certain ages exhibiting higher antioxidant activities. Furthermore, the choice of cultivation system plays a crucial role in influencing the overall antioxidant potential of the rhizomes. Harvesting Bentong ginger at the age of 8 months proved optimal for conventional and fertigation farming in achieving high antioxidant capacity. However, hydroponic farming exhibited varying harvesting ages for polyphenol and flavonoid content, as well as antioxidant activity. Insights from this study provide valuable information for optimizing the harvesting time and selecting appropriate cultivation methods to enhance the antioxidant attributes of Bentong ginger. Understanding the combined impact of harvesting age and cultivation system on antioxidant capacity contributes to the development of sustainable practices for cultivating Halia Bentong with enhanced potential health benefits.

Keywords: Halia Bentong, conventional, hydroponic, fertigation, antioxidant capacity

INTRODUCTION

Bentong ginger is known for its robust and aromatic flavour. It is often described as having a strong, pungent, and slightly spicy taste compared to other ginger varieties. The aroma is intense and contributes to its popularity in culinary applications. The rhizomes of Bentong ginger are usually pale yellow to light brown in colour. The skin is thin, and the flesh is firm. The rhizomes can vary in size and shape. Bentong ginger is predominantly cultivated in the Bentong district of Pahang, Malaysia. The region's climate and soil conditions are believed to contribute to the distinctive qualities of this ginger variety. The strong flavour and aroma of Bentong ginger can enhance the overall taste of a dish. Like other ginger varieties, Bentong ginger is associated with potential health benefits. It is often consumed for its anti-inflammatory, antioxidant, and digestive properties.

Ginger rhizomes with its wide range of antioxidants can be a major source of natural or phytochemical antioxidants (Ghasemzadeh et al. 2010). Antioxidants are substances that can help prevent or slow damage to cells caused by free radicals, which are unstable molecules produced by the body as a result of metabolism and exposure to certain environmental factors. The antioxidant potential of plants and crops may vary significantly depending on the age at which they are harvested, highlighting that different harvesting ages can yield distinct levels of antioxidant activity. The harvesting age for ginger can vary depending on the variety, growing conditions, and the specific needs of farmers or consumers. However, ginger is generally harvested when the

plant is about 8-10 months old. At this stage, the plant has reached maturity, and the rhizomes have developed enough for harvest. Some farmers may prefer to harvest ginger earlier for a milder flavour, while others may wait until it's more mature for a stronger taste. It's essential to consider factors like the size of the rhizomes, the intensity of flavour desired, and the specific requirements of the market or culinary preferences. Therefore, there isn't a fixed harvesting age for ginger, but it is typically done around 8-10 months after planting.

Apart from the harvesting age, different cultivation methods can impact the antioxidant capacity of ginger. Cultivation practices for ginger encompass a range of methods and approaches aimed at maximizing its growth and productivity. These methods typically take into account factors like soil composition, climate conditions, and resource availability. In this research, three distinct cultivation systems - conventional, hydroponic, and fertigation - were employed to cultivate Bentong ginger. Conventional cultivation refers to the traditional method of growing plants in soil, where nutrients are supplied through the soil. In conventional farming, crops are planted in the ground, and nutrients are supplied through organic matter, fertilizers, or other soil amendments. This method has been widely practiced for centuries. Conventional cultivation is familiar and often less resource-intensive in terms of infrastructure. It is suitable for a wide range of crops and can be practiced in various climates.

Fertigation is a method of applying fertilizers and nutrients to plants through irrigation systems. The term "fertigation" is derived from combining "fertilizer" and "irrigation." In this method, water-soluble fertilizers are dissolved in irrigation water and applied directly to the plant's root zone. This allows for precise control over nutrient levels, and it is often used in agriculture, horticulture, and greenhouse cultivation. Fertigation provides efficient nutrient delivery, reduces nutrient waste, allows for precise control of nutrient levels, and is suitable for various crops.

