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Changes in the Contents of Oleoresin and Pungent Bioactive Principles of Jamaican Ginger (*Zingiber officinale* Roscoe.) during Maturation

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Changes in the yields of the oleoresin and content of pungent bioactive principles: [6], [8], [10] gingerols and [6] shogaol of Jamaican ginger (*Zingiber officinale*) were investigated during different stages of maturity (7−9 months). Ethanolic oleoresin extracts were prepared (95%, w/w) by cold maceration of dried ginger powder, and their percentage yields were calculated (w/w). The pungent bioactive principles in the ginger oleoresin were extracted with methanol and quantitatively analyzed by high performance liquid chromatography (HPLC). Ginger harvested at 8 months from Bourbon, Portland had the highest oleoresin yield (8.46 ± 0.46%). [6] Gingerol was found to be the most abundant pungent bioactive principle in all the oleoresin samples investigated, with the 9 months sample from Bourbon, Portland containing the highest level (28.94 ± 0.39%). The content of [6] gingerols was also found to be consistently high (7−9 months) in oleoresin samples from Johnson Mountain, St. Thomas (15.12 ± 0.39 to 16.02 ± 0.95%). The results suggest that Bourbon in Portland may be the most ideal location for cultivating ginger for high yields and quality, however, Johnson Mountain in St. Thomas could prove to be the least restrictive location, allowing for harvesting of good quality material throughout the maturity period (7−9 months).

KEYWORDS: *Zingiber officinale*; maturity; oleoresin; pungent bioactive principles; gingerols; shogaols; nutraceutical; HPLC

INTRODUCTION

Ginger, the underground stem (rhizome) of the herbaceous perennial monocotyledon *Zingiber officinale* Roscoe, is cultivated in many tropical and subtropical countries including China, India, Nigeria, Australia, Jamaica, and Haiti. China and India are the world's leading producers (*1*). Ginger has long been known for its worldwide use as a spice, flavoring agent, as well as a herbal medicine. The pungent aromatic rhizome is also an important export crop, valued for its powder, oil, and oleoresin (*2*). The extractives (oil and oleoresin) are highly concentrated, low-volume, high-value products, normally used in beverages, pickles, spicy perfumes, as well as pharmaceutical processing (*3, 4*).

Ginger rhizome contains a rich source of pungent bioactive principles of importance, which have long been recognized. These substances, which are phenolic ketones, include the gingerols as well as the shogaols, which exist as a series of homologues ([4], [6], [8], and [10] gingerols and shogaols) with a range of unbranched alkyl chain lengths (*5–7*). Representative structures are presented in **Figure 1**. [6] Gingerol is reportedly the most abundant constituent in the gingerols series (*6*). The shogaols are thought to be the dehydration products of the gingerols, derived from thermal processing (drying/heating) or long-term storage (*3, 5–7*) and are more pungent than the gingerols (*4, 8*). These compounds possess a wide range of pharmacological and physiological effects, which include cardiovascular, gastro-intestinal (antiemetic, antinausea, antiulcer), antioxidant, anti-inflammatory, antimicrobial (analgesic, sedative, antipyretic, antibacterial), as well as thermogenic activities (*8, 9*). As a consequence of these health benefits, there has been widespread use of ginger as an ingredient in various commercial natural products being offered in the emerging nutraceuticals and functional foods market (*3*). The uniqueness of Jamaican ginger (i.e., its flavor, oil content, and appearance) has provided the basis on which the standards of other gingers have been assessed (*10*). These characteristics have ultimately placed Jamaica's fledgling ginger industry in an ideal position to benefit from this billion dollar industry.

Ginger is cultivated throughout Jamaica, however, cultivation is concentrated mainly in the parishes of Clarendon, Manchester, St. Ann, and St. Thomas (Rural Agricultural Development

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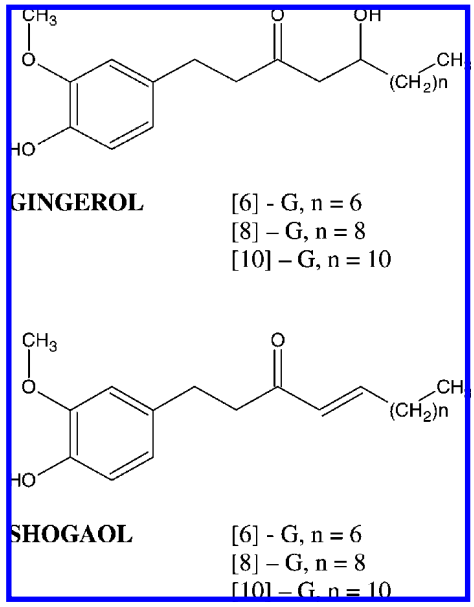

Figure 1. Structures of major chemical constituents.

Authority (RADA), Parish Offices. Personal Communication, 2007.), in areas with steep topography, cool temperatures, and soils rich in clay. Several studies have investigated the yields of oleoresin and the content of pungent bioactive principles of Jamaican ginger (*3, 11–14*). However, it is still unclear what changes occur during the period leading up to 9 months maturity, since this has never been investigated. The aim of this study was to investigate the changes in the contents of ginger oleoresin and pungent bioactive principles during maturity (7−9 months) from the main ginger growing areas in Jamaica. This information can be useful to ginger farmers as well as manufacturers and exporters of ginger based nutraceutical products in selecting the appropriate period and location for harvesting ginger in order to maximize the yields of oleoresin and content of the pungent principles for the nutraceutical/functional foods industries.

