



## Research article

Effect of variety, location & maturity stage at harvesting, on essential oil chemical composition, and weight yield of *Zingiber officinale roscoe* grown in Sri LankaNayana Damenu Bandara Jayasundara<sup>\*</sup>, Palitha Arampath

Department of Food Science and Technology, University of Peradeniya, 20400, Peradeniya, Sri Lanka

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## ABSTRACT

Our study investigated whether the chemical intensity and weight yield of essential oil fraction of *Zingiber officinale roscoe* was significantly affected by variety, maturity stage or cultivated location in Sri Lanka. Two varieties, Rangoon and Siddha planted in two geographical locations of Sri Lanka were harvested at three maturity stages. Chinese variety was studied as the control. Study revealed that the ginger essential oil (GEO) weight yield decreased with increasing maturity stage. Maturity stage and location of cultivation was significantly affecting GEO weight yield while chemical intensities were significantly affected by maturity stage only. Variety factor was not significantly affecting any of the dependent variables. Interaction effects between factors suggested that Siddha and Rangoon were the best varieties to cultivate in Sri Lanka. Best time to harvest rhizomes was at 5 months maturity for any tested variety. 13 major compounds were identified in Siddha while 12 major compounds were identified in Rangoon. It was suggested that variety Siddha was better than Rangoon from its antibacterial chemical profile and composition.

## 1. Introduction

Essential oil fraction of *Zingiber officinale roscoe* rhizome extract comprises of a majority of chemicals responsible for various physiological and medicinal effects expressed on humans. These chemicals in essential oil extract of ginger are very important to humans in many ways. Phytochemicals such as eugenol, cineol, citral and sesquiterpenoids, such as bisabolene, farnesene and  $\beta$ -sesquiphellandrene found in ginger were shown responsible for antibacterial activity (O'hara et al., 1998). Compounds such as 6,8,10-gingerole, 6,8,10 Shagoles and 6-gingediol were responsible for pungency effect of the ginger rhizome extract (He et al., 1998). Compounds like zingiberine, camphene, ar-curcumene, citral,  $\beta$ -sesquiphellandrene, nerolidol and  $\alpha$ -terpinol were responsible for the overall flavor. Most intense flavor compounds in ginger were chemicals like linalool, citronellal, geraniol, neral, isoborniol, borniol and several newly identified compounds such as 2-pinen-5-ol identified as main fragrance factors in ginger oil extract. These compounds accounted for highest flavor dilution (FD) factor values (Nishimura, 1995). A recent study on formation of anti-biofilms and antibacterial characteristics of ginger essential oil (GEO) had shown that inhibition percentage for bacteria tested were more than

80%. Presence of terpenes such as zingiberine, camphene, geraniol, farnesene,  $\alpha$ -bisabolene,  $\beta$ -sesquiphellandrene, neral, linalool, citronellal,  $\alpha$ -pinene and borneol were the reason behind antibacterial activity and anti-biofilm forming activity of ginger essential oil (Das et al., 2019).

Another systematic analysis revealed 69 compounds in GEO. This oil fraction accounted for 96.93% of the total weight of the extract. Anti-fungal activity and anti-oxidant potential were both present in GEO fraction extracted (Singh et al., 2004). Presence of 48 bioactive compounds in ginger rhizome extract showed bactericidal qualities against 6 bacteria. The inhibition zone diameters for all the bacteria ranged from  $4.93 \pm 0.29$  cm to  $0.89 \pm 0.21$  cm. Results suggested that bactericidal activity was due to naphthalenamine decanal and  $\alpha$ -copaene (Shareef et al., 2016).

Ability of ginger rhizome extract to work as medicinal materials was remarkable. They acted as antioxidants, anti-inflammatory agents, anti-carcinogenic as well as antibacterial agents. Antioxidant liver enzyme levels were elevated in mice after oral administration of 500 mg/Kg of GEO for 30 days. Consequently, super oxide dimutase levels, glutathione peroxidase enzyme levels and glutathione-S-transferase enzyme levels were also elevated suggesting ample antioxidant activity in liver tissue

\* Corresponding author.