Hydroponics is a soilless method of growing plants where plants receive their nutrients directly from a nutrient-rich water solution, typically without the use of soil. Plants are grown in a controlled environment, and their roots are submerged in nutrient solutions. Various hydroponic systems exist, such as nutrient film technique (NFT), deep water culture (DWC), and aeroponics. Hydroponic systems offer efficient use of water, space, and nutrients. They provide precise control over growing conditions, allowing for faster growth and potentially higher yields compared to traditional soil-based cultivation.

Each cultivation method has its own set of pros and cons, and the choice depends on factors such as the type of crop, available resources, environmental considerations, and the specific goals of the grower. It's plausible that different cultivation systems might impact the antioxidant potential of ginger rhizomes. Therefore, this study aimed to investigate the impact of diverse harvesting ages and cultivation systems on Bentong ginger rhizomes, with a primary focus on understanding the changes in antioxidant potential across different growth stages and farming techniques. Besides evaluating the antioxidant capacity of fresh ginger rhizomes, dried samples were also analyzed. Drying stands out as a crucial processing method for fresh ginger, playing a vital role in its adaptation for various products and prolonged preservation. The elevated moisture content in fresh ginger (85–95%, wet basis) poses a risk of microbial spoilage, leading to a shorter shelf life (Ghafoor et al, 2020).

MATERIALS AND METHODS

Bentong ginger cultivation

Three distinct cultivation techniques were utilized in this Bentong ginger study, incorporating conventional, hydroponic, and fertigation systems. Commencing at 3 months old, ginger was harvested monthly until reaching 8 months old under each cultivation system. The visuals depicting each month for every cultivation method are illustrated in Figure 1.

Figure 1: Images of Bentong ginger rhizomes across three cultivation methods over the 3 to 8 months age range.

Age of ginger	Conventional	Hydrophonic	Fertigation
3 month			
4 month			

5 month			
6 month			
7 month			
8 month			

Sample preparation and extraction

Fresh Bentong ginger rhizomes were sliced into approximately 4 mm pieces using a slicer. The rhizomes were then processed in two ways: one part was ground using a mill grinder as fresh rhizome, and the other part was dried in a cabinet dryer at 50 °C for 19 hours until the moisture content reached below 10%, with each part laid out in a single layer. The dried ginger was subsequently pulverized using a mill grinder and the ground fresh and dried rhizomes were stored in airtight bottles. The ground fresh and dried ginger rhizomes underwent extraction with distilled water. Each mixture was placed in a centrifuge tube and continuously shaking using an orbital shaker at 150 rpm at room temperature for 1 h. The mixture was then centrifuged at 8,500 rpm for 10 min. The supernatant was filtered through Whatman No.541 filter paper to obtain a clear extract. The filtrates were assayed for their antioxidant capacity assay, as described below.

Determination of total phenolic content (TPC)

Total phenolic in all samples was determined with Folin-Ciocalteau assay (Norra et al. 2021) by using gallic acid as a standard phenolic compound. 50 μL of appropriately extracts solutions and standard gallic acid solutions were mixed with 50 μL of distilled water in 96-well microplate, then 100 μL of Folin-Ciocalteau reagent solution (prediluted 10-fold with distilled water) was added. After 6 min, 100 μL of 7.5% (w/v) Na_2CO_3 was added and mixed gently. The reaction mixture was kept in dark for 2 h and its absorbance was measured at 765 nm against distilled water as a blank solution using the microplate reader. The TPC was expressed as gallic acid equivalents (GAE) which was determined from known concentrations of gallic acid standard.

