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MICROENCAPSULATION OF GINGER (*Zingiber officinale*) EXTRACT BY SPRAY DRYING TECHNOLOGY

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Running title: **Microencapsulated ginger extract powders**

Abstract

The aim of this study was to evaluate the effect of microencapsulation of ginger (*Zingiber officinale* Roscoe) extract using maltodextrin (MD) and/or gum arabic (GA) as microencapsulation agents on its 6-gingerol content, total phenolic and antioxidant activity. Four slurries containing 95 mL/100 mL of ginger extract (2 g solids/100 mL) and 5 g/100 mL of a blend of maltodextrin:gum arabic of weight ratios (4:1, 1:4, 5:0, and 0:5 g:g) were prepared and they were separately spray dried at 160°C inlet air temperature to produce ginger extract powders. Ginger extract contained 20.6 ± 0.2 (mg/g solids) 6-gingerol, 7.7 ± 0.6 (mg/g solids) gallic acid equivalents and had an antioxidant activity of 19.9 ± 0.8 (μmol Trolox/g solids). Microencapsulation resulted in a decline in the quantity of 6-gingerol present in ginger extract regardless of the maltodextrin and gum arabic blend. Microencapsulation of ginger extract also reduced gallic acid equivalents and antioxidant activity. Ginger extract dried with maltodextrin:gum arabic (1:4 g:g) and (0:5 g:g) had larger particle size than that dried with maltodextrin:gum arabic (4:1 g:g) and (5:0 g:g). Maltodextrin:gum arabic (4:1 g:g) and (5:0 g:g) had better morphological properties than maltodextrin:gum arabic (4:1 g:g) and (5:0 g:g). Microencapsulated ginger extract powder may be used as a novel food ingredient.

Key words: maltodextrin; gum arabic; 6-gingerol; 6-shogaol

1. Introduction

Jamaican ginger (*Zingiber officinale* Roscoe, family Zingiberaceae) is a light reddish-yellow, hot, spicy underground monocotyledenous stem (rhizome) which was introduced to Jamaica from India or South East Asia in the 1500s. It has been recognized as a premier among gingers due to its quality flavour, oil content and appearance, providing the basis on which the standards of other gingers are evaluated. The rhizome is mainly cultivated in the parishes of Clarendon, Manchester, St. Ann, Hanover, Portland and St. Thomas, where climatic conditions are ideal for its growth. Planting begins in April to June of each year with harvesting occurring between December and March. It is recommended that ginger be harvested 8 to 9 months after planting so that the roots do not become fibrous and flavour development is optimal. Ginger harvested at eight months have shown high yields of oleoresin (Bailey-Shaw et al., 2008). Jamaica export of ginger continues to increase with the product being positioned in niche markets. In the United States, ginger was named one of the top twenty selling herbal supplement earning over US $1.57 million in 2011 (Blumenthal, Lindstrom, Ooyen & Lynch, 2012).

Ginger is associated with a number of health benefits which has led to its comprehensive use in a variety of commercial natural products offered in the emerging nutraceuticals and functional foods market. Medicinal properties include anticancer (Cheng, Liu, Peng, Qi & Li, 2011; Karna, et al., 2012; Shukla & Singh, 2007), antioxidant (El-Ghorab, Nauman, Anjum, Hussain & Nadeem, 2010), anti-inflammatory (Minghetti et al., 2007) and antidiabetic (Afshari et al., 2007) activities. Gingerols, paradols, shogaols and zingerones (Figure 1) are some of the known bioactive compounds present in fresh ginger, but the most important of them is 6-gingerol (Hiserodt, Franzblau & Rosen, 1998). These phenolic ketones have a range of alkyl side chains. 6-Shogaol is formed from the dehydration of 6-gingerol and is more pungent (Bhattarai, Tran &

Duke, 2001; Zancan, Marques, Petenate & Meireles, 2002; Ok & Jeong, 2012). The concentration of 6-shogoal ranges from 3 to 5 mg/g in fresh ginger extracts increasing to approximately 22 mg/g after dehydration (Ok & Jeong, 2012). Its occurrence may be used as an indicator of long time storage or thermal treatment of ginger products as its content increases with an increase in drying and extraction temperatures (Ok & Jeong, 2012). The quantity and quality of these indigenous compounds differ on the basis of factors, such as plant cultivar and genetics, soil type, growing conditions, maturity and post-harvest conditions (Pawar, Pai, Nimbalkar & Dixit, 2011).