MATERIAL AND METHODS

Standards and Reagents. Standards of [6], [8], [10] gingerols and [6] shogaols were obtained from Chromadex Inc., Irvine, CA. Nonanoic acid vanillylamide (NVA) standard was obtained from Sigma Chemicals, St. Louis, MO. Ethanol was obtained from Pharmco Products, Brookfield, CT. Analytical grade hexane, ethyl acetate, formic acid, methanol, glacial acetic acid, sulfuric acid, and HPLC grade acetonitrile and methanol were obtained from Fisher Scientific, Fair Lawn, NJ. The water used for HPLC analyses was deionized then purified with a Milli-Q ultrapure water system. All other solvents used were of analytical grade, unless stated otherwise.

Sample Collection. Samples of ginger were collected from plots established according to common cultural practices in seven locations across the island, namely Clarendon (Sandy River, Top Alston), Trelawny (Lorrimers), Manchester (Coleyville), St. Thomas (Johnson Mountain), Portland (Bourbon), and St. Mary (Retreat). Plots were established between April and August using setts of native Jamaican ginger obtained from a single uniform genetic pool. Prior to the first reaping at 7 months, the plots were corded off into grids measuring approximately 0.9 m × 0.9 m (3 ft × 3 ft) each. Each grid was designated a number between 1 and 165 based on the size of the plot. A computer generated random number table was then used to select the grids (25% of the total plot size at each reaping) for sampling, thus ensuring that there was no bias. Between 22.7 and 31.8 kg of fresh ginger rhizome was collected from each location at monthly intervals, starting at 7 months after planting and continuing up to 9 months.

Sample Preparation. Rhizomes were washed to remove debris and dirt, drained, and then sliced into thin strips using a mechanical slicer. Samples were then spread thinly on mesh drying trays, and drying was effected over 5 days by means of a solar dryer. Dried samples were then removed and milled into a coarse powder prior to extraction.

Extraction of Ginger Oleoresin by Cold Maceration. Samples of dried ground ginger at different stages of maturity and from the seven locations were subjected to the following procedure. Approximately 100 g of dried ground ginger was weighed into a 2 L conical flask, and 1 L of 95% ethanol was added. The flask was covered to prevent evaporation of the ethanol and then stirred atop a magnetic stirrer for 6 h. The resulting solution was gravity filtered, and the filtrate stored. The residue was re-extracted with 500 mL of 95% ethanol for 2 h and gravity filtered; both filtrates were pooled. This was then concentrated to a paste or oleoresin in a tared round-bottom flask using a rotary evaporator at 50 °C. The oleoresin yield was calculated as percentage weight per weight. Six determinations were made for each sample.

Extraction of the Pungent Principles for Quantitative Analysis by HPLC. Pungent principles in ginger oleoresin were extracted according to an International Organization for Standards (ISO) certified method to which minor modifications were made (*14*).

Extraction of Ginger Oleoresin. Ginger oleoresin (0.25 g) was accurately weighed into a 50 mL volumetric flask. The oleoresin was then dissolved in analytical grade methanol and diluted to the graduation mark. The flask was stoppered and shaken vigorously. Each sample was prepared in duplicate, and the exact concentrations in milligrams per milliliter were calculated.

Quantification of the Pungent Principles by HPLC. The pungent principles were quantified by way of an external standard method in which nonanoic acid vanillylamide (NVA) was used (*14*).

Preparation of Standard Solutions. A stock solution was prepared by dissolving 0.1 g of accurately weighed NVA in HPLC grade methanol (100 mL). Standard solutions were prepared (ca. 0.2 and 0.4 mg/mL) by diluting the initial solution (5 and 10 mL respectively, to 25 mL) with HPLC grade methanol. The exact concentrations were calculated, and all three solutions were stored at −10 °C until required.

A standard mixture containing [6], [8], and [10] gingerols as well as [6] shogaols was prepared at a concentration of 1 mg/mL with respect to each standard. Individual standards were also prepared at 1 mg/mL. These were used to confirm the identities of the peaks in the sample solutions.

Preparation of the Mobile Phase. The mobile phase consisted of acetonitrile containing 1% acetic acid (65:35 before degasification). HPLC grade acetonitrile (520 mL) was filtered through a FH-type Millipore filter (0.5 μm). Water and glacial acetic acid were mixed in the proportions 99:1 (v/v), and this mixture (280 mL) was passed through a HA-type Millipore filter (0.45 μm) into the filtered solution of acetonitrile. The mixture was degassed under vacuum with stirring for 30 min, and the mobile phase was transferred to the reservoir of the chromatograph.

HPLC Analysis. Analyses were carried out using a Hewlett-Packard HP 1050 Series HPLC equipped with an autosampler, HP ChemStation software, and variable wavelength detector set at 280 nm. An analytical reversed phase column (Supelco Hypersil ODS, 5μm, 250 mm × 4.6 mm) was used to separate the samples isocratically at a flow rate of 1.0 mL/min at ambient temperature. Each external standard solution (20 μL) was injected 3 times, while the sample solutions (20 μL), the individual standards (20 μL of each), as well as the standard mixture (20 μL) of the pungent bioactive principles were injected twice. The run times for the external standard were 10 and 20 min, respectively, for the standards of pungent principles and ginger oleoresin. An appropriate dilution was made for the ginger oleoresin where the peak areas for [6] gingerol were found to be greater than those of NVA in the 0.4 mg/mL standard.