Determination of DPPH free radical scavenging activity

This spectrophotometric assay uses stable radical 2,2-diphenyl-1-picrylhydrazyl (DPPH) as a reagent, according to a method of Norra et al. 2021. To determine the scavenging activity, 100 μl of the extracts was added to 200 μl of a 0.008% methanol solution of DPPH in a 96-well microplate. After a 40 min incubation period at room temperature, the absorbance was read against a blank at 517 nm using microplate reader. The percentage of inhibition of free radical DPPH by the extracts was calculated as follow:

$$\text{Inhibition (\%)} = (A_{\text{blank}} - A_{\text{sample}} / A_{\text{blank}}) \times 100$$

Where A_{blank} is the absorbance of the control reaction (containing all reagents except the test compound), and A_{sample} is the absorbance of the test compound.

Determination of ferric reducing antioxidant power (FRAP)

The FRAP assay was performed as previously described by Norra et al. 2021. Briefly, The FRAP reagent was prepared by mixing ten volumes of 300 mM acetate buffer (pH 3.6), with one volume of 10 mM TPTZ in 40 mM HCl and with one volume of 20 mM $FeCl_3 \cdot 6H_2O$ (10:1:1) and the mixture then incubated at 37 °C for at least 10 minutes. A total of 20μL of extract solution and 80 μL of distilled water were added to 200 μL of freshly prepared FRAP reagent in a 96-well microplate. After eight min, the absorbance was read using a microplate reader at 593 nm against reagent blank, which was prepared by the same procedure described above except that extract solution was substituted by 20 μL of water. The FRAP value was calculated and expressed as ferrous equivalents (FE) based on a calibration curve plotted using $FeSO_4$ as a standard.

Determination of Trolox Equivalent Antioxidant Capacity (TEAC)

The method of Rajurkar & Hande 2011 was adopted for the determination of TEAC using the stable blue/green radical cation $ABTS^{\cdot+}$ (2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid). The antioxidant capacity is measured as the ability of test compounds to decrease the color reacting directly with the $ABTS^{\cdot+}$ radical. $ABTS^{\cdot+}$ radical cations were prepared by mixing equal volume of ABTS (7 mM in H_2O) and potassium persulfate (4.9 mM in H_2O), and the solution was stood in the dark for 12 - 16 h at room temperature (time needed to obtain stable absorbance at 734 nm). After incubation, The ABTS solution was then diluted with water to obtain an absorbance of 0.700 ± 0.02 at 734 nm. 20 μL of appropriately diluted samples was added to 280 μL of ABTS solution in a 96-well microplate and the absorbance was recorded at 734 nm after 30 min of incubation at room temperature. A standard curve was obtained by using trolox standard solution at various concentrations and the results are expressed as trolox equivalent (TE).

Determination of total flavonoids contents (TFC)

Estimation of the total flavonoids content (TFC) was carried out using aluminium colourimetric method, according to Ali, El-Nour & Yegi, 2018. Different concentrations of quercetin as a standard were prepared by serial dilutions using 90% ethanol ranging from 1.56 – 200ug/mL. To 100 μL of sample or standard quercetin solutions, a volume of 100 μL of 2% aluminium chloride ($AlCl_3$) ethanol solution was added in a 96-wellplate. After one hour at room temperature, the absorbance was measured at 420 nm. A yellow colour indicated the presence of flavonoids. The concentration of total flavonoid content in the test samples was calculated from the calibration plot and expressed as quercetin equivalent (QE). All the determinations were carried out in triplicate.

Statistical analysis

Statistically significant differences in the antioxidant properties of the samples were determined by two-way analysis of variance (ANOVA) and the differences among the means were determined by Duncan Multiple Range Test (DMRT) using the Statistical Analysis Software (SAS) package (version 9.4 of SAS Institute, Inc. Cary, NC, 2008).