Microencapsulation is a technique that has been utilized to protect flavor components from destructive changes and to convert flavor into a free flowing form. It is employed to preserve the stability, bioactivity and bioavailability of active components (Sansone, Mencherini, Picerno, d'Amore, Aquino & Lauro, 2011; Schweiggert, Hofmann, Reichel, Schieber & Carle, 2008). The process allows sensitive ingredients to be blended or homogenised in a solution which contains macromolecules and emulsifiers to form a stable emulsion. Encapsulating agents are used exclusively or in association with other encapsulating agents to achieve an ideal composition (Fernandes, Candido & Oliveira, 2012). Maltodextrin, gum arabic, pectin and guar gum are examples of encapsulating agents which have been utilized in the encapsulation of bioactive compounds (Ravichandran et al., 2012). Hydrolysed starch may be combined with a surface-active biopolymer, such as gum arabic which has become a popular and common spray drying ingredient due to its emulsifying properties providing excellent volatile retention during the drying process. Combinations of gum arabic and maltodextrin were found to be effective for the encapsulation of oils (Jafari, Assadpoor, He & Bhandari, 2008). Spray drying is the most widely utilized method of microencapsulation in the food and beverage industry (Gharsallaoui, Roudaut,

Chambin, Voilley & Saurel, 2007). More recent technologies include emulsion electrospraying which has the advantage of encapsulating under milder conditions and can be utilized for thermosensitive bioactives (Gomez-Mascaraque & Lopez-Rubio, 2016). Quercetin has been encapsulated utilizing Pluronic F127 poloxamers by the supercritical antisolvent technique (Fraile, Buratto, Gomez, Martin & Cocero, 2014)

There is presently limited information in the scientific literature regarding the microencapsulation of ginger extract. Hence the aim of the present study was to produce microencapsulated ginger extract using maltodextrin and/or gum arabic as encapsulation agents and to evaluate the effect of microencapsulation on the 6-gingerol content, total phenolic content and antioxidant activity of ginger extracts.

2. Materials and methods

2.1 Materials

A standard of 6-gingerol was obtained from Sigma-Aldrich, USA. Acetonitrile, acetic acid and methanol were HPLC grade and obtained from Fisher Scientific, USA. Maltodextrin with a Dextrose Equivalent of 9 to 13 was obtained from NOW Foods Company, (Bloomingdale, IL). Gum arabic was obtained from Frontier Natural Products Co-Op (Norway, IA). Water utilized for HPLC analyses was purified with a Milli-Q water system (Millipore Corp., Bedford, MA, USA).

2.2 Ginger extract

Fresh ginger (*Zingiber officinale*) rhizomes were harvested after 8 months of planting from a farm in St Ann Jamaica. The ginger (15 kg) was washed, cleaned, blotted dry, and diced at ambient temperature (25^{o}C). The diced ginger was extracted with 4.65 L of a 95 mL/100 mL

ethanol solution for 72 h, filtered and evaporated under reduced pressure at 60-65 °C to produce the ginger extract which was immediately stored at 4 °C.