Calculations. This was conducted according to the equations outlined in the ISO certified method (*14*). The area for each NVA peak was recorded, and the mean was calculated. This was used to calculate the response factor (K) of NVA, which was used to further calculate the response factors for each gingerol and shogaol identified. The values of K_{NVA} calculated for the two concentrations were not allowed to differ by more than 2%, thus ensuring a linear response. The peak areas corresponding to the gingerols and shogaol given in the order of

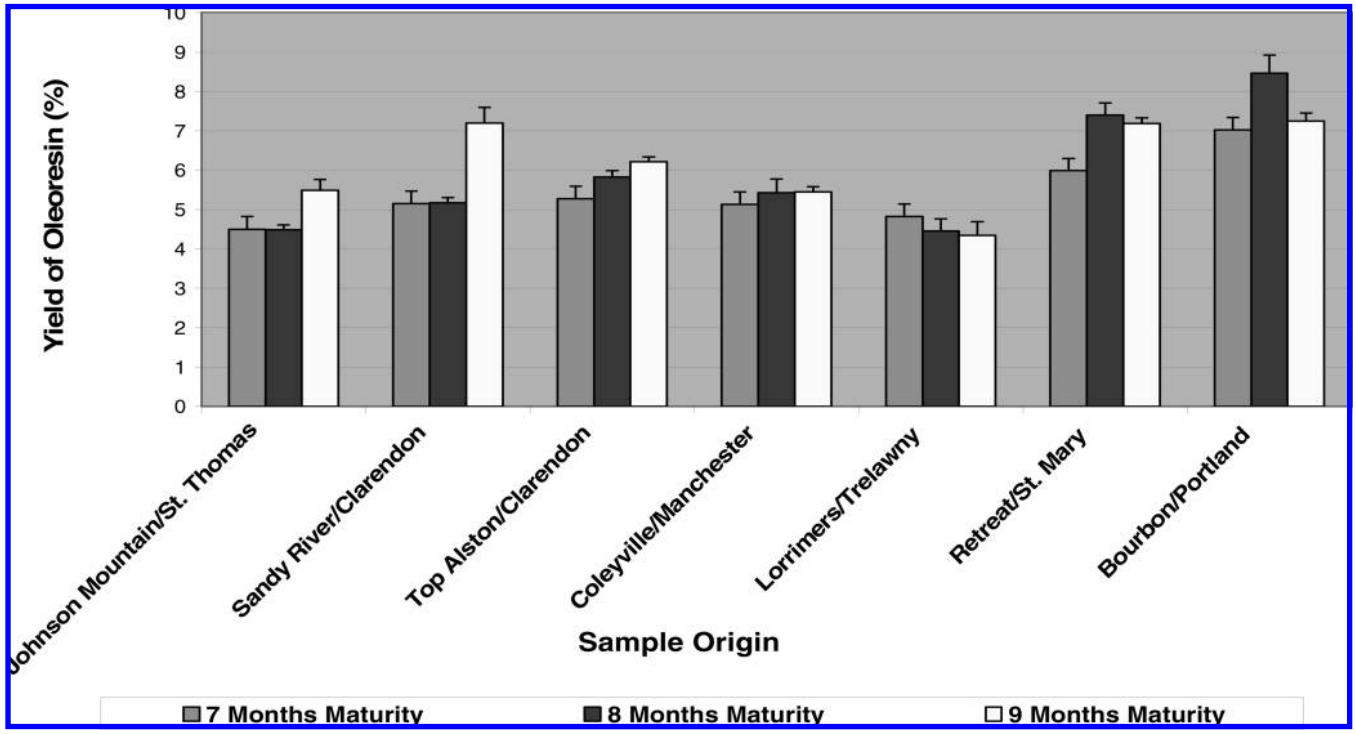

Figure 2. Variations in oleoresin yields of Jamaican ginger during maturation.

retention times for the samples were recorded, and the concentration of each present in the samples was calculated.

Graphs and Statistical Analysis. Summary statistics and graphs were obtained using Microsoft Office Excel 2003. Means were compared using analysis of variance (ANOVA) at $p \leq 0.05$.

RESULTS AND DISCUSSION

Oleoresin Content. Variations in the yields of oleoresin obtained from ginger harvested between 7 and 9 months from the seven plots across the island are presented in **Figure 2**. Of the seven sites studied, the highest overall yields were obtained from Bourbon, Portland, suggesting that this location could be the most ideal for cultivating ginger, if interest lies in the oleoresin yields. Ginger harvested at 8 months from this location produced the highest percentage oleoresin yield (8.46 ± 0.46%). The percentage yields of oleoresin obtained from samples harvested at 7 and 9 months were also high (7.02 ± 0.47 and 7.25 ± 0.20%, respectively) but not significantly different from each other ($p \leq 0.05$). The latter results compared well with oleoresin yields obtained from ginger harvested at 8 and 9 months from Retreat, St. Mary (7.40 ± 0.31 and 7.18 ± 0.15%, respectively), the site with the second highest yields. It is of interest to note that oleoresin yields obtained for ginger harvested at 9 months from Sandy River, Clarendon (7.19 ± 0.40%) were comparable to those obtained from Retreat at 9 months (7.18 ± 0.15%). The yields obtained from ginger harvested at 7 and 8 months for Coleyville, Manchester (5.13 ± 0.04 and 5.42 ± 0.35%) and Sandy River (5.15 ± 0.18 and 5.17 ± 0.13%) and Top Alston (5.27 ± 0.13 and 5.83 ± 0.15%) in Clarendon were found to be the next highest. The lowest yields were obtained for ginger harvested at 7 months (4.50 ± 0.04%) and 8 months (4.48 ± 0.13%) for Johnson Mountain, St. Thomas and Lorrimers, Trelawny, for ginger harvested at 8 months (4.46 ± 0.30%) and 9 months (4.34 ± 0.35%).