RESULTS

Total polyphenol content (TPC) and total flavonoid content (TFC)

Table 1: Total polyphenol content (TPC) and total flavonoid content (TFC) of fresh and dried Bentong ginger rhizomes at different harvesting ages and cultivation methods

Cultivation method	Harvesting age	TPC (mg GAE/ g dw)		TFC (mg QE/ g dw)	
		fresh	dried	fresh	dried
Conventional	3M	4.06 ± 0.50^{bB}	8.70 ± 0.12^{aA}	1.62 ± 0.57^{a}	nd
	4M	4.75 ± 0.88^{bA}	6.40 ± 0.66^{bA}	0.57 ± 0.61^{bB}	0.75 ± 0.01^{bA}
	5M	5.55 ± 0.73^{bB}	8.53 ± 0.88^{aA}	nd	nd
	6M	7.58 ± 1.91^{aA}	8.55 ± 1.18^{aA}	nd	nd
	7M	5.19 ± 0.56^{bB}	8.63 ± 0.14^{aA}	0.11 ± 0.02^{bB}	1.12 ± 0.27^{abA}
	8M	5.67 ± 0.06^{bB}	9.62 ± 0.47^{aA}	0.11 ± 0.01^{bB}	1.23 ± 0.20^{aA}
Hydrophonic	3M	7.30 ± 2.69^{aA}	10.81 ± 2.18^{aA}	1.32 ± 0.20^{a}	nd
	4M	5.79 ± 0.33^{abB}	8.39 ± 0.56^{bA}	0.33 ± 0.02^{bA}	0.15 ± 0.02^{bB}
	5M	5.83 ± 0.55^{abB}	7.76 ± 0.72^{bA}	0.13 ± 0.01^{cB}	0.70 ± 0.32^{aA}
	6M	4.49 ± 0.67^{bB}	7.88 ± 0.81^{bA}	0.16 ± 0.03^{c}	nd

	7M	5.77 ± 1.19^{abB}	8.53 ± 0.96^{bA}	0.19 ± 0.04^{bcB}	0.71 ± 0.12^{aA}
	8M	5.47 ± 0.09^{abA}	6.75 ± 0.86^{bA}	0.08 ± 0.00^{cB}	0.45 ± 0.08^{abA}
Fertigation	3M	5.83 ± 1.49^{abB}	10.47 ± 0.19^{aA}	1.92 ± 0.23^{a}	nd
	4M	6.11 ± 0.68^{abA}	7.79 ± 1.14^{cdA}	0.28 ± 0.02^{bA}	0.29 ± 0.17^{bA}
	5M	5.55 ± 0.64^{abB}	8.83 ± 0.44^{bcA}	0.11 ± 0.01^{bB}	1.02 ± 0.10^{aA}
	6M	4.65 ± 0.21^{bB}	8.11 ± 0.45^{cdA}	0.16 ± 0.04^{b}	nd
	7M	5.39 ± 1.03^{abA}	7.55 ± 0.90^{dA}	0.16 ± 0.05^{bB}	0.42 ± 0.17^{bA}
	8M	7.15 ± 1.01^{aB}	9.63 ± 0.23^{abA}	0.13 ± 0.03^{bB}	0.42 ± 0.14^{bA}

Values are expressed as mean ± SD (n = 3). Values with different lowercase superscript within the column for every cultivation method, while values with different uppercase superscript within the row for all fresh and dried rhizomes are significantly different ($p<0.05$). GAE: gallic acid equivalent; QE: quercetin equivalent; dw: dry weight

Table 1 illustrates that the polyphenol content of dried ginger rhizomes was significantly higher ($p<0.05$) than that of the fresh form across all three cultivation methods. Additionally, different cultivation methods exhibited the highest polyphenol content ($p<0.05$) at varying harvesting ages. Specifically, the conventional method demonstrated the highest polyphenol content at 6 months of age for the fresh form, whereas hydroponic cultivation peaked at 3 months of age, and fertigation method showed the highest polyphenol content at 8 months of age. Conversely, for the dried form, the highest TPC content was observed at 3 months of age for all cultivation methods, except for the conventional method, which exhibited no significant difference at all harvesting ages except for 4 months of age.

