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Extraction, Processing, and Storage Effects on Curcuminoids and Oleoresin Yields from *Curcuma longa* L. Grown in Jamaica

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Aromatic diarylheptanoid compounds from *Curcuma longa* Linn grown in Jamaica were quantified by UV–vis spectrophotometry and high-performance liquid chromatographic (HPLC) analyses. The oleoresin yields from ethanolic extracts were quantified and evaluated with regard to the effects of the type of postharvesting process and the type of extraction method conducted on the plant material. Fresh samples that were hot solvent extracted provided the highest oleoresin yields of 15.7% ± 0.4 ($n = 3$), and the lowest oleoresin yields of 7.8% ± 0.2 ($n = 3$) were from the dried milled samples that were cold solvent extracted. Data from the ASTA spectrophotometer assay confirmed that dried samples contained the highest curcuminoid content of 55.5% ± 2.2 ($n = 6$) at the fifth month of storage, and the fresh samples showed a curcuminoid content of 47.1% ± 6.4 ($n = 6$) at the third month of storage. A modified HPLC analysis was used to quantify curcumin content. Data from the HPLC analysis confirmed that the dried treated, hot extracted, room temperature stored samples had the highest curcumin content of 24.3%. A novel high-performance thin layer chromatography (HPTLC) method provided a chemical fingerprint of the *C. longa* with the use of a commercial curcumin standard.

KEYWORDS: *Curcuma longa*; curcumin; curcuminoids; extraction; Jamaican spice; postharvesting; stability testing; storage; turmeric grown in Jamaica

INTRODUCTION

Many research studies have been conducted on *Curcuma longa* L. (turmeric), in particular with regard to its secondary metabolites as sources of antioxidants (*1*). However, there is no recorded data pertaining to the abundance and quality of curcuminoids from the turmeric grown in Jamaica. On the basis of emerging scientific data on turmeric from various parts of the Indian subcontinent with regard to its therapeutic values (*2*), we have decided to establish oleoresin yields and the chemical fingerprints for the turmeric grown in Jamaica. The aforementioned paucity in the literature is resolved as a result of the data generated from this research work performed on the turmeric grown in Jamaica.

C. longa L. is a perennial rhizomatous erect herb from the Zingiberaceae family that belongs to the class Monocotyledons (*3*). Most of the available turmeric in Jamaica is wild grown and is not cultivated as much as its spicy counterpart, ginger. The main turmeric-growing parishes in Jamaica are Clarendon, Hanover, St. Ann, St. James, and Westmoreland (*4*). Systematic research has revealed a wide range of pharmacological applications for *C. longa* (*5*). Some of the therapeutically active compounds in the oleoresin extracted from the rhizomes of *C. longa* are called curcuminoids. Curcuminoids are inherent compounds of the species *C. longa* and are responsible for the antioxidant activity of the oleoresin (*1*).

There are three main compounds of this pigmented curcuminoid complex, namely, curcumin [(*E*,*E*)-1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione], demethoxycurcumin [feruloyl(4-hydroxycinnamoyul)methane], and bisdemethoxycurcumin or bis(4-hydroxylcinnamoyl)methane (**Figure 1**). Curcumin ($C_{21}H_{20}O_6$) constitutes 50–60% of the curcuminoids found in *C. longa*. In addition to the curcuminoids, there are essential oils containing monocyclic monoterpenes, sesquiterpene (bisabolanes and germacranes), arabinogalactans (ukonan), and *ar*-turmerone (*6*).

The confluence of healthy living and eating has been the impetus for the scientific disciplines of functional foods and nutraceuticals (*7*). Although there have been many characterization studies of the turmeric rhizome (*2*), there is still uncertainty with regard to the effects of extracting freshly processed rhizomes versus dried milled rhizomes on the quantity and quality of their oleoresins. The phenolic secondary metabolites, curcumi-

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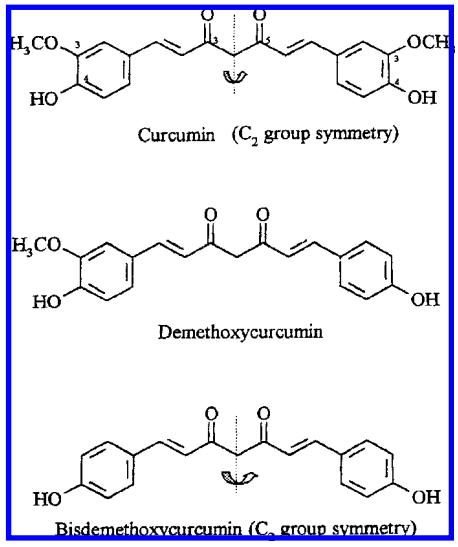

Figure 1. Three curcuminoid structures.

noids, play an important role in the quality of turmeric-containing foods because they affect the organoleptic traits of the foods in terms of aroma, flavor, and taste. The stability of curcuminoids, their biosynthesis, and degradation are influential to food quality. In terms of biosynthesis, one of the key enzymes, phenylalanine ammonia-lyase, can be induced by different environmental stress conditions (*8*). Appropriate postharvesting processing of the rhizome can sustain phenolic quality of plant material (*8*).