E-mail address: [nayana.jayasundera@google.com](mailto:nayana.jayasundera@google.com) (N.D.B. Jayasundara).<https://doi.org/10.1016/j.heliyon.2021.e06560>

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(Jeena et al., 2013). GEO expressed anti-inflammatory effects by secondary metabolites of terpenes which prevented chronic joint inflammation in mice (Funk et al., 2016). Moreover, anti-carcinogenic properties were shown to be present in ginger rhizome extract and demonstrated successful decrease in the incidence of cancer of the colon of mice. Carcinogenesis in the colon was controlled by ginger phytochemicals at initiation and post initiation stages of cancer (Manju and Nalini, 2005). It was known from traditional remedies that GEO exhibited similar effects on humans as well.

Moreover, recent research regarding chemical composition or yield variation of *Zingiber officinale roscoe* essential oil transpired that the weight yield and chemical composition of GEO varies with cultivated geographical location of the world. *Zingiber Officinale roscoe* species grown in China confirmed 43 chemicals such as  $\alpha$ -zingiberene,  $\beta$ -sesquiphellandrene,  $\beta$ -bisabolene,  $\alpha$ -curcumene,  $\alpha$ -bergamotene, and ar-turmerone identified as the most abundant chemicals. The GEO weight yield was 4.07% from the total sample weight (Feng et al., 2018). Same *Zingiber officinale roscoe* species cultivated within a totally different area of the world such as at Ghaziabad in India revealed 80 compounds in its essential oil. The oil weight yield percentage was 1.26% from the weight of the sample. Moreover, zingiberene, citronellyl n-butyrate, valencene,  $\beta$ -phellandrene, selina-4(14), 7(11)-diene and  $\beta$ -funebrene were the most abundant compounds. All these compounds were more than 1% in relative abundance. Zingiberene content accounted for a maximum 46.7% abundance (Sharma et al., 2016). Comparative samples from Fiji had a higher content of neral and geraniol than that of the Indian ginger. This result showed clearly that the essential oil composition varied with cultivated geographical area (Begum et al., 2018).

In the Sri Lankan context, limited research had been performed to analyze weight yield variation or chemical composition variation on Sri Lankan grown ginger essential oil. Few researches exist in which various varieties cultivated in different geographical areas were subjected to analysis. Moreover, none of these researches were conducted to find out how the composition or the essential oil weight yield varied with maturity stage at harvest. Therefore, the importance of the current study in understanding chemical composition and weight yield variation was unequivocal. Weight yield and chemical composition variation on various varieties and various harvesting stages after cultivation is a very important factor; it is considered important in industries using ginger as a raw material. As lesser knowledge exists on this study area, it is difficult to make better judgment on the correct stage for harvesting for each product. As chemical components of ginger oil are used readily inside food industrial products, our study aimed to use the knowledge collected for many ginger-based food industries in Sri Lanka.

## 2. Materials and methods

### 2.1. Design outline

The protocols of all methodologies (procedures, experimental designs analysis assays) were adopted from earlier published work (Pellerin, 1991). Two varieties of *Zingiber officinale roscoe* with a Chinese variety named "Chinese" as the control were cultivated in experimental plots of two potentially important ginger cultivating areas of Sri Lanka. Experimented varieties were Rangoon and Siddha. All varieties were planted in separate plots in two location strata. Cultivated geographical locations were at Makandura and Allawwa areas in Sri Lanka. Experimental plots were all similar in size. Similar fertilization, irrigation as well as amounts of solar radiation exposure was provided. All initially planted rhizomes were similar in size and age. Harvesting stages were 5, 7 and 8 months after plantation. Eighteen ( $3 \times 2 \times 3$ ), variety-location-maturity stage combinations were sampled. Experimental design model utilized in this study was three factor factorial design.

### 2.2. Sample preparation

Rhizomes of ginger were harvested, washed with distilled water. Skin of the rhizomes were peeled and were cut in to small pieces. Average thickness of a cut piece was 5mm while average length was 15mm. Cut pieces were mixed well to obtain a good representative sample. 40–45kg of wet sample per each variety-location-maturity combination was obtained and was taken to the laboratory for air drying (AD) in an oven at  $50 \pm 5$  °C until the moisture content of ginger reached 10–12%. An optimum temperature of 50 °C was used for ginger rhizome drying to preserve as many volatile compounds as possible from losses by high heat (Munda et al., 2018). Required moisture level was reached after three to four days of air drying. Air drying (AD) technique was the best drying method identified after comparing with freeze drying (FD), microwave drying (MD), infrared drying (ID) and intermittent microwave and convective drying (IM&CD) (An et al., 2016). Air drying technique was also the best to retain as much volatile chemicals as possible. Final dried sample weight obtained was around 4–5.5 kg. Dried sample was packed in moisture tight 160-gauge polyethylene container with anhydrous silica gel and kept at 4 °C in the cold storage until further use.