In the assessment of total flavonoid content, the highest content was observed at the 3-month harvesting age of fresh ginger rhizomes across all cultivation methods. However, for the conventional method, the flavonoid content of fresh rhizomes at 5 and 6 months of age was undetectable. Flavonoid content appeared to decrease across the harvesting ages, indicating possible degradation. Conversely, dried ginger rhizomes exhibited unstable flavonoid content, which could be attributed to the effects of high temperatures leading to the degradation of flavonoid compounds in ginger.

Ferric reducing antioxidant power (FRAP)

As depicted in Table 3, the FRAP value of ginger rhizomes cultivated using the conventional method was notably high at the 8-month harvesting age for both fresh and dried forms. However, the highest FRAP values were observed at the 3-month age for the hydroponic and fertigation methods for both fresh and dried forms, except for the 8-month age of the fertigation method, which did not show a significant difference ($p<0.05$) compared to the 3-month age. According to the data, dried rhizomes consistently demonstrate higher FRAP values across all cultivation methods compared to their fresh counterparts.

Table 2: FRAP value of fresh and dried Bentong ginger rhizomes at different harvesting ages and cultivation methods

Cultivation method	**Harvesting age**	**FRAP (mg FE/g dw)**	
		fresh	**dried**
Conventional	3M	15.94 ± 2.42^{bcB}	41.49 ± 0.71^{abA}
	4M	15.31 ± 2.11^{dB}	22.58 ± 3.21^{dA}
	5M	21.94 ± 4.68^{abB}	36.96 ± 3.01^{bcA}
	6M	24.08 ± 3.95^{aB}	32.61 ± 1.55^{cA}
	7M	24.38 ±4.30^{aB}	41.36 ± 1.25^{abA}
	8M	25.63 ± 2.45^{aB}	47.18 ± 6.06^{aA}
Hydrophonic	3M	32.96 ± 17.99^{aA}	54.41± 20.74^{aA}
	4M	16.37 ± 0.98^{bB}	37.64 ± 2.05^{abcA}
	5M	19.90 ± 2.11^{abA}	20.64 ± 1.98^{cA}
	6M	21.21 ± 4.11^{abB}	42.96 ± 6.73^{abA}
	7M	20.92 ± 4.77^{abB}	39.21 ± 2.50^{abA}
	8M	22.74 ± 1.19^{abB}	32.96 ± 4.59^{bcA}
Fertigation	3M	28.36 ± 9.27^{aB}	52.46 ± 1.43^{aA}
	4M	17.34 ± 1.82^{bB}	39.71 ± 4.62^{cA}
	5M	19.16 ± 2.65^{abA}	17.36 ± 1.04^{eA}
	6M	21.96 ± 2.89^{abB}	44.89 ± 0.57^{bA}
	7M	21.17 ± 5.88^{abB}	32.33 ± 1.01^{dA}
	8M	29.57 ± 6.98^{aB}	48.27 ± 1.24^{bA}

Values are expressed as mean ± SD (n = 3). Values with different lowercase superscript within the column for every cultivation method, while values with different uppercase superscript within the row for all fresh and dried rhizomes are significantly different ($p<0.05$). FE: ferrous equivalent; dw: dry weight

DPPH radical scavenging activity

The DPPH radical scavenging activity seem to rise after 5 months of age across all three cultivation methods, as depicted in Table 3. Conventional cultivation shows high DPPH % inhibition at 5 months of age, while for hydroponic and fertigation methods, the optimum DPPH % inhibition is observed at 6 to 8 months of age.