The aim of this research is to examine the effects of two different postharvest technologies on the quality and quantity of turmeric extracts. It must be emphasized that the postharvesting technology conducted in this research should not be mistaken for the conventional postharvesting treatment (PHT) of turmeric (a cultural farming practice), which involves curing of the rhizomes (*9*). The first postharvesting technology (PHT1) produced freshly processed rhizomes, which involved washing and slicing of freshly harvested rhizomes. The second postharvesting technology (PHT2) produced dried milled rhizomes, which involved washing, steam drying, and milling of the rhizomes. Along with the investigation of the effects of different PHTs on the extract quality, there was also the examination of the stability of the extract under different storage conditions over a period of time. From this research, the postharvesting conditions that promoted the best quality and quantity of oleoresin yields were confirmed. The stability of plant extracts is vital in the health food industry, in particular, to the functional foods and nutraceutical industries (*10*). These novel scientific findings will no doubt build leverage for the turmeric grown in Jamaica in the marketplace, benefiting the various Jamaican spice houses and commercial exporters of the spice.

MATERIALS AND METHODS

Chemicals. Commercial curcumin standard was purchased from Sigma-Aldrich (St. Louis, MO). Reagent grade ammonium molybdate was purchased from British Drug Houses Ltd., Poole, U.K. The 95% ethanol was purchased from Pharmco-AAper (Shelbyville, KY). HPLC grade glacial acetic acid, isopropanol, chloroform, and methanol, reagent grade acetone, ethyl acetate, hexane, sulfuric acid, toluene, and Fisherbrand 25 mm 0.45 μm nylon syringe filters were purchased from Fisher Scientific (Fair Lawn, NJ). Whatman no. 1 filter paper was purchased from Whatman International Ltd., Maidstone, U.K.

Materials. Turmeric rhizomes were collected from the town of Alston in the parish of Clarendon in Jamaica for the storage study, whereas samples for HPTLC analyses were collected from the parish of Westmoreland.

Postharvesting Technology. There were two postharvesting technologies. Within 24 h of harvesting the rhizomes, the debris and soil were removed from the rhizomes by washing. One half portion of the washed rhizomes was sliced with a mechanical pilot plant slicer; this was PHT1. The second half portion was dried in an air convection dryer at 65 °C and ground in an industrial particle reducer mill; this was PHT2.

Moisture Content Determination. For the purposes of quality control, the moisture contents of the fresh and dried milled rhizomes were determined by a gravimetric method. Freshly sliced rhizomes and dried milled turmeric were both prepared in triplicate portions of 2.5 g and were oven-dried at 70 °C until constant weight was achieved for both the fresh set and the dried milled set. The percentage moisture content was determined and expressed as percentage (w/w). It has been taken into account that the oven temperature set at 70 °C will result in the evaporation of water as well as some volatile compounds within the matrices for both fresh plant material and dried milled material.

Cold Solvent Extraction. From the PHT1 material, 200 g of freshly sliced rhizomes was weighed and blended with 500 mL of 95% ethanol in a stainless steel blender. After the rhizomes were blended, they were quantitatively transferred into a 2 L conical flask with an additional aliquot of 200 mL of ethanol. The conical flask was covered with aluminum foil to minimize solvent loss through evaporation. The mixture was then placed on a magnetic stirrer and extracted for 6 h. When the extraction was completed, the extract was filtered by gravity. The residue obtained from the filtration was re-extracted with 300 mL of ethanol for 2 h. Both filtrates were pooled together and concentrated *in vacuo* using a rotary evaporator in a water bath set at 50 °C. The oleoresin obtained was quantified, and the yield was calculated as percentage (w/w).

From the PHT2 material, a 50 g portion of the dried milled turmeric was weighed in a 2 L conical flask and 700 mL of 95% ethanol added. The same extraction protocol for the fresh samples was applied to the dried turmeric sample. Extractions for both fresh and dried turmeric were conducted in triplicate.

Hot Solvent Extraction. From the PHT1 material, freshly sliced rhizomes (200 g) were weighed and blended with 500 mL of 95% ethanol in a stainless steel blender. After the rhizomes were blended, they were quantitatively transferred into a 2 L round-bottom flask with an additional 200 mL of ethanol. A condenser was fitted to the round-bottom flask to prevent solvent loss. The round-bottom flask with the condenser was submerged into a water bath, which was set at 80 °C. The mixture in the round-bottom flask was refluxed for 6 h. Upon completion of the extraction, the solution was vacuum filtered and the residue re-extracted for 2 h with 300 mL of ethanol. Both filtrates were pooled together and then concentrated to an oleoresin using a rotary evaporator *in vacuo*.

From the PHT2 material, 50 g of dried milled turmeric was weighed in a 2 L round-bottom flask and 700 mL of 95% ethanol added. A condenser was fitted to the round-bottom flask to prevent solvent loss. The round-bottom flask with the condenser was submerged into a water bath, which was set at a temperature of 80 °C and refluxed for 6 h. Upon completion of the extraction, the solution was vacuum filtered and the residue re-extracted for 2 h with 300 mL of ethanol. The filtrates were pooled together and then concentrated to an oleoresin using a rotary evaporator in a water bath set at 50 °C. The oleoresin yields were determined as percentages (w/w). All extractions were conducted in triplicate.