### 2.3. Method of extraction of ginger essential oil

Hydro distillation or steam distillation using a modified Clevenger light oil arm apparatus separated essential oil portion from the crude sample. It was shown that steam distillation method of extraction was the best by far compared to hexane solvent extraction as the extraction yields were around 2.5–3 times greater (Pellerin, 1991). 100 g of dried ginger sample was transferred to a 1000 ml flat bottom flask. 500 ml of distilled water was transferred into the flask so that weight ratio of sample to water was 1:5 or 10:2 in solvent to feed (SF) ratio. This ratio was close to the solvent to feed ratio reported in a recent Indonesian study which concluded that 10:1.7 SF ratio was the optimum water to sample ratio for the extraction of maximum oil yields around 3.7% (w/w) (Azizah et al., 2019). Glass thermometer was immersed in the liquid portion via the secondary neck of the flat bottom flask. Using the heating mantle flask was heated to 70 °C and maintained in that temperature for 30 min. This ensured that the ginger pieces were soaked and saturated well before heated up evenly for the distillation process to begin. Then the temperature was gradually raised to start the distillation. Condenser was tap water cooled and the distillation was conducted for 4 h. Optimum hydro distillation time was found to be around 4 h or 240 min for 4 days dried ginger samples according to a recent Indonesian study (Hasmita et al., 2015). Therefore, optimal parameters were used in the current study according to the requirement. Apparatus was let to cool for 15–20 min until the last of the vapors were condensed in to the collecting arm. Hydro extracted essential oil was collected to sample tubes and 0.1 g of anhydrous sodium sulphate was introduced to absorb any trapped moisture. Sample tubes were labeled and stored in cold storage at 4 °C until further analysis. For each variety-location-maturity combination three replicates were collected. A total of 54 ( $3 \times 2 \times 3 \times 3$ ) replicates were collected and measured.

### 2.4. Gas chromatography (GC) analysis

Carbowax 20M capillary column in SHIMADZU GC analyzer was injected with 300  $\mu$ l of essential oil in two splits. Chemicals were separated using nitrogen mobile phase gas at a flow rate of 1 mL/min. Initial temperature of the packed column was 40 °C. Materials were eluted for 5 min in this temperature and increased rapidly up to 200 °C at a rate of increase of 6 °C per minute. Two holds first at 80 °C for one minute and second for 20 min at 200 °C. Separation was continued for further 20 min at 200 °C until all the materials were reasonably separated. Final chromatographs were obtained after 40 min. Flame ionization detector (FID) at a temperature of 300 °C was utilized as the detector for the measurement of intensities of chemical peaks (Munda et al., 2018).

Essential oil constituents were identified by utilization of internal standards. Reference retention indexes of various constituents in a computer database were matched with the reported KI values. Further, retention times and peak patterns were matched with GC charts of previous research (Paranagama, 1991). Reported charts were compared with charts obtained by Paranagama in 1991 for further confirmation.

### 2.5. Outline of statistical analysis

The statistical analysis and evaluation of data was conducted by multi factor factorial design ANOVA using Minitab statistical software version 14.12.0. General linear model tool was used for analysis of variance. 95% significant level was set up at  $p = 0.05$ .

## 3. Results & discussion

### 3.1. Essential oil weight yield variation with harvest stage

GEO weight yield was highest at 5 months after planting and lowest at 8 months after planting. Weight yield was gradually decreasing with increasing maturity stage for all the varieties (Figure 1). This pattern of reducing weight yield was observed equally in all the variety-location combinations tested in this research. We suggest increased rate of production of fibrous matter in ginger rhizomes with maturity in Sri Lankan conditions could be a reason for this result. It implies that the rate of essential oil production is lower than the fibrous matter accumulation rate after 5 months. At five months maturity stage, maximum weight yield percentage per dried sample weight (3.36%) was recorded by Rangoon variety grown at Makandura. Lowest oil weight yield percentage (1.61%) at 5 months after planting was recorded by Siddha variety planted also in Makandura area. Maximum and minimum weight yields recorded a 79.1% and 63.1% yield drop respectively when they reached