Yields of oleoresin obtained from this study (from 4.34 ± 0.35 to 8.46 ± 0.46%) were found to agree with yields of between 3.6 and 10% reported in the literature (*2, 13*). Additionally, oleoresin content reportedly decreases with increasing maturity of ginger (*13*). However, this was only evident in the instance of Lorrimers, Trelawny, which showed a decrease in yields of oleoresin (from 4.82 ± 0.11% at 7 months to 4.34 ± 0.35% at 9 months) over the maturation period studied. This decrease was not significant ($p \leq 0.05$). Maximum oleoresin content, on the other hand, has been reported to occur between 180 and 220 days after planting in Northern India, 245−265 days after planting in Southern India and Sri Lanka, 230−255 days in Taiwan and China, and 270−290 days in Australia and was constant at 1% (fresh weight basis) over 34 weeks in Hawaii (*13*). This information clearly conforms to the findings from this study, which shows that maximum oleoresin content varies with location.

Pungent Bioactive Principles. Figure 3 represents a typical HPLC chromatogram of ginger oleoresin. [6] Gingerol peaks were found to be the most abundant in the oleoresin extracts and were inversely proportional to the sizes of the [6] shogaol peaks (**Figure 3**), a finding that is in keeping with that reported in the literature (*14, 15*).

Figures 4−7 represent variations in the content of pungent bioactive principles [6], [8], [10] gingerols and [6] shogaol, respectively, in oleoresin obtained from ginger at the various stages of maturity from the seven locations. The profiles obtained at 7, 8, and 9 months were similar with respect to the order of the levels or concentrations of the pungent bioactive principles present. [6] Gingerol was found to be the most abundant, followed by [10] gingerols and [8] gingerols, with [6] shogaols present in the lowest concentrations.

[6] Gingerol Content. Quantities of [6] gingerol obtained from oleoresin samples from the seven locations ranged from 10.11 ± 0.31 to 28.94 ± 0.39% (**Figure 4**). Oleoresin samples obtained from ginger harvested from Bourbon, Portland at 9 months had the highest [6] gingerol content (28.94 ± 0.39%). High contents were also observed for the 8 months samples (20.97 ± 0.70%); however, contents of [6] gingerol observed for the 7 months samples (10.23 ± 1.05%) were not significantly different from those obtained from samples of the same maturity from Lorrimers (11.19 ± 0.30%), Coleyville (10.11 ± 0.31%),

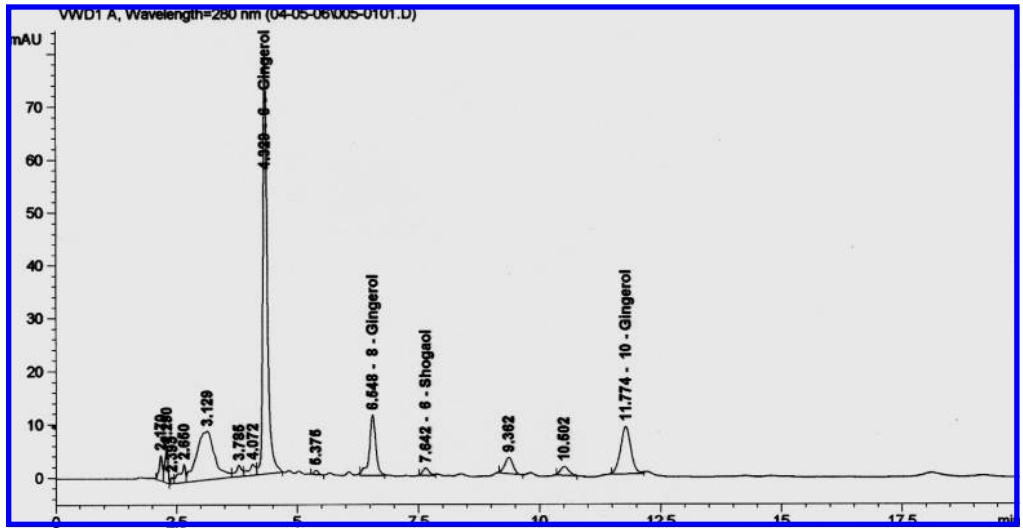

Figure 3. Typical HPLC chromatogram of the pungent principles in Jamaican ginger oleoresin.