Storage Conditions. There were two storage conditions prepared for the oleoresins (extracted above) for stability testing over a 10 month period. Due to certain stipulations such as laboratory conditions and refrigerator temperature, these two storage conditions were chosen for the experimental design. The first storage condition was arranged at room temperature (27 °C) with a relative humidity of 55–65%; half portions of the fresh cold, fresh hot extracted, dried cold, and dried hot extracted samples were stored in this first storage condition. The second storage condition was arranged at a low temperature in the refrigerator, set at 4 °C, where the other half portions of the fresh cold, fresh hot extracted, dried cold, and dried hot extracted samples were stored.

ASTA Spectrophotometer Analysis. A modified version of the American Spice Trade Association (ASTA) analytical 18.0 spectrophotometer method (*11*) was used to measure curcuminoid content of the storage-treated oleoresins over a 10 month period. With the aid of an analytical balance, 0.03 g of the treated oleoresin sample was

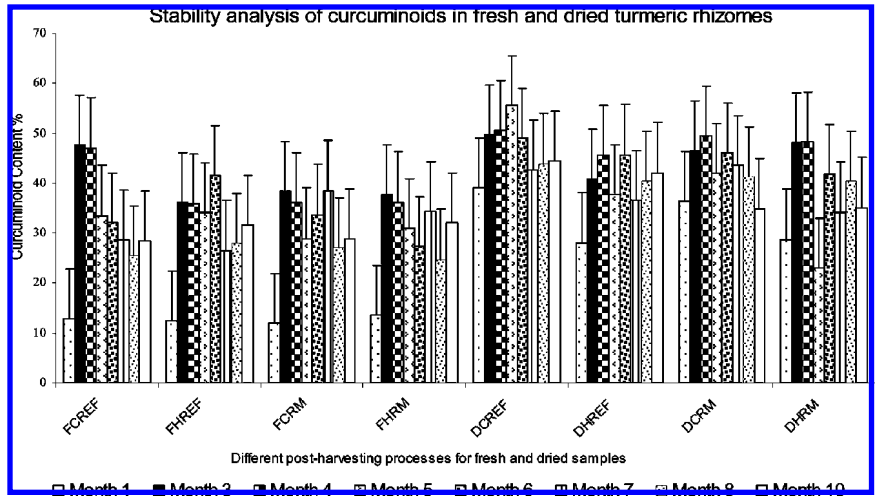

Figure 2. Stability analysis of curcuminoids in fresh and dried turmeric rhizomes. FCREF, fresh cold extracted, refrigerated; FHREF, fresh hot extracted, refrigerated; FCRM, fresh cold extracted, room temperature; FHRM, fresh hot extracted, room temperature. The symbols for the dried samples are in accord with the fresh samples.

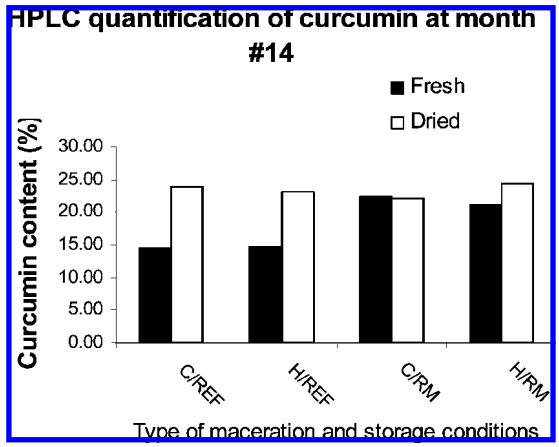

Figure 3. Dried and freshly processed rhizomes quantified for curcumin content at the 14th month of storage analyzed via HPLC analysis.

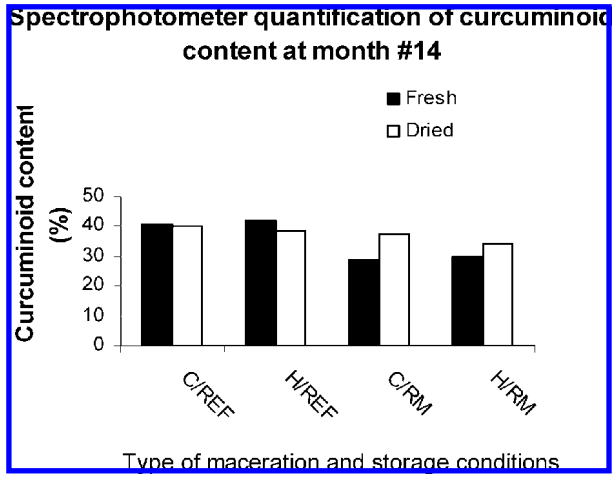

Figure 4. Dried and freshly processed rhizomes quantified for curcuminoid content at the 14th month of storage analyzed by UV–vis spectrophotometer.

weighed accurately and dissolved in 100 mL of reagent grade acetone. From this stock, a 0.1 mL aliquot was removed and transferred to a 10 mL volumetric flask and made up to 10 mL with reagent grade acetone. A commercial curcumin standard was prepared in the same manner as the oleoresin samples. The screening samples and the standard were both transferred into silica cuvettes and introduced into a Spectronic