8 months of maturity. All the variety-location combinations in average showed more than 55% drop of weight yield when their maturity reached 8 months after planting. Therefore, decline of oil yield weight with maturity stage was highly evident. Statistical analysis on GEO weight yield using ANOVA showed that  $p$  values for main effects 'maturity stage' and 'location' of cultivation was less than 0.05 at 95% confidence level ( $p < 0.05$ ). Statistical analysis further showed that factor interaction effects between maturity stage-variety, maturity stage-location and variety-location also had a  $p$  value less than 0.05 at 95% confidence interval ( $p < 0.05$ ). However, 'variety' factor had a  $p$  value higher than 0.05 at 95% confidence interval ( $p > 0.05$ ).

### 3.2. Phytochemicals identified

Twenty-five (25) chemical compounds were positively identified after analysis via gas chromatography followed by comparison with typical ginger essential oil chromatograph. Siddha variety accounted for 13 major compounds while Rangoon accounted for 12 major compounds. Compounds were more than 2% in abundance level. Nine compounds identified in Siddha variety such as  $\alpha$ -pinene (7.2%), camphene (12.4%),  $\beta$ -phellandrene (12.4%), citronellal (12.4%), citral-a (8.3%), borneol (5.2%)  $\beta$ -sesqui-phellandrene (10.9%),  $\beta$ -zingiberene (5.7%), geraniol (6.7%) were more than 5% in relative abundance while seven compounds identified in Rangoon variety such as  $\alpha$ -pinene (8.4%), camphene (13.6%),  $\beta$ -phellandrene (13.6%), citral-a (7.5%),  $\beta$ -sesqui-phellandrene (12.2%),  $\alpha$ -zingiberene (9.7%), geraniol (11.8%) were also more than 5% in abundance level (Table 1). Variation of chemical intensities or abundance of these twenty-five compounds were irregular with increase of maturity stage (Figure 2). However, in general, a trend of decrease in chemical intensity or abundance for almost all compounds in both the varieties were observed. In addition, highest intensities were observed at 5 months stage while lowest were observed at 8-month stage.

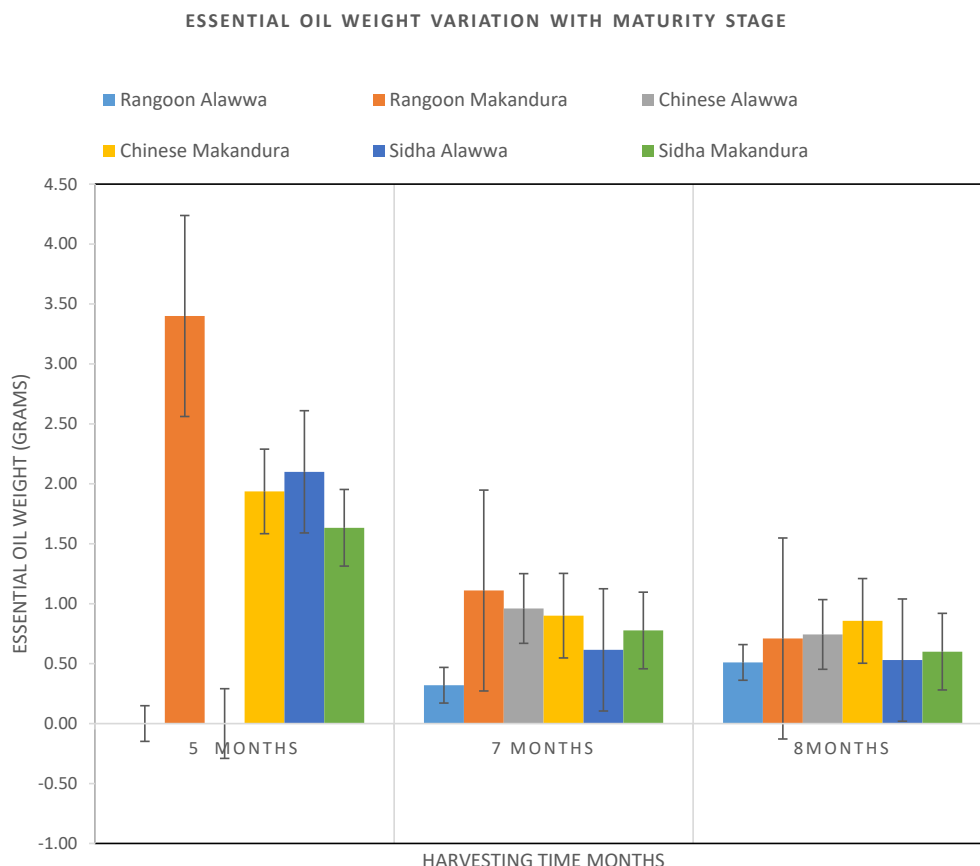


Figure 1. Essential oil weight yield variation with maturity stage.