2.3 Microencapsulation of Ginger Extract

Slurries containing ginger extract (20 g/L ginger solids), maltodextrin and/or gum arabic were prepared by mixing ginger extract (475 mL) and maltodextrin and/or gum arabic (25 g). The resulting slurries had a 7 g/100 mL solid content. The encapsulating agents represented 71.43 g/100 g of the total solids of the slurries. The slurries were homogenized using an ultra-shearing device (OMNI, Ultrashear M, Omni International, Kennesaw, GA) for 5 min. at 20,000 rpm. Four slurries were produced by combining 475 mL of ginger extract with a 25 g blend of maltodextrin (MD):gum arabic (GA) prepared at different weight ratios (4:1, 1:4, 5:0, 0:5 g:g) resulting in MD4GA1, MD1GA4, MD5, and GA5, respectively. Four feed mixtures were produced by combining ginger extract with a blend maltodextrin:gum arabic prepared at different weight ratios (4:1, 1:4, 5:0, 0:5 g:g) resulting in MD4GA1, MD1GA4, MD5, and GA5, respectively. The concentration of 6-gingerol, trolox and gallic acid present in the feed mixtures was 5.9 $\pm$ 0.2 mg/g of solid, 5.7 ± 0.3 µmol trolox /g of solid and 2.2 ± 0.2 mg gallic acid /g of solid, respectively. MD4GA1, MD1GA4, MD5, and GA5 were separately spray dried under co-current air flow conditions using a pilot plant scale spray dryer (FT 80 Tall form spray dryer, Armfeild Inc., Jackson, NJ). Inlet air was heated at 160 °C and was blown into the drying chamber. Slurries were atomized into the drying chamber and the outlet temperature of the spray dryer was 65 °C. Droplets were dried producing the microencapsulated samples. In total, four microencapsulated ginger extract powders were produced including spray dried MD4GA1, spray dried MD1GA4, spray dried MD5 and spray dried GA5 (DMD4GA1, DMD1GA4, DMD5 and DGA5, respectively). The resulting powders were analysed for moisture content following the

AOAC method 930.15 (AOAC, 1999). The resulting powders were stored at 4 °C until needed for analysis. The spray drying procedure was carried out in triplicate.

2.4 Determination of 6-gingerol content

Approximately, 5 mL of ginger extract were dissolved in methanol (1 mL) and centrifuged at 21480 x *g* for 5 min. The resulting supernatant (0.5 mL) was utilized for HPLC analyses. Microencapsulated samples (500 mg) were dissolved in 4 mL of 90 mL/100 mL ethanol and stirred for 30 min. Samples were centrifuged at 21480 x *g* for 5 min and 50 µL of the resulting supernatant were utilized for analyses. Analyses for 6-gingerol were performed utilizing HPLC. The HPLC system consisted of Waters (Milford, MA) 510 pumps, a 715 Ultra WISP injector, and 410 UV and 470 fluorescence detectors. A reversed phase C18 column, 25 cm × 4.6 mm diameter 5 µm Supelcosil LC-Si (Supelco, Bellefonte, PA), was used. Elution was isocratic using a mobile phase consisting of acetonitrile, water, acetic acid 500:450:50 mL:mL:mL, with a flow rate of 1.0 mL/min and a temperature of 30 °C. A Variable Wavelength Detector (VWD) at 282 nm was used to detect 6-gingerol which was identified and quantified based on the retention time of a 6-gingerol standard. The 6-gingerol content was calculated by using the standard calibration curve, $y = 639191 (X) + 33305$ ($R^2 = 0.9997$).

2.5 Microencapsulation efficiency (ME) of ginger extract

The microencapsulation efficiency (ME) of ginger extract using maltodextrin and/or gum arabic was calculated using Eq. 1:

$$ME = \frac{6\text{-gingerol in powder (mg/g solids)}}{6\text{-gingerol in slurry (mg/g solids)}} * 100 \qquad (1)$$

2.6 The 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging assay

DPPH assay was performed according to the method of Brand-Williams, Cuvelier and Berset (1995). Microencapsulated samples (500 mg) were dissolved in 4 mL of 90 mL/100 mL ethanol

and stirred for 30 min. Samples (200 µL) were reacted with 2.8 mL of DPPH for 30 min in the dark. The absorbance was recorded at wavelength 515 nm using a spectrophotometer (Spectronic™ GENESYS™ 2, Thermo Fisher Scientific, Waltham, MA). Samples were analysed in triplicate and reported as Trolox equivalents.