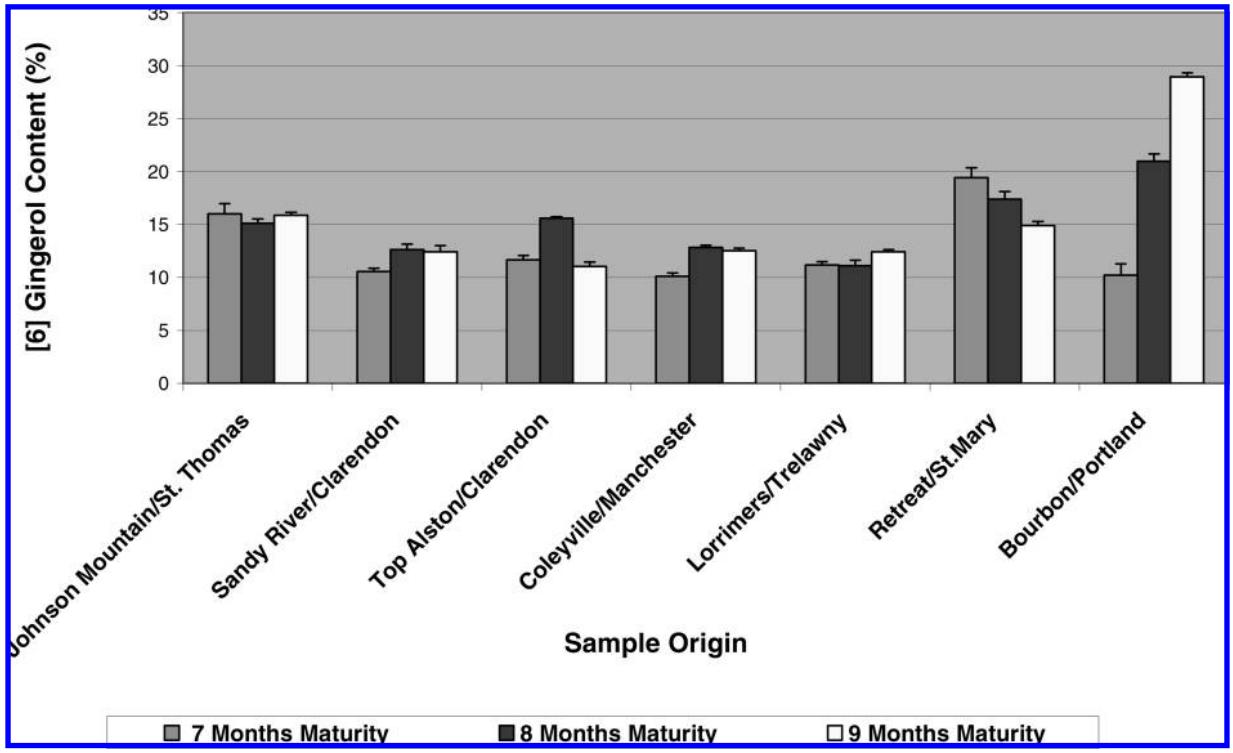

Figure 4. Variations in [6] gingerol content of Jamaican ginger oleoresin during maturation (7−9 months).

Top Alston (11.65 ± 0.43%), and Sandy River (10.54 ± 0.34%). Retreat was found to be the second best producing site with respect to [6] gingerol content. An inverse relationship response with respect to maturity was observed between Retreat and Bourbon in that the content of [6] gingerol was highest in the 7 months oleoresin samples and lowest in the 9 months samples, the opposite of observations made for the Bourbon samples. Johnson Mountain had the third highest overall contents of [6] gingerol. However, there was no significant difference in content over the maturation period (7−9 months) with values ranging between 15.12 ± 0.39 and 16.02 ± 0.95% ($p \leq 0.05$). This suggests that, if farmers or manufacturers were interested in obtaining raw material with a consistent supply of [6] gingerol at relatively high concentrations throughout the maturation period, then Johnson Mountain could possibly be the most ideal location, since farmers would be less confined with respect to times for harvesting.

[8] Gingerol Content. Quantities of [8] gingerol ranged between 1.39 ± 0.07 and 5.42 ± 0.59% for samples of oleoresin obtained from the seven locations across Jamaica (**Figure 5**). The highest overall content of [8] gingerol was found in 7 and 8 months oleoresin samples from Retreat, which had concentrations of 5.42 ± 0.59 and 4.86 ± 0.55%, respectively. The content at 8 months was however not significantly different from that of the 9 months oleoresin sample from Bourbon (4.76 ± 0.08%, $p \leq 0.05$). As was observed for [6] gingerol, an inverse relationship response with respect to maturity was observed between the sites with the highest overall contents of [8] gingerol at Retreat and Bourbon. Of note is that the [8] gingerol content for the 8 months oleoresin sample from Sandy River (3.44 ± 0.46%) was comparable to the [8] gingerol content for samples of the same maturity from Bourbon (3.32 ± 0.10%). The content of [8] gingerol obtained for 8 months (3.06 ± 0.30%) and 9 months (3.05 ± 0.15%) oleoresin samples from Lorrimers was