**Table 1.** Relative percentage abundance of chemicals identified in each variety-location-maturity combination. Key (S-M) Siddha at Makandura, (R-M) Rangoon at Makandura (%).

Chemical	Ref-peak number	S-M 5 months	S-M 7 months	S-M 8 months	R-M 5 months	R-M 7 months	R-M 8 months
$\alpha$ - Pinene	2	7.2	0.7	4.1	8.4	2.5	3.3
Camphene	3	12.4	3.8	15.8	13.6	9.7	12.5
$\beta$ - Pinene	4	1.0	0.4	0.4	1.2	0.7	0.7
Myrcene	7	2.6	1.7	1.1	3.6	2.9	2.9
Limonene	8	2.3	2.3	1.4	2.9	3.0	2.9
$\beta$ -Phellandrine	9	12.4	15.6	14.0	13.6	13.6	14.2
Terpinolene	12	1.3	0.9	0.5	0.6	0.5	0.5
Citronellal	14	12.4	0.6	0.0	0.3	0.3	0.3
Linalool	16	3.1	3.0	1.6	2.1	2.5	2.5
$\beta$ - Caryophyllene	18	1.3	1.5	0.7	0.8	0.3	0.6
Citral a	22	8.3	13.9	6.7	7.5	11.8	12.6
$\alpha$ - Terpeneole	23	4.1	6.5	2.7	2.9	3.8	3.8
Borneol	14	5.2	8.1	4.3	2.6	3.9	4.3
Guainene	26	0.0	15.6	9.0	1.0	13.6	2.6
$\alpha$ -Zingiberene	27	0.0	0.6	1.6	9.7	10.7	14.2
$\beta$ -Sesqui-Phellandrene	30	10.9	4.1	2.3	12.2	2.6	6.9
$\beta$ - Zingiberene	32	5.7	3.4	1.8	1.0	2.2	1.8
Gereneol	36	6.7	6.2	3.4	11.8	12.0	10.1
Methyl-iso-Eugenol	37	0.5	2.2	0.0	0.6	1.0	0.7
$\alpha$ -Nerolidol	38	0.8	1.3	15.8	1.3	0.9	1.2
Elemol	39	0.3	1.5	7.4	0.6	0.8	0.6
Cedrol	40	0.4	1.8	1.4	0.5	0.0	0.4
Eugenol	42	0.3	1.3	1.3	0.6	0.8	0.4
$\beta$ -Eudesmol	44	0.4	1.8	1.4	0.6	0.2	0.2
Farnesal	45	0.4	1.4	1.1	0.0	0.2	0.4

In chromatographs of the tested ginger oil, three high peak density areas could be identified in which contained the majority of high intensity peaks. These areas were unique to ginger essential oil typical chromatograph and the first observed area (A) was marked from  $\alpha$ -pinene and ended with terpinolene, second observed area (B) was marked from citronellal and ended with geraniol as third observed area (C) was marked from methyl-iso-eugenol and ended with farnesal (Table 1). In both the varieties chemical peak intensity fluctuations in area C with varying maturity were different to the behavior of areas A and B. Area C peak intensities and relative abundance levels were either remaining steady or showing a slight increment with maturity.

Main effect 'maturity stage' and interaction effect of variety-maturity combination showed a probability of error ( $p$ ) value less than 0.05 at 95% confidence level ( $p < 0.05$ ). However, main effect 'variety' showed a probability of error ( $p$ ) value higher than 0.05 at 95% confidence interval ( $p > 0.05$ ).