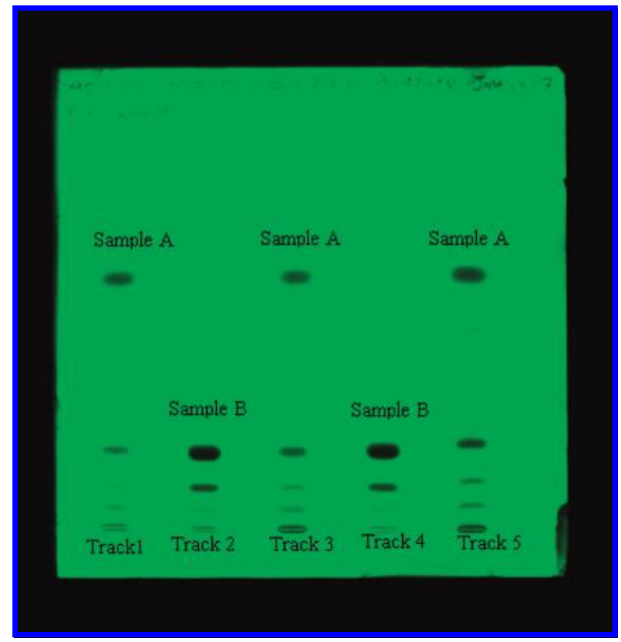

Figure 5. Ammonium molybdate/H_2SO_4 spray reagent, 254 nm.

Genesys 2 (Milton Roy) spectrophotometer, which was set at a UV range of 415−425 nm. The spectrophotometer was zeroed automatically with acetone. This analysis was repeated each month to monitor the stability of the extract. Due to circumstances beyond our control, no data were recorded for the second and ninth months of storage.

HPLC Quantification of Curcumin. A modified version of the HPLC quantification of curcumin from Amsar Private Limited (*12*) was used to quantify the curcumin levels of the stored oleoresins. The HPLC analysis was performed using a Hewlett-Packard (HP) 1050 series, which included an integration of several modules. The modules included ChemStation software, a quaternary pump with a solvent module 1050 (HP), a carousel autosampler, a column compartment, and an ultraviolet (UV)−vis detector 1050 (HP). An Agilent Lichrosphere reversed phase RP C18 250 × 4 mm i.d. column was used for separation of the curcuminoids. A mobile phase consisting of methanol, isopropyl alcohol, water. and acetic acid in the proportions 20:4:27:48:5 v/v was used for elution. The mobile phase was degassed and filtered. There was a flow rate of 0.5 mL min^{-1}. The sample and the standards were injected with a volume of 20 μL each. The isocratic elution was monitored at a wavelength of 420 nm. Oleoresin samples were accurately weighed to 0.05 g and dissolved in 100 mL of HPLC-grade methanol. These samples were filtered through a 0.45 μm nylon syringe filter and transferred into HPLC

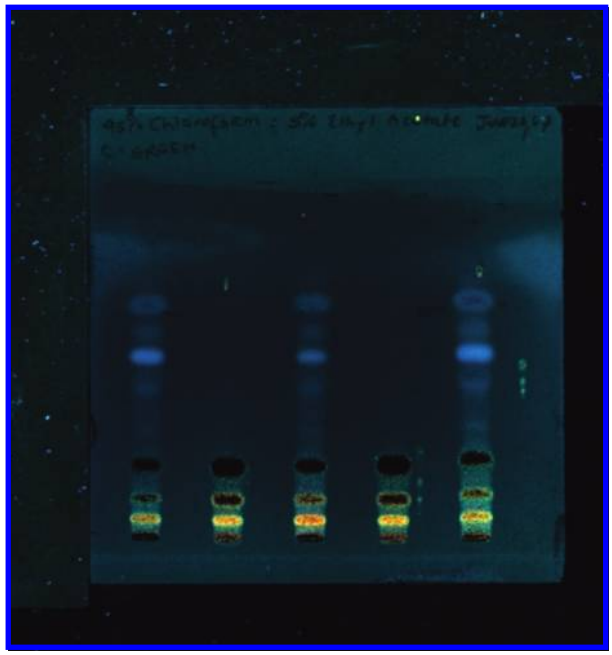

Figure 6. Ammonium molybdate/H_2SO_4 spray reagent, 366 nm.

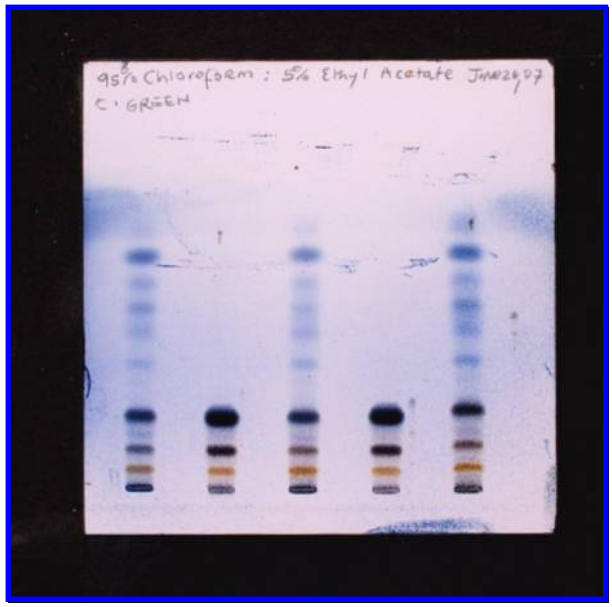

Figure 7. Ammonium molybdate/H_2SO_4 spray reagent, white light.

autosampler vials. The commercial curcumin standard was prepared in the same manner as the oleoresin samples.