Table 3: DPPH radical scavenging activity (%) of fresh and dried Bentong ginger rhizomes at different harvesting ages and cultivation methods

Cultivation method	Harvesting age	DPPH (% inhibition)	
		fresh	dried
Conventional	3M	27.67 ± 0.84^{cB}	79.69 ± 2.82^{bA}
	4M	78.36 ± 3.58^{abA}	78.56 ± 2.80^{bA}
	5M	84.18 ± 0.73^{aB}	85.98 ± 0.33^{aA}
	6M	73.62 ± 7.23^{bA}	79.99 ± 5.64^{bA}
	7M	76.73 ± 2.74^{bA}	68.79 ± 1.03^{cB}
	8M	77.30 ± 1.76^{bA}	70.00 ± 2.45^{cB}
Hydrophonic	3M	67.06 ± 6.97^{cB}	80.12 ± 3.50^{dA}
	4M	59.55 ± 4.16^{dB}	87.08 ± 0.16^{aA}
	5M	80.19 ± 2.43^{abA}	82.87 ± 1.47^{bcdA}
	6M	83.70 ± 1.51^{aA}	85.94 ± 1.50^{abA}
	7M	75.13 ± 0.94^{bB}	80.60 ± 0.95^{cdA}
	8M	83.13 ± 1.94^{aA}	84.09 ± 2.01^{abcA}
Fertigation	3M	64.28 ± 11.10^{cA}	79.20 ± 1.28^{bcA}
	4M	72.33 ± 1.83^{bcB}	85.31 ± 3.83^{abA}
	5M	76.54 ± 1.64^{abB}	81.96 ± 0.65^{abcA}
	6M	84.51 ± 1.05^{aA}	86.98 ± 1.25^{aA}
	7M	81.47 ± 1.73^{aA}	76.29 ± 7.58^{cA}
	8M	83.10 ± 3.02^{aA}	85.40 ± 1.34^{abA}

Values are expressed as mean ± SD (n = 3). Values with different lowercase superscript within the column for every cultivation method, while values with different uppercase superscript within the row for all fresh and dried rhizomes are significantly different ($p<0.05$). Results expressed in percent of free radical inhibition.

Trolox equivalent antioxidant capacity

TEAC exhibited the highest values when ginger reached 7 and 8 months of age for all three cultivation methods, as depicted in Table 5. The highest TEAC value for dried rhizomes showed no significant difference from the fresh form. Drying ginger did not significantly affect the TEAC value.

Table 5: Trolox equivalent antioxidant capacity (TEAC) of fresh and dried Bentong ginger rhizomes at different harvesting ages and cultivation method

Cultivation method	Harvesting age of ginger	TEAC (mg TE/g dw)	
		fresh	dried
Conventional	3M	14.16 ± 1.58^{bB}	21.94 ± 0.44^{bA}
	4M	4.69 ± 0.73^{cB}	6.77 ± 0.08^{dA}
	5M	13.89 ± 2.32^{bB}	21.64 ± 1.60^{bA}
	6M	17.73 ± 5.80^{bA}	19.16 ± 1.12^{cA}
	7M	24.23 ± 2.43^{aA}	25.20 ± 0.76^{aA}
	8M	25.86 ± 3.04^{aA}	24.25 ± 0.85^{aA}
Hydrophonic	3M	15.52 ± 4.24^{bB}	23.45 ± 0.08^{bA}
	4M	12.50 ± 0.93^{bcA}	11.19 ± 0.43^{dA}
	5M	15.12 ± 1.31^{bB}	21.71 ± 2.09^{bA}
	6M	9.71 ± 1.74^{cB}	17.85 ± 1.31^{cA}
	7M	23.05 ± 4.92^{aA}	23.88 ± 0.55^{bA}
	8M	23.89 ± 0.55^{aB}	32.16 ± 3.20^{aA}
Fertigation	3M	17.37 ± 2.62^{bA}	21.43 ± 0.25^{cA}
	4M	12.71 ± 1.93^{bcA}	10.77 ± 0.22^{eA}
	5M	14.59 ± 1.01^{bcB}	22.00 ± 0.81^{cA}
	6M	9.93 ± 0.98^{cB}	19.99 ± 0.97^{dA}
	7M	25.54 ± 5.89^{aA}	23.56 ± 1.06^{bA}
	8M	29.63 ± 3.48^{aB}	38.76 ± 0.41^{aA}