Based on the interaction plots (Figure 3a and Figure 3b) the highest GEO weight yield and highest chemical intensities were recorded in the ginger rhizomes harvested at 5 months maturity. Rangoon and Siddha varieties showed high oil weight yields at 5 months maturity stage. Both these varieties recorded high weight yields when they were planted at Makandura geographical location in Sri Lanka. Interaction plots further demonstrated that Rangoon variety was the maximum producer of GEO when planted at Makandura area. Although Siddha variety showed the minimum GEO weight yield at Makandura it contributed to the maximum oil weight yield at Allawwa area. As different varieties respond variably to weather patterns and soil nutrient levels, it is suggested that Rangoon responded best to conditions in Makandura while conditions in Allawwa suited Siddha. Interaction plot (Figure 3b) for chemical intensities in GEO showed that Siddha variety was better than Rangoon if harvested at 5 months maturity. In general, Rangoon variety showed very low chemical intensity variation with the maturity stages while Siddha showed a dramatic drop of chemical intensities with

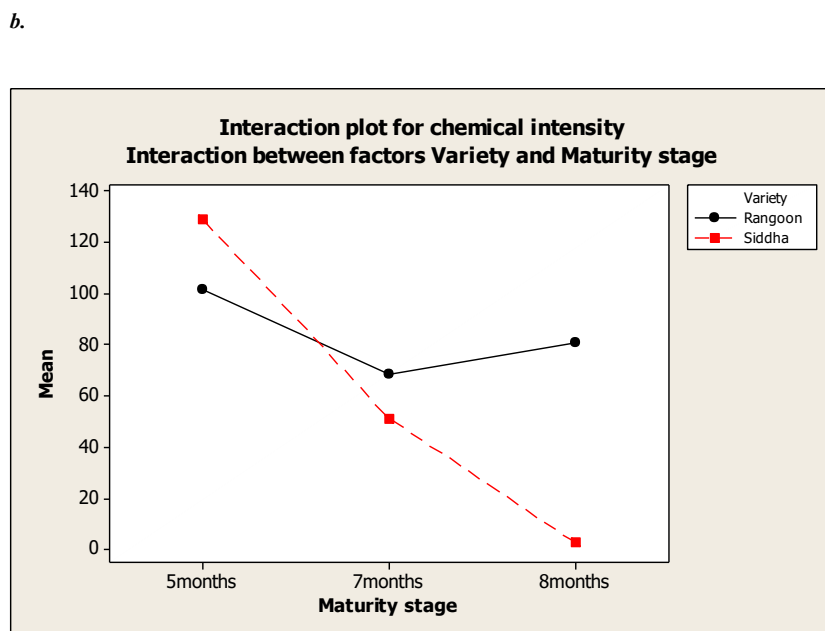
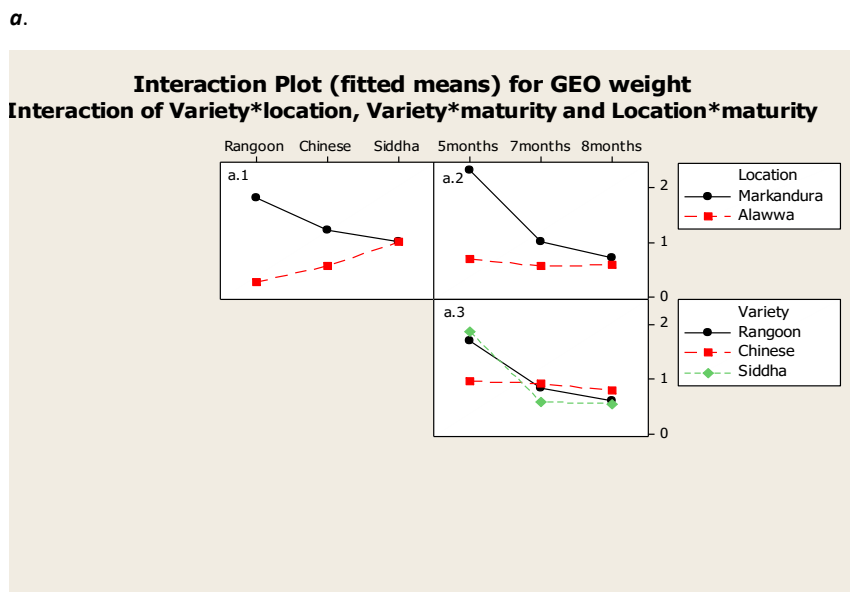
increasing maturity stage. Possible cause for this could lie deep in the genetics of the two varieties.