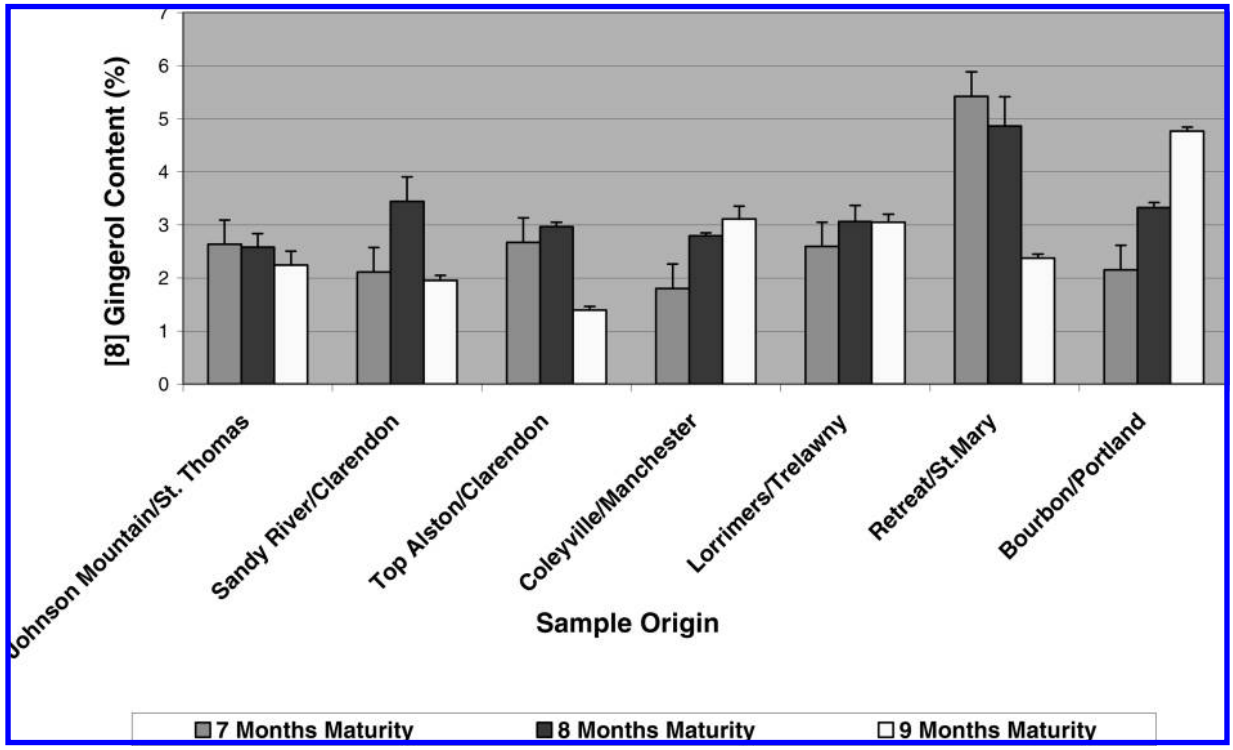

Figure 5. Variations in [8] gingerol content of Jamaican ginger oleoresin during maturation (7−9 months).

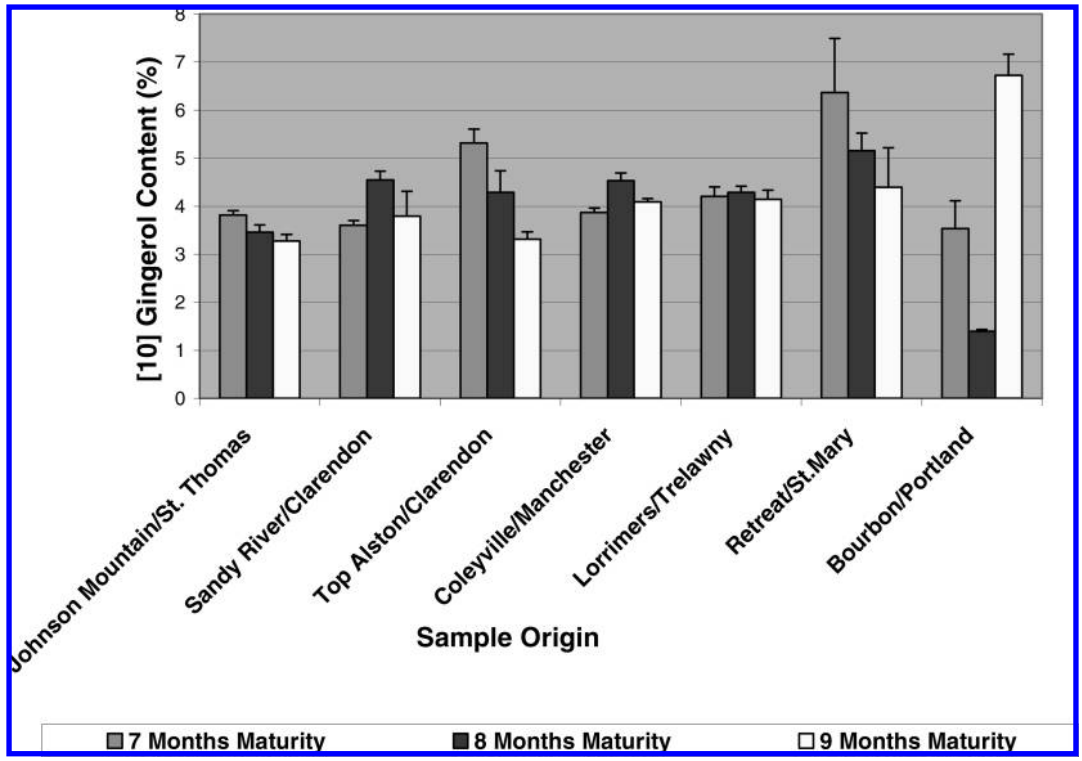

Figure 6. Variations in [10] gingerol content of Jamaican ginger oleoresin during maturation (7−9 months).

also notably high but was not significantly different from contents obtained from 8 months samples from Top Alston (2.96 ± 0.09%) and 9 months samples from Coleyville (3.11 ± 0.24%). The lowest content of [8] gingerol was obtained from the 9 months oleoresin samples from Top Alston (1.39 ± 0.07). On the other hand, oleoresin samples from Johnson Mountain had the least variations in [8] gingerol content during the 7−9 months period studied.

[10] Gingerol Content. The quantities of [10] gingerol obtained from oleoresin samples across the seven locations studied ranged between 1.39 ± 0.04 and 6.72 ± 0.44% (**Figure 6**). The [10] gingerol content from oleoresin collected from Bourbon at 9 months was found to be the highest (6.72 ± 0.44%), but it was not significantly different from the [10] gingerol content of the 7 months oleoresin sample for Retreat (6.36 ± 1.13%). There was also no significant difference