Values are expressed as mean ± SD (n = 3). Values with different lowercase superscript within the column for every cultivation method, while values with different uppercase superscript within the row for all fresh and dried rhizomes are significantly different ($p<0.05$). TE: gallic acid equivalent; dw: dry weight

DISCUSSION

Different cultivation methods lead to varying harvesting ages that produce the highest polyphenol and flavonoid content. Similarly, in terms of antioxidant activity, the conventional method yields the highest FRAP and DPPH values at different harvesting ages compared to the hydroponic and fertigation methods. However, TEAC values show an optimal range at 6 to 8 months of age for all three methods. Each cultivation method has the potential to influence antioxidant activity, the specific effects may vary depending on the crop, environmental conditions, and management practices. In general, both hydroponic and fertigation methods can influence antioxidant activity positively by providing controlled nutrient levels, optimal water supply, and minimizing environmental stressors. These methods allow for precise management of nutrient uptake and water availability, which can promote the synthesis of antioxidants in plants. Additionally, the controlled environment in hydroponic and fertigation systems can reduce the risk of soil-borne diseases and nutrient deficiencies, further supporting plant health and antioxidant production. Meanwhile, in the conventional method, plants are grown in soil with traditional farming practices. Antioxidant activity may be influenced by factors such as soil quality, nutrient availability, and exposure to environmental stressors. The presence of beneficial microorganisms in the soil can contribute to nutrient uptake and enhance antioxidant synthesis in plants. However, the risk of soil-borne diseases and nutrient imbalances may also affect antioxidant production.

Furthermore, the study results indicate that dried ginger rhizomes exhibit elevated levels of polyphenols, flavonoids, and antioxidant activity. The drying process renders the tissue brittle, leading to the breakdown of cell structure during milling and the subsequent release of intracellular compounds into the solvents (Musatafa & Chin, 2023). Additionally, the breakdown of cellular constituent's releases bound cellular compounds, thereby enhancing yield. Furthermore, drying treatments enhance sample porosity, leading to higher rates of solute and solvent diffusion and increased extract yield. Intracellular spaces (pores) previously filled with water are replaced by air or compressed due to shrinkage during the drying process (Shirsath et al, 2012; Aprajeeta et al, 2015).

CONCLUSION

Identifying the ideal harvesting age to attain the highest antioxidant capacity poses a challenge. Various cultivation methods exhibit peak antioxidant activity at distinct harvesting ages. According to the findings presented, harvesting Bentong ginger rhizomes at 8 months seems to be most favorable for conventional cultivation. During this period, it demonstrates the highest FRAP and TEAC values. Additionally, the total phenolic content and DPPH radical inhibition percentage reach satisfactory levels in the dried form. However, in hydroponic cultivation, the peak for polyphenol and flavonoid content occurs at 3 months, with varied antioxidant activity. FRAP peaks at 3 months, while DPPH levels rise after 5 months. TEAC, however, peaks between 7 and 8 months. Conversely, fertigation farming indicates optimal harvesting at 8 months, similar to conventional farming, with high levels of polyphenol content and antioxidant activity. Each method offers its own advantages, enabling farmers to select based on their specific requirements. However, it is evident that, aside from prolonging shelf life, drying significantly enhances the antioxidant capacity of Bentong ginger rhizomes when compared to fresh ones. Dried ginger rhizomes demonstrate elevated total phenolic content and antioxidant activity compared to their fresh counterparts.

ACKNOWLEDGEMENT

The author expresses gratitude for the financial assistance provided by the Malaysia Agricultural Research and Development Institute (MARDI) under Project ICA56, as well as for the valuable assistance of the staff at the Food Science and Technology Research Centre (FT), particularly Noor Fadilah Mohd Bakri, Sabeetha Sarmin, Aishah Mohd Ramli, Aida Mohamad dan Mohd Fadli Ali.

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