### 3.3. Chemical composition variation with maturity stage

Regarding GEO chromatograph of local variety Siddha, chemical compounds in areas A and B were decreasing in intensity with increasing maturity stage. In relation to area A, average all chemical peak intensity drop from 5 to 7 months was 66%. It was 97% drop from 5 to 8 months. In relation to graph area B, average all chemical peak intensity drop from 5 to 7 months was 42% while chemical intensity drop from 5 to 8 months was 98%. In relation to graph area C, average all chemical peak intensity increment from 5 months to 7 months was 48%. Considering all 25 major chemical peaks, a 72% average drop of intensity from 5 to 8 months was recorded. Maximum intensity peaks of areas A and B were reported at 5 months maturity. On the contrary, area C did not show any dramatic fluctuation. Maximum intensities of area C were reported at 7 months after planting.  $\alpha$ -nerolidol in Siddha variety appeared in area C at 8 months of maturity which showed an unusual 15.8% abundance. Moreover, regarding GEO chromatograph of Rangoon, areas A and B showed maximum chemical intensities at 5 months maturity. Area C intensities remained relatively steady with increasing maturity stage. Considering all major peaks, a drop of average peak intensity from 5 months to 8 months was observed. In relation to chromatograph area A this value was 42%. In relation to area B it was 6%. Peak intensity drop in chromatographic area C was 12%. Rangoon variety planted in Makandura did not show dramatic peak intensity fluctuations as compared to Siddha variety planted in the same location. Then again, we suspect the difference in variation may be due to the genetics of the two varieties. Further, some compounds showed a decrease following an initial increment of intensity with time. This unusual fluctuation could be due to compound conversion to other structurally related compounds or expenditure of certain compound for cellular processes for a brief period of time.



Figure 2. Percentage relative abundance of chromatography areas A, B and C vs maturity stage, a.1, a.2, a.3 (Rangoon at Makandura), b.1, b.2, b.3 (Siddha at Makandura).



**Figure 3.** a.1 Interaction plot for GEO weight yield between factors Variety and Location a.2 between Maturity stage and location a.3 between maturity stage and variety b. Interaction plot for chemical intensity between factors maturity stage and variety.

**3.4. Effect of maturity stage at harvest on essential oil weight yield**

Maturity stage at harvest is a very important parameter to determine before harvesting ginger for industrial use. Different maturity stages of ginger rhizome would manifest variable weight yields and GEO chemical profiles. Prevailing knowledge was that at five-months maturity rhizomes were less fibrous and less in chemical intensity than that of seven to nine months matured rhizomes (Kiran et al., 2013). Essential oil content was considered to be high at higher maturity stages (Bag, 2018). However, in this research we demonstrated that in Sri Lankan conditions, highest chemical intensity and GEO weight yields were reported by five-month matured ginger rhizomes. Rangoon variety reported the highest percentage yield of 3.36% by weight. Local Siddha variety did not record the highest extraction percentage as expected. Percentage weight yields decreased sharply after 5 months maturity. Moreover, maximum chemical peak intensities were also reported by five months old rhizomes rather than by eight months old rhizomes.

GEO yields obtained in this research was in the range 1%–3% (w/w) were higher in comparison to the weight yields obtained in India which was 0.28% (Munda et al., 2018). Local ginger variety (Siddha) yielded around 1% in average while Rangoon and control variety Chinese yielded as high as 3% indicating that the Sri Lankan conditions are best suited for the growing of ginger for higher GEO yields.

**3.5. GEO chemical profiles in different parts of the world**

In Iranian grown ginger,  $\beta$ -sesquiphellandrene, Zingiberene, caryophyllene,  $\alpha$ -curcumene, farnesene were the major compounds in the chemical profile of GEO while  $\alpha$ -pinene, camphene, borneol (isoborneol), germacrene, eucalyptol, terpineol were the minor constituents. Altogether ten chemical peaks were prominent in the chemical profile (Noshirvani et al., 2017). *Zingiber officinale* grown in Ecuador had a different profile in which a sum of 70 compounds were identified. Six chemicals citral, geraniol (10.5%), neral (9.1%), camphene (7.8%),