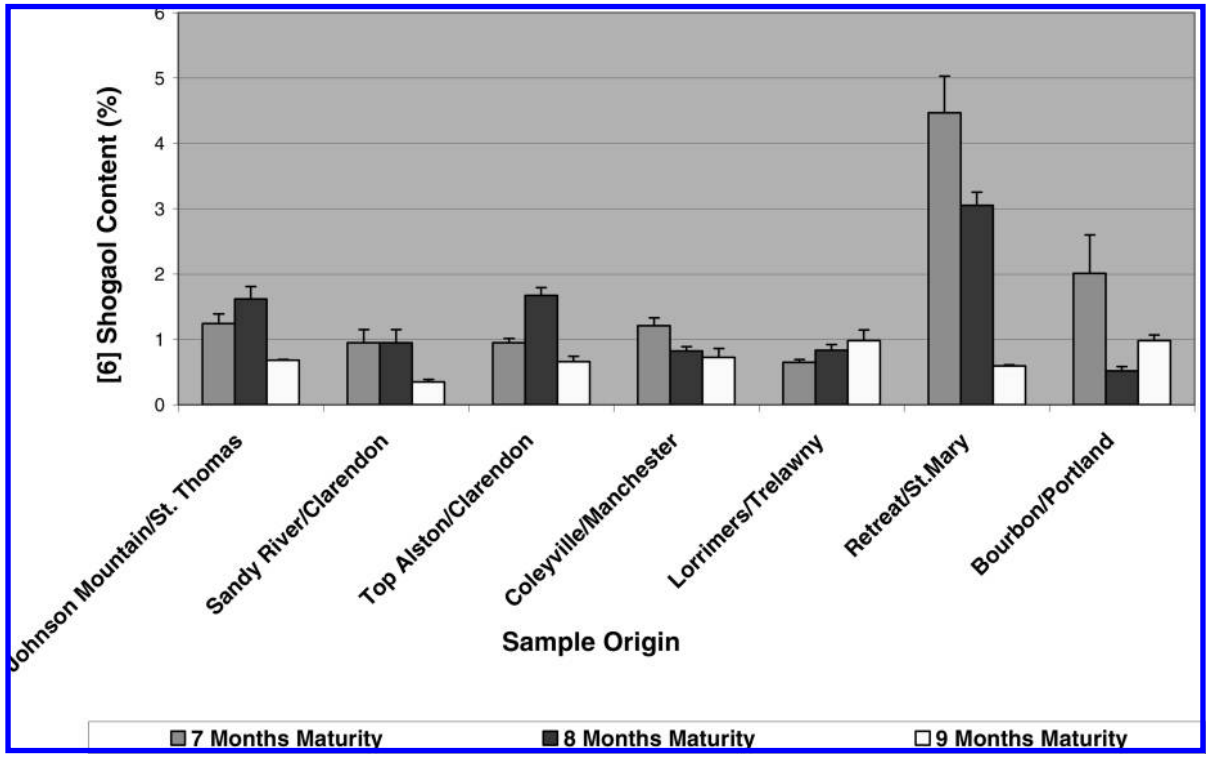

Figure 7. Variations in [6] shogaol content of Jamaican ginger oleoresin during maturation (7−9 months).

between the [10] gingerol content of 7 months oleoresin samples from Top Alston (5.31 ± 0.29%) and that of the 8 months oleoresin samples from Retreat (5.15 ± 0.37%). A significant decrease was however observed between the 7 and 9 months oleoresin samples from Bourbon, resulting in the 8 months sample having the lowest [10] gingerol content (1.39 ± 0.04%).

[6] Shogaol. The quantities of [6] shogaol were found to range between 0.52 ± 0.06 and 4.47 ± 0.56% for oleoresin samples obtained from the seven locations during the maturation period (**Figure 7**). High levels of [6] shogaol were observed in 7 months (4.47 ± 0.56%) and 8 months (3.05 ± 0.20%) oleoresin samples from Retreat and 7 months samples (2.01 ± 0.59) from Bourbon, relative to values ranging between 0.35 ± 0.04 and 1.67 ± 0.12% for the other five locations. Previous findings (*3*) indicated a mean content of 1.01 ± 0.10% for [6] shogaol in Jamaican ginger oleoresins extracted by similar method from various locations across the island. Shogaols are usually found at very low concentrations in fresh ginger, forming during storage (aging) of either dried ginger or ginger oleoresin (*15*). Heating and drying are also other factors, which can result in an increase in shogaols (*3*). Contents of [6] shogaol obtained for all other locations compared favorably with previous findings (*3*).

Standard percentages of total gingerols in ranges between 3 and 20% have been identified in commercial distribution (*3, 16*). Total gingerols found in Jamaican ginger oleoresin were found to range between 15.78 and 40.42% (**Table 1**) across the seven sites studied. This suggests that the content of the pungent principles in the local product comply with required international standards and in some instances far exceeds these standards; hence, a niche market may be possible. Incorporation of Jamaican ginger oleoresin into nutraceutical/functional food formulations could therefore eliminate the need for blending, a common practice of mixing extracts of different concentrations from different locations, in order to increase the concentration of gingerols in final products. This would ultimately result in savings to manufacturers in terms of valuable time and money and possibly a better end product.

Table 1. Total Gingerol Content (%) of Jamaican Ginger Oleoresin at 7, 8, and 9 Months Maturation[a]

	total gingerol content (%)		
sample origin	7 months	8 months	9 months
St. Thomas Johnson Mountain	22.46	21.15	21.36
Clarendon Sandy River	16.25	20.59	18.15
Top Alston	19.63	22.84	15.76
Manchester Coleyville	15.78	20.16	19.70
Trelawny Lorrimers	17.98	18.44	19.59
St. Mary Retreat	31.18	27.39	21.67
Portland Bourbon	15.91	25.68	40.42

[a] Values represent the sum of [6], [8], and [10] gingerols at each maturation period.