2.7 Total phenolic content

The total phenolic content was determined by the Folin-Ciocalteu method, adapted from Swain and Hillis (1959). Microencapsulated samples (500 mg) were dissolved in 4 mL of 90 mL/100 mL ethanol and stirred for 30 min. The samples and ginger extract (125 µL) were centrifuged at 21480 x *g* for 5 min. The resulting supernatant was then combined with distilled water (0.5 mL) and Folin-Ciocalteu reagent (0.25 mol/L, 125 µL). The mixture was allowed to react in the dark during 6 min; then, 1.25 mL of a 7 g/100 g Na_2CO_3 solution and 1 mL distilled water were added. The solution was incubated at room temperature in the dark for 1.5 h. The absorbance was measured at 760 nm using a spectrophotometer. Samples were analysed in triplicate and expressed as gallic acid equivalents.

2.8 Color of microencapsulated extract powders

The color of microencapsulated samples was measured using the chroma meter LABSCAN XE (Hunterlab, VA, USA) and reported in CIELAB colour scales L*, a*, and b* values (L* is the degree of lightness to darkness, a* is the degree of redness to greenness, and b* is the degree of yellowness to blueness). The instrument was calibrated with standardized black and white standard. The chroma and hue angle values were calculated using Equations 2 and 3, respectively (Solval, Sundararajan, Alfaro & Sathivel, 2012).

$$\text{Chroma} = [(a^*)^2 + (b^*)^2]^{1/2} \quad (2)$$

$$\text{Hue} = \tan^{-1}(b^* / a^*) \quad (3)$$

2.9 Scanning electron microscopy (SEM) and particle size distribution of microencapsulated samples

The morphology of the microencapsulated samples was evaluated utilizing a scanning electron microscope (SEM) (JSM-6610LV, JEOL Ltd. Japan). Samples were mounted on aluminium SEM stubs and coated with gold:palladium (60:40) in an Edwards S150 sputter coater. The samples were systematically observed with 1000x magnification. The particle size distribution was measured using a Microtrac S3500 system. The powdered sample was placed in a test chamber with circulating ethyl-alcohol. A 10 s ultrasound mixing at 20 W was used before each test. The sample was pumped through the cell at 40 % of the maximum flow rate. The light was scattered from three lasers from low to high angles. The whole light scatter pattern was collected and the particle size calculated using the Modified Michelson interferometer (MIE) scattering technique which measures the angular distribution of backscattered light (Solval, Sundararajan, Alfaro & Sathivel, 2012).

2.10 Data analysis

All data were analysed using SAS software version 9.2 (SAS Institute Inc., 2008). Means and standard deviations of the data were presented. Analysis of Variance (ANOVA) and Tukey's studentized range test were carried out to determined differences among treatments at the significant level of $P < 0.05$. ANOVA was used to compare the means of the variables investigated for each drying agent utilized.

3. Results and discussion

3.1 Content of 6-gingerol in ginger extract

Fresh ginger rhizome is a rich source of biologically active compounds of which gingerols are the major active components (Bhattarai, Tran & Duke, 2001). Results from this study

209 confirmed that Jamaican ginger had a greater concentration of 6-gingerol (20.6 ± 0.2 mg/g) than
210 ginger grown in different geographical locations and would therefore be considered more
211 pungent. Studies conducted in Australia have shown that fresh extracts of a cultivar known as
212 "Jamaican" ginger contained the highest level of 6-gingerol and was the most potent compared to
213 gingers extracts from different geographical regions (Wohlmuth, Leach, Smith & Myers, 2005).
214 Brazilian ginger rhizome extracts contained a total of 20.10 ± 0.10 mg/g pungent principles
215 calculated as the sum of 4-, 6-, 8- and 10-gingerol and 6-, 8-, 10-shogaols of which 6-gingerol
216 (14.1 mg/g) was the major component present (Schweiggert, Hofmann, Reichel, Schieber &
217 Carle, 2008). Fresh ginger extracts from China contained 11.5 mg/g of 6-gingerol (Cheng, Liu,
218 Peng, Qi & Li, 2011) while 6-gingerol content of ginger from India was found to range from
219 0.12 to 2.08 (mg/g) (Pawar, Pai, Nimbalkar & Dixit, 2011).