The screening samples and the standard were eluted for separation with a run time of 25 min for peak identification. The HPLC analysis was performed once, at the 14th month of storage. The determination of the curcumin content involved the calculations of the concentrations of the standard with the concentration of the sample, the percent purity of the commercial curcumin standard, and the peak areas of the curcumin and the marker compound. The content of the curcumin was expressed as percentage of curcumin.

HPTLC Profiles. A new HPTLC method was developed to identify and authenticate the turmeric grown in Jamaica. The HPTLC equipment was an integrated system outfitted with several modules that interfaced with each other to employ planar chromatographic principles. There was a Camag Linomat 5 automated sample applicator for bandwise sample application. A Camag Reprostar 3, which is a digital camera with three illumination modes, at 254 nm (short wavelength UV-direct), 366 nm (long wavelength UV-direct), and white light (direct), was used for detection purposes. There was desktop WinCats software for documentation, for setting parameters for sample application, and for

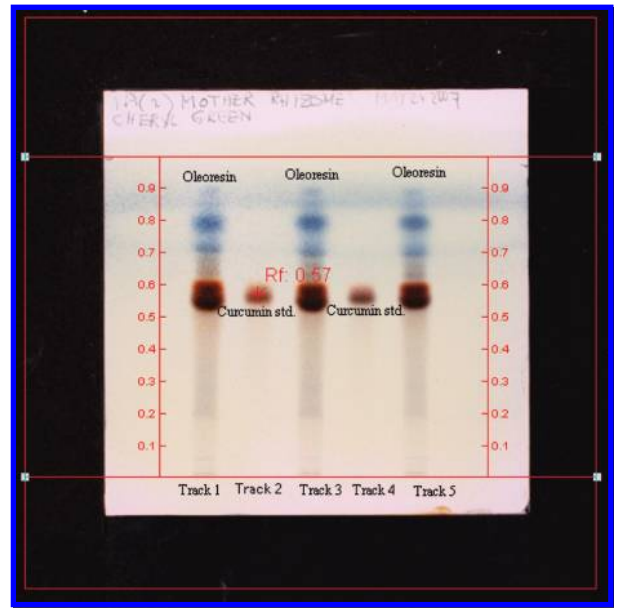

Figure 8. Ammonium molybdate/H_2SO_4 spray reagent, white light. Annotated with a R_f value of 0.57 for a curcumin standard.

retrieval of documents and scanned images. In the preparation of the sample, 0.15 g of turmeric oleoresin was weighed, and 30 mL of ethanol was added to it to give a concentration of 5 mg/mL. In the preparation of the standard 0.15 g of commercial curcumin was weighed and 30 mL of ethanol was added to it to give a concentration of 5 mg/mL of the standard. In the preparation of the ammonium molybdate/sulfuric acid spray reagent, 5% ammonium molybdate was prepared in a 10% aqueous sulfuric acid (H_2SO_4) solution. This solution was carefully transferred into a Camag spray reagent conical flask affixed with a rubber bulb for spraying. The mobile phase was prepared by mixing chloroform and ethyl acetate in the proportional ratio 95:5 (v/v) at a total volume of 10 mL.

R_f values may vary due to certain conditions such as saturation conditions in the developing chamber, the absorbent layer used, and the kind of mobile phase used. To obtain reproducible R_f values, the conditions must be standardized (*13*).

The stationary phase used was HPTLC 10 × 10 cm nanosilica gel 60 F 254 plates. The sample and the standard were both evenly applied on the plate with a total volume of 5 μL at a bandwidth of 5 mm. There were a total of five tracks ordered from left to right on the plate. The plate was developed in a Camag 10 × 10 chamber saturated with the mobile phase for about 20 min. The developed plate was evaluated under UV 254 nm, 366 nm, and white light. The plate was sprayed with ammonium molybdate/H_2SO_4 spray reagent under a fume hood. The sprayed plate was examined under UV 254 nm, 366 nm, and white light. Scanned images from both the developed and sprayed plates were captured using the Reprostar 3 (**Figures 5–8**). **Figure 8** shows a plate that was developed in a mobile phase consisting of isopropanol, hexane, toluene, and water in the proportional ratio 2:4:2:0.2 (v/v).

Statistical Analysis. Data for oleoresin yields were expressed as percentage (w/w). Data for curcumin and curcuminoid content were expressed as percentage. The extractions of oleoresins were done in triplicate, and hence the mean values, standard deviations, and standard errors (SE) were calculated accordingly with Microsoft 2003 version Excel application. There were six replicate determinations for the spectrophotometry analysis for the eight treated samples. From a single-factor analysis of variance (ANOVA) furnished with degrees of freedom, the sum of squares, and variance, significant differences for the variations in the curcuminoid levels and the oleoresin yields were computed at $p \leq 0.05$. The HPLC analysis was comprised one set of data points, expressed in a bar graph.