$\alpha$ -zingiberene (17.4%),  $\alpha$ -farnesene (6.8%) and  $\beta$ -sesquiphellandrene (6.7%) were the most abundant in the chemical profile (Höferl et al., 2015). In Indian grown ginger, eighty total compounds were identified in the chemical profile and five compounds such as valencene (7.61%), zingiberene (46.71%),  $\beta$ -funebrene (3.09%) and selina-4(14), 7(11)-diene (1.03%) were the most abundant sesquiterpenes while four compounds such as camphene (2.59%), citronellyl n-butyrate (19.34%),  $\beta$ -phellandrene (3.70%) and  $\alpha$ -pinene (1.09%) were the predominant monoterpenes above 1% abundant level (Sharma et al., 2016). These indicate the diversity of chemical profiles of the same species of ginger cultivated in different geographical regions of the world. In the current study, all major chemicals were more than 2% in relative percentage abundance which was higher than the lowest abundance level of the previously mentioned researches.

### 3.6. Essential oil from siddha

Chemical  $\alpha$ -zingiberene was found in trace amounts in local Siddha variety as compared to the related GEO research from other regions of the world. Current research results agreed with the Macleod's report results which stated that the  $\alpha$ -zingiberene content was low in local variety Siddha (Macleod and Pieris, 1984). Further, current results indicated that sesquiterpenes such as ar-cucumene, and  $\beta$ -bisabolene were not abundant in high amounts in Siddha's ginger oil. It is for future research to find out which factors were responsible for the varying levels of sesquiterpene in Sri Lankan grown ginger.

Monoterpenes such as  $\alpha$ -pinene,  $\beta$ -pinene, myrcene 1,8-cineole, borneol, camphor, which possess a strong effect against microbial activity (Santoyo et al., 2005) by disruption of bacterial membrane integrity (Knobloch et al., 1989) was found in Siddha GEO. These chemicals seem to limit the rate of diffusion of hydrophobic compounds through the lipopolysaccharide layer (Burt, 2004). The dissipation of ion gradient lead to impairment of essential processes in the bacterial cell and finally to the cell's death (Ultee et al., 1999). Current research indicated that some of these monoterpenes were in high abundance in the Siddha GEO extract while other bactericidal compounds such as  $\beta$ -sesqui-phellandrene, farnesal, and eugenol were in high abundance as well. Therefore, the antibacterial potential can be shown substantial in Siddha variety than in Rangoon. Local Siddha variety further contained high fragrance chemicals in high abundance. These chemicals include geraniol, linalool and borneol (Nishimura, 1995). Therefore GEO in Siddha variety was highly fragrant than Rangoon.

Gingerols and shogaols in ginger rhizomes were responsible for the pungent taste (Kikuzaki et al., 1994). 6-gingerol and 6-shogaol were the major gingerol and shogaol occurred in the ginger rhizome (Connell and McLachlan, 1972). Shogaols were more pungent than gingerols and were usually derived from the corresponding gingerols during thermal processing or long-term storage (Zhang et al., 1994). Neither Rangoon nor Siddha the Sri Lankan variety yielded considerable amounts of pungency related chemicals. Consequently, it's imperative not to recommended Rangoon or Siddha varieties for industrial ginger pungency requirements.

## 4. Conclusion

In conclusion, the best stage to harvest ginger rhizomes for higher essential oil weight yield was at 5 months maturity. In addition, ginger essential oil weight yield was decreasing with increasing maturity stage. Both Rangoon and Siddha varieties were recommended for high oil weight yield under Sri Lankan conditions. Makandura area was the best geographical location in Sri Lanka to plant Rangoon variety for maximum oil yields. Siddha variety can be recommended to be cultivated in both the geographical locations Makandura and Alawwa. Considering chemical intensities of major peaks in the GEO fraction, Siddha variety yielded the best qualitative GEO chemical profile at 5 months maturity stage.

Based on statistical analysis, GEO weight yield was significantly affected by location of cultivation and maturity stage at harvesting. However, weight yields were not significantly affected by variety factor at 95% confidence interval ( $p > 0.05$ ). Moreover, chemical peak intensity of ginger essential oil was significantly affected by maturity stage. However, variety factor was not significantly affecting the chemical peak intensities of GEO at 95% confidence interval ( $p > 0.05$ ).

## Declarations

### Author contribution statement

Nayana Damenu Bandara Jayasundara: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Palitha Arampath: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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### Data availability statement

Data associated with this study has been deposited at Mandelley Data under the accession number 10.17632/2vn45wpddn.2.

### Declaration of interests statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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