220 **3.2 Content of 6-gingerol in microencapsulated ginger extract**

221 In this study, ginger extract was microencapsulated with maltodextrin and gum arabic using
222 spray drying technology. Gingerols are stable at a pH range from 1 to 7 at 37 °C but start to
223 degrade at temperatures of 60 °C and above (Cheng, Liu, Peng, Qi & Li, 2011). In aqueous
224 solution, 6-gingerol shows maximum stability at pH 4 and at 37 °C (Bhattarai, Tran & Duke,
225 2001; Young, Chiang, Huang, Pan & Chen, 2002). Also, it has been reported that ginger extracts
226 stored at 4 °C or room temperature over a period of 5-6 months have not shown any significant
227 variation in the concentration of 6-gingerol and 8-gingerol present (Salmon, Bailey-Shaw,
228 Hibbert, Green, Smith & Williams, 2012; Wohlmuth, Leach, Smith & Myers, 2005).

229 Gingerols are thermally labile due to the presence of a β-hydroxyl ketone group in their
230 structure (Bhattarai, Tran & Duke, 2001). They undergo dehydration-hydration transformations

with shogoals and exhibit novel reversible kinetics (Bhattarai, Tran & Duke, 2001) which may account for the occurrence of the 6-gingerol peak as a doublet in the HPLC profile (Figure 2). At high temperatures gingerols are converted to 6, 8, and 10-shogaol (Wohlmuth, Leach, Smith & Myers, 2005; Zhang, Iwaoka, Huang, Nakamoto & Wong, 1994). An increase in the levels of shogaol, specifically 6-shogaol, has been associated with improved anticancer activity which may be due to its α- and β-unsaturated ketone moiety (Cheng, Liu, Peng, Qi & Li, 2011). In a study conducted by Schweiggert, Hofmann, Reichel, Schieber and Carle (2008), spray drying resulted in a 45 % decline in the pungent principles of ginger which was attributed to the high temperatures utilized in the drying chamber.

The concentration of 6-gingerol present in the feed (mixture of the drying agents and ginger extract) was 5.9 $\pm$ 0.2 mg/g for all blends of maltodextrin and gum arabic. It reduced to the range of 2.0-2.4 mg/g extract during spray drying regardless of the maltodextrin and gum arabic blend used to microencapsulate the ginger extract (Table 1). The maltodextrin and gum arabic and their blends used as microencapsulation agents for ginger extract were not different in terms of microencapsulation efficiency (protection) of 6-gingerol against degradation during the microencapsulation process with percentage recoveries of 33 – 40 %.

According to Krishnan, Bhosale and Singhal (2005) gum arabic is a very effective microencapsulation agent because it can produce stable emulsions over a wide pH range. Also, gum arabic is compatible with a wide variety of gums, starches, carbohydrates and proteins (Carneiro, Tonon, Grosso & Hubinger, 2013; Tomas-Navarro, Vallejo, Borrego & Tomas-Barberan, 2014). On the other hand, maltodextrins are also good carrier agents (drying agents); however, they have less emulsifying ability (capacity). Therefore, they may show marginal retention of volatile compounds. Maltodextrins as carrier agents have the advantage of being

bland in flavor, relatively inexpensive, having low viscosity in large quantities and provide superb protection from oxygen (Ferrari, Germer, Alvim, Vissotto, Mauricio de Aguirre & 2012; Carneiro, Tonon, Grosso & Hubinger, 2013). Oxygen barrier properties are based on the dextrose equivalent (DE) of the hydrolyzed starch. Higher-DE systems are less permeable to oxygen and result in powders with higher encapsulation efficiencies. The retention of volatiles capacity of maltodextrins is also a function of their DE (Reineccius, 1988). High DE maltodextrin has been successfully utilized in the encapsulation of orange peel oil to protect it from oxidation (Anandaraman & Reineccius 1986). However, in our study there was no significant differences in gingerols content in the microencapsulated ginger extract with either maltodextrin or gum arabic or their blends.