Table 2 contains data of the reported monthly rainfall and altitude of the plot locations. It was observed that Bourbon received the highest total rainfall (3173 mm) over the crop cycle, followed by Johnson Mountain (2724 mm). The lowest total rainfall was recorded for Coleyville (1027 mm). A rainfall of 2500−3000 mm well distributed over the year is optimal for ginger growth, but good crop production has also been reported from rainfall levels of 1500−2000 mm with supplementary irrigation (*13*). The established plots were however entirely rain grown. It is interesting to note that, although the highest yields of oleoresin and pungent principles were obtained from ginger harvested in Bourbon, there was no clear correlation between these high yields and the high level of rainfall observed, especially when the results of other plot locations were

Table 2. Reported Monthly Rainfall (mm) per Plot Location during Time Course of Experiment (June 2005−May 2006)[a]

	monthly rainfall (mm) during crop cycle[b]											
plot locations[c]	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb.	March	April	May
St. Thomas												
Johnson Mountain (305 m)	562	495	135	171	781	136	311	70	57	6		
Clarendon												
Sandy River (671 m)	216	654	216	252	802	114	43	17	37	30		
Top Alston (610 m)		644	130	124	526	122	14	9	67	36	148	
Manchester												
Coleyville (914 m)	31	353	47	149	337	45	16	4	20	25		
Trelawny												
Lorrimers (914 m)	154	469	300	625	535	121	60	32	87	48		
St. Mary												
Retreat (381 m)		392	49	78	411	467	78	166	181	60	24	
Portland												
Bourbon (366 m)			139	131	619	951	377	221	409	48	194	84

[a] The data in **Table 2** were obtained from climate control stations closest to each plot location and are therefore approximate. Source: Meteorological Service, Jamaica. [b] Rainfall data represented for each location are an indication of when ginger setts were first planted and the last harvesting date. [c] Data in parentheses represent altitude of the locations.

Table 3. Soil Properties of Ginger Cultivation Plots (*17*)

plot locations	soil type	pH	nitrogen (%)	phosphate (ppm)	potash (ppm)
St. Thomas					
Johnson Mountain	mix of: Belfield clay (Entic Chromuderts)	6.1−6.5 (slightly acidic top soil)	>0.2 (low)	>60 (low)	>225 (high)
	Llandewey clay loam (Typic Ustropepts)	6.6−7.3 (neutral top soil) 7.4−8.4 (mildly alkaline below)	>0.2 (low)	>60 (low)	>225 (high)
	Bonnygate stony loam (Lithic Troporthents and Lithic Ustorthents)	7.4−8.4 (mildly alkaline)	>0.2 (low)	>60 (low)	>140 (low)
Clarendon					
Sandy River	Wirefence clay loam (Dystropepetic Tropudulls)	5.1−5.5 (strongly acidic)	>0.2 (low)	>60 (low)	140−225 (medium)
Top Alston	Donnington gravely clay loam (Typic Dystropepts)	5.6−6.0 (medium acidic)	>0.2 (low)	60−100 (medium)	140−225 (medium)
Manchester					
Coleyville	Carron Hall clay (Typic Chromuderts)	7.4−7.8 (slightly alkaline)	>0.2 (low)	>60 (low)	>225 (high)
Trelawny					
Lorrimers	Carron Hall clay (Typic Chromuderts)	7.4−7.8 (slightly alkaline)	>0.2 (low)	>60 (low)	>225 (high)
St. Mary					
Retreat	mix of: Bonnygate stony loam (Lithic Troporthents and Lithic Ustorthents)	7.4−8.4 (mildly alkaline)	>0.2 (low)	>60 (low)	>140 (low)
	Lucky Hill clay loam (Typic Tropudults)	6.1−7.3 (neutral slightly acidic)	>0.2 (low)	60−100 (medium)	>140 (low)
Portland					
Bourbon	Cuffy Gully gravely sandy loam(Typic Dystropepts)	6.1−6.5 (slightly acidic)	>0.2 (low)	60−100 (medium)	140−225 (medium)

examined. Similarly, although ginger is normally grown at low altitudes (*13*), there was no clear correlation between the altitude of the plots and yields obtained.

The data in **Table 3** give information on the soil properties at each plot location. The soil type at Bourbon appeared to have the most ideal pH (6.1−6.5) for the growth of ginger based on literature, which reported a preferred pH range 6.0−7.0 (*13*). A low percentage (>0.2%) of nitrogen was indicated for soil types of all plots; phosphate levels ranged from low to medium (>60−100 ppm), while potash ranged from low to high (>140 to < 225 ppm), indicating varying natural fertility for the different plots.

In summary, the most appropriate time to harvest ginger in Jamaica varies with locality. This will ultimately depend on whether farmers or manufacturers are more interested in oleoresin yields or quality (pungent bioactive principles), since yield and quality were never simultaneously high in the samples investigated. Whereas Bourbon may prove to be the most ideal location for harvesting ginger at 8 months for maximum oleoresin yields and 9 months for extracts of high quality, the Johnson Mountain location should not be ignored. The consistent quality of extracts from the latter location throughout the maturation period (7−9 months) could also allow for a longer harvesting period, thus ensuring maximum returns for farmers and manufacturers alike.

A combination of factors including rainfall, altitude, and complex soil profiles appear to govern the overall yields of oleoresin and pungent principles. It is however recommended that the study be repeated over several (at least, but not limited to three) crop cycles for sounder results. A more detailed study of the relationship between the contents of oleoresins, pungent bioactive principles, and parameters such as rainfall, altitude, soil types, and also temperature should be conducted to further strengthen the results.

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