RESULTS AND DISCUSSION

Moisture Content Determination. It was observed that approximately 5 g of fresh turmeric yields 1 g of dried milled

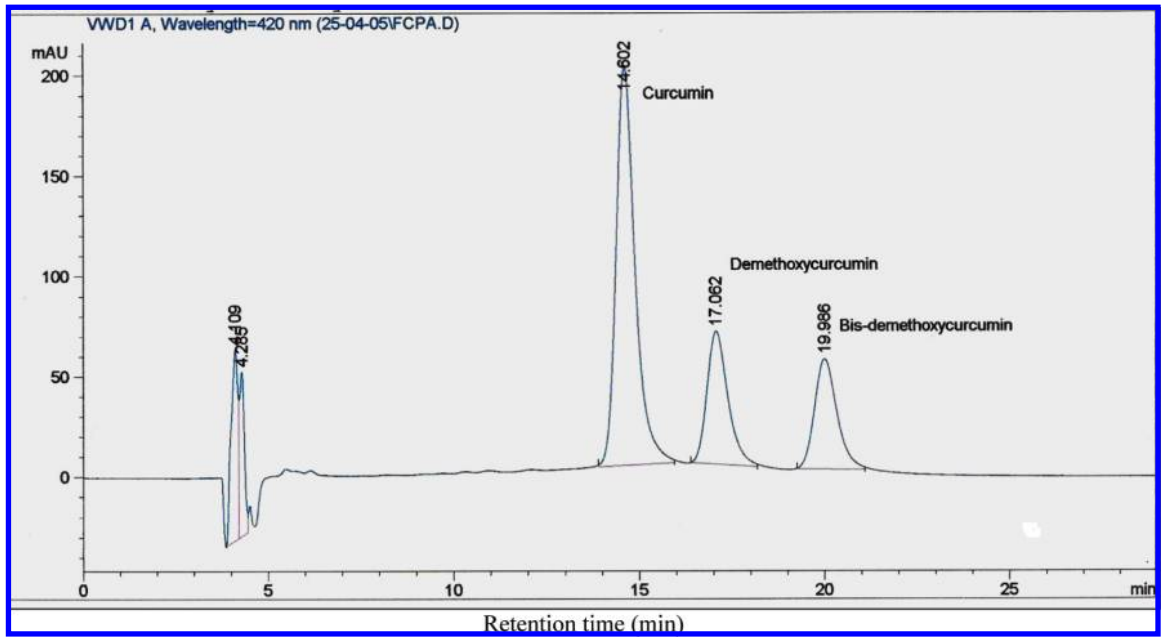

Figure 9. Representative chromatogram depicting the three curcuminoid polyphenolic compounds from turmeric grown in Jamaica.

Table 1. Mean Percentage Moisture Content for Fresh and Dried Plant Material from *Curcuma longa* Rhizomes

sample	mean yield[a] ± SE (%)
fresh sliced rhizomes	82.1 ± 0.1
dried milled rhizomes	3.7 ± 0.2

[a] Mean values represent three replicates.

Table 2. Mean Percentage Oleoresin Yields for Various Extract Preparations of *Curcuma longa* Rhizomes

sample	mean yield[a] ± SE (%, w/w)
fresh pureed hot extracted rhizomes	2.8 [15.7][b] ± 0.4
fresh pureed cold extracted rhizomes	2.8 [15.3] ± 0.8
dried milled hot extracted rhizomes	12.4 [12.9] ± 0.2
dried milled cold extracted rhizomes	7.4 [7.8] ± 0.2

[a] Mean values represent three replicates. [b] Adjusted percentages due to moisture content variations between dried and fresh samples are given in brackets.

turmeric. The mean percentage moisture content for the fresh rhizomes was determined to be 82.1 ± 0.1% (n = 3), and for the dried milled plant material, it was 3.7 ± 0.2% (n = 3) (**Table 1**). As a result of the determination of the moisture content for the fresh and dried samples, the percentage oleoresin yields for fresh and dried plant material were adjusted accordingly. See **Table 2** for the adjusted oleoresin yields.

Effects of Different Postharvesting Technologies and Different Extraction Modes on the Percentage Oleoresin Yields. The oleoresin yields were routinely higher in the fresh rhizomes rather than the dried rhizomes, see **Table 2**. Thus, the values of 15.7 ± 0.6 and 15.3 ± 1.4% (n = 3) were obtained from the fresh blended hot and the fresh blended cold extracted rhizomes, respectively. The lowest oleoresin yield, 7.8 ± 0.3%, was from the dried milled, cold extracted rhizomes. The dried milled hot extracted rhizomes had a value of 12.9 ± 0.4%. For the dried samples the use of the hot extraction was considerably more effective than the use of the cold extraction method; this was significant at p = 0.0004. For the fresh samples there was no significant difference between the hot extracted or cold extracted samples. There was a marked difference between fresh cold extracted and dried cold extracted samples, with higher yields found in the fresh cold extracted batch with a p value of 0.004. There was a significant difference between fresh hot extracted and dried hot extracted samples, with higher yields found for the fresh hot extracted batch with a p value of 0.014 (**Table 2**). According to the literature, solvent extraction of comminuted rhizomes gave yields of about 7–15% oleoresin (*9*). The turmeric grown in Jamaica contains oleoresin yields as high as 15.7 ± 0.6% from the fresh rhizomes and 12.8 ± 0.4% from the dried milled rhizome.