3.3 Moisture content of microencapsulated ginger extract

All four encapsulated ginger extract powders had similar moisture contents regardless of encapsulating agent (Table 1). The moisture content of microencapsulated samples may be affected by a number of factors which include the air flow rate, drying air temperature of the spray dryer, (Goula & Adamopoulos, 2005) and evaporation rate droplet size (Obón, Castellar, Alacid & Fernández-López, 2009, Chranioti, Chanioti, & Tzia, 2016, Noshad, Mohebbi, Koocheki & Shahidi, 2015). An increase in air flow rate and air temperature results in lower residual moisture content due to faster diffusion rates (Bhattarai, Tran & Duke, 2001). In this study, we used similar spray drying conditions for all trials, including inlet air spray drying temperature (160 °C). The spray conditions might have contributed to producing encapsulated ginger extract powders with similar moisture content.

3.4 Total phenolic content and antioxidant activity of the microencapsulated ginger extract powders

277 Fresh ginger extract contained 19.85 ± 0.26 µmol trolox /g and 7.74 ± 0.64 mg gallic acid /g.
278 This is expected since phenolic compounds are water soluble antioxidants present at high
279 concentrations in plants (Pawar, Pai, Nimbalkar & Dixit, 2011). The total phenolic content in all
280 of the microencapsulated ginger extract powders was not significantly different ($P \leq 0.05$) (Table
281 1). The results may be related to the antioxidant activity results. In this study, the antioxidant
282 activity (trolox content) of the ginger extract and microencapsulated ginger extract powders was
283 investigated using the DPPH assay. Antioxidant activity was higher in the ginger extract (19.85 ±
284 0.26 µmol trolox /g) than in the microencapsulated ginger extract powders (Table 1). However,
285 all the powders had similar trolox content, except maltodextrin:gum arabic (5:0) (Table 1). The
286 concentration of trolox present in the powders was similar, except maltodextrin:gum arabic (5:0),
287 to the feed mixtures. In our study there was no significant differences in gallic acid content
288 (phenolic compound) in the microencapsulated ginger extract with either maltodextrin or gum
289 arabic or their blends (Table 1). This study indicated that the drying agents protected phenolic
290 compounds during spray drying.

291 **3.5 Particle size and color of the microencapsulated ginger extract powders**

292 The mean particle size distribution of the microencapsulated samples ranged from 8.2 to 15.3
293 µm (Table 2). It was also observed that maltodextrin:gum arabic (1:4) and maltodextrin:gum
294 arabic (0:5) powders had a significantly ($P \leq 0.05$) higher mean particle size than those
295 microencapsulated with a higher ratio of maltodextrin. Similar findings are reported by
296 Fernandes, Candido and Oliveira (2012). Droplet size increased as the quantity of gum arabic
297 increased.

298 All of the powders had a whitish color (Table 2). However, maltodextrin:gum arabic (1:4)
299 was significantly ($P \leq 0.05$) lighter compared to the rest of the powders. Chroma values were

300 significantly ($P \leq 0.05$) higher in maltodextrin:gum arabic (4:1) and maltodextrin:gum arabic
301 (0:5) than in the other microencapsulated ginger extracts. The chroma measurement is indicative
302 of the vividness of color. Even more, maltodextrin:gum arabic (1:4) and maltodextrin:gum arabic
303 (0:5) had significantly ($P \leq 0.05$) lower Hue angle values compared to those of maltodextrin:gum
304 arabic (4:1) and maltodextrin:gum arabic (5:0). Hue angle describes color based on a circle, a
305 hue angle of 0°, 90°, 120°, and 240° indicates a red, yellow, green, and blue color, respectively.
306 Powders containing higher amounts of maltodextrin had stronger yellow color.

307 **3.6 SEM analysis of the microencapsulated ginger extract powders**

308 It was observed under scanning electron microscopy that maltodextrin:gum arabic (4:1) and
309 maltodextrin:gum arabic (5:0) had the most uniform shapes and appeared more spherical than the
310 other samples. Samples with higher levels of gum arabic (maltodextrin:gum arabic (1:4) and
311 (maltodextrin:gum arabic (0:5)) had evidence of more denting with some broken and incomplete
312 particles (Figure 3). Denting is a common feature of particles as they inflate at high
313 temperatures and break upon evaporation (Solval, Sundararajan, Alfaro & Sathivel, 2012). It is
314 influenced by drying speed, the mechanism of water removal and the type of microencapsulating
315 agent utilized for spray drying process (Kagami, Sugimura, Fujishima, Matsuda, Kometani &
316 Matsumura, 2006). Low drying air velocity tends to more dent formation. According to
317 Krishnan, Bhosale and Singhal (2005), microcapsules containing gum arabic may show dents at
318 the surface which are signs of shrinkage. It is desired that bioactive microcapsules have uniform
319 surfaces with minimum cracks or dents since that promotes protection and retention of the core
320 material. The microencapsulated bioactive is protected from degradation for longer times when
321 encapsulated in sound (minimum cracks and dents) particles. More sound particles were
322 apparent in samples microencapsulated with maltodextrin. The incorporation of carbohydrates

323 into wall systems has been shown to improve the drying properties of the wall matrix. This may
324 be due to an enhancement in the formation of a dry crust around drying droplets (Sheu &
325 Rosenberg 1995). Combinations of maltodextrin and other drying agents should be investigated
326 for process optimization.

327 **4. Conclusion**

328 The study developed microencapsulation of Jamaican ginger extract using maltodextrin
329 and/or gum arabic. Gingerols, bioactive compounds present in fresh ginger, were reduced during
330 the encapsulation. Drying agents including maltodextrin and/or gum arabic and their blends did
331 not prevent reduction of gingerols. Also, microencapsulation reduced the total phenolics content
332 and antioxidant activity of ginger extract. However, our study showed that significant amounts
333 of gingerols and phenolics were in encapsulated ginger extract. The encapsulated extract is in a
334 powder form and could be readily incorporated into food products such as tea and bread.
335
336

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List of Figures

Figure 1. Pungent compounds found in ginger.

Figure 2. HPLC chromatogram profile of fresh and microencapsulated ginger extracts. A reversed phase C18 column was eluted with a mobile phase consisting of acetonitrile, water, acetic acid 500:450:50 mL:mL:mL for the analyses.
(A) GE, (B) DMD4GA1, (C) DGA4MD1, (D) DMD5, and (E) DGA5. GE = ginger extract; MD = maltodextrin; GA = gum arabic; DMD4GA1 = microencapsulated GE with MD:GA mixed at a weight ratio of 4:1 g:g; DMD1GA4 = microencapsulated GE with MD:GA mixed at a weight ratio of 1:4 g:g; DMD5 = microencapsulated GE with MD; DGA5= microencapsulated GE with GA.

Figure 3. Scanning electron micrographs (x1000) of the microencapsulated ginger extract powders. (A) =DMD4GA1; (B) =DMD1GA4; (C) =DMD5; (D) = DGA5. Particle size distribution was measured using a Microtrac S3500 system.
GE = ginger extract; MD = maltodextrin; GA = gum arabic; DMD4GA1 = microencapsulated GE with MD:GA mixed at a weight ratio of 4:1 g:g; DMD1GA4 = microencapsulated GE with MD:GA mixed at a weight ratio of 1:4 g:g; DMD5 = microencapsulated GE with MD; DGA5= microencapsulated GE with GA.

Table 1. Moisture content, 6-gingerol, gallic acid equivalents and trolox of microencapsulated ginger extract powders