Analysis of Curcuminoid Variations on a Monthly Basis. There were a total of eight differently treated oleoresin samples that were screened for curcuminoid content via spectrophotometer. Data from the spectrophotometer analysis conveyed an overall loss of curcuminoid content over time (**Figure 2**). After 5 months of storage, the highest retention of curcuminoids was 55.5 ± 2.2% (n = 6) from the dried oleoresins. After 10 months of storage, the retention of curcuminoids had fallen to 44.4%. At the 14th month of storage, the curcuminoid levels fell even more to 40.4% for the same dried oleoresin batch, as is depicted in **Figure 4**. It must be noted that the first four highest overall yields of curcuminoid content for the storage study were from the same sample batch, the dried treated, cold extracted, and refrigerated. They ranged from the highest values of 55.5 ± 2.2% (n = 6) occurring in the fifth month of storage, to 50.5 ± 2.2% in the fourth month of storage, to 49.7 ± 2.1% in the third month of storage, and to 49.4% ± 1.3 in the fourth month of storage. The sample that ensued the dried cold, extracted, refrigerated batch, was the dried, cold extracted, room temperature sample, with 48.9 ± 2.4% curcuminoid content occurring in the sixth month of storage. The highest yields of curcuminoid content of 47.7 ± 6.4% from the freshly processed samples originated from the batch that was cold extracted and refrigerated occurring in the third month of storage, followed by 47.1 ± 3.3% for the same sample batch occurring in the fourth month of storage. The lowest curcuminoid content was evidenced in the freshly blended, cold extracted, room temperature samples in the first month of the storage study, with a curcuminoid content of 11.8 ± 0.7% in **Figure 2**. The first month of storage showed an overall low curcuminoid yield for all eight samples (for both fresh and dried extracts). This unexpectedly low reading has been observed previously in other in-house pre-

liminary tests. This unexplained initial low reading requires further investigation to decipher the mechanism of action occurring in the crude extract subsequent to extraction.

Analysis of the Curcuminoid Variations between Dried and Fresh Samples. The mean range for the top five highest curcuminoid contents from the dried samples was 56–48%, whereas the mean range for the top five highest curcuminoid contents from the fresh samples was 47–38%, emphasizing that the dried samples possessed curcuminoid levels which were consistently higher than that of the fresh samples with a p value of 0.008 (**Figure 2**). These findings supported what was reported in the literature. In the literature one particular study required that the dried rhizomes undergo a dehydration process followed by a heat treatment, which further lowered the moisture content of the rhizomes. Both the dried treated rhizomes and the fresh rhizomes were tested for curcuminoid pigmentation. The dried treated samples gave higher levels of curcuminoid pigments in contrast to that from the fresh turmeric (*14*).

Analysis of the Curcuminoid Variations between Hot and Cold Extractions. The variations in curcminoid levels between hot and cold extracted turmeric rhizomes were rendered as follows. The difference between the two extracted methods for fresh samples that were room temperature stored was not significant, with a p value of 0.84. In the case of the fresh samples that were refrigerated, the difference between the cold and hot extracted samples was not significant, with a p value of 0.762 (**Figure 2**). The dried, room temperature samples that were cold and hot extracted had no marked difference. However, there was a significant difference between the two extracted methods for dried samples that were refrigerated, with a p value of 0.02. From this assessment for the dried samples, the cold extracted method gave favorably higher curcuminoid yields in contrast to the hot extracted samples (**Figure 2**).

Analysis of the Curcuminoid Variations between Room Temperature and Refrigerated Storage Conditions. The variations in curcminoid levels in regard to the two storage conditions were rendered as follows. There was no difference between the two storage conditions (room temperature and refrigerated temperature) for fresh samples that were cold extracted, with a p value of 0.766. In the case of the fresh samples that were hot extracted, the difference between the two storage conditions was also considered to be not significant, with a p value of 0.792. There was no significant difference between the two storage conditions for dried samples that were cold extracted, with a p value of 0.12. In the case of the dried samples that were hot extracted, there was also an inconsequential difference between the two storage conditions, with a p value of 0.571. All of the p values in all cases indicated that storage conditions did not affect curcuminoid levels (**Figure 2**).

HPLC Quantification of Curcumin. HPLC analysis at the 14th month of storage indicated that the highest curcumin content was evidenced in the dried treated, hot extracted, room temperature stored samples. The lowest curcumin content was found in the fresh, cold extracted, refrigerated samples in **Figure 3**. The HPLC chromatograms for the three coloring principles from the turmeric oleoresin are shown in **Figure 9**.

In the literature a study was conducted to evaluate variation of curcuminoids in *C. longa*. From that study the curcumin content from the ethanolic extract was determined to be 8–16% (*15*). The work conducted in this research on ethanolic extracts from turmeric grown in Jamaica had results for curcumin content ranging from 14 to 24% (see **Figure 3**).

Comparison of Data from HPLC and Spectrophotometer Quantification of Curcumin and Curcuminoids. The light absorbance difference between HPLC and spectrophotometer is apparent. The data from the spectrophotometer gave higher percentage readings than the readings from the HPLC analysis (**Figures 3** and **4**). These differences are based on the techniques used for measurement. In the case of the HPLC, there is separation of the components within the analyte prior to the actual light absorbance measurement for each separated component. Light measurement for HPLC is selective for each component passing through the stationary phase column and traveling toward the detector, where light measurement takes place for each component that is eluted at different retention time (*16*). For the spectrophotometer there is no such selectivity because the entire sample prepared usually in a solvent is measured as a single entity. This explains the overall higher percentage readings from the spectrophotometer method in comparison to the HPLC method, whereby one method provides a distinct and selective approach and the other does not (*16*). HPLC provides percentage concentration for curcumin and its analogues, respectively, whereas the spectrophotometer provides percentage concentration for the curcuminoid pigmented complex holistically in the screening sample (*16*).

HPTLC Chemical Fingerprinting of Jamaican Turmeric. Through the use of planar chromatography, the turmeric grown in Jamaica was authenticated with a commercial curcumin standard. Sample A was positioned at tracks 1, 3, and 5; whereas sample B was positioned at tracks 2 and 4. It is clear from the scanned images that both samples A and B have their own distinct patterns of spot distribution, as observed in **Figures 5**–**7**. The spot that is third from the top, positioned at track 3, showed a paler hue in comparison to the other corresponding spots at tracks 1 and 5. Curcumin was readily recognized when the corresponding spots from both the samples and the standard marker aligned with each other in **Figure 8**. As a result of the equally aligned corresponding spots, the R_f value of 0.57 was determined for the curcumin constituted in the turmeric oleoresin with respect to the commercial curcumin standard (see the annotated image in **Figure 8**). The newly developed HPTLC method provides a reliable fingerprint for *C. longa*, distinguishing it from other *Curcuma* species.

Postharvesting Recommendations for the Turmeric Oleoresins. The data garnered from this research showed that the oleoresin yields varied according to the type of postharvesting processes used prior to extraction and according to the type of extraction method used to extract the oleoresins. On the basis of the data, extraction from the fresh plant material produced a concomitantly larger quantity of oleoresin than that from the dried treated plant material in retort and with respect to the oleoresin yields (%, w/w) produced (see **Table 2**). According to the research results for the fresh samples, the cold extraction was equally effective as the hot extraction. This is good news for manufacturers from the standpoint of cost effectiveness, because the cold extraction requires less energy input.

Postharvesting and Shelf-Life Recommendations for Curcuminoids. The quality of the oleoresin is based on the stability of the endogenous phenolic compounds. To better understand what contributes to the phenolic quality, one must look at the mechanism of action in regard to the antioxidant activity of the curcumin and its analogues. The mechanism of action for curcumin, however, is still not fully understood. However, what is known is that the hydroxyl and methoxy groups on the benzene ring and the 1,3-diketone system seem to play a vital role as the inherent structural feature responsible for its property as an antioxidant. The role of its diketone system is to lend itself as a potent ligand for metals such as iron. Its antioxidant

activity increases when the methoxy group is in the ortho position on the phenolic ring (*19*).

There are environmental factors that are deleterious to the quality of curcuminoids such as light, moisture, and air (*17*). The reality is that deterioration begins for most crops as soon as they are harvested. Manufacturers should take precaution in processing and storing plant materials before they become unacceptably deteriorated. Deterioration is an ongoing process, and special handling is required to prevent loss of potency of the plant material (*18*).

On the basis of the data, extraction from dried plant material produced a better quality of oleoresin in contrast to the fresh plant material in retort and with respect to the amount of curcuminoid compounds that it contains. This information proves to be convenient and practical for manufacturers in terms of the ease with which to work with dried rhizomes in contrast to working with fresh rhizomes. Due to the higher moisture content in fresh materials, the fresh material is more prone to microbial infestation and hence spoilage (*18*).

The trend for both the dried and fresh turmeric samples showed that there was a direct relationship between length of time of storage and loss of curcuminoid content (which could translate into loss of quality). After 5 months of storage, the highest retention of curcuminoids of $55.5 \pm 2.2\%$ ($n = 6$) was from the dried processed extracts. The recommended length of time for storage of turmeric oleoresin is 4−6 months at 4 °C in a refrigerator. Between the 5th and 10th months, no difference was detected, with an insignificant difference at $p = 0.95$. From the data, cold extraction produced a better quality oleoresin in contrast to hot extraction in retort and with respect to curcuminoid contents (**Figure 2**). This is good news for manufacturers of the extract because the choice of cold extraction is considerably more cost-effective due to less energy input required for it in contrast to the hot extraction.

In the literature a report highlighted that a certain cultivar of turmeric was extracted under conditions similar to those used in this research. The curcuminoid compositon from that cultivar was determined using HPLC analysis. All three main curcuminoids were quantified, and the total curcuminoid concentration from the extract was 10% (whereby it was determined that there was 7.34% curcumin, 1.97% demethoxycurcumin, and 0.7% bisdemethoxycurcumin) (*20*). The HPLC analyses conducted on the turmeric grown in Jamaica gave curcumin values ranging from 15.0 to 24.0% ($n = 6$). In the literature a methanolic extract from another study gave results of 12.3% curcumin, 4.86% bisdemethoxycurcumin, and 3.62% demethoxycurcumin via HPLC analysis (*21*). Finally, with the high curcumin content associated with the turmeric grown in Jamaica, special attention should be paid to developing and utilizing the rhizome for food, condiments, and health-related applications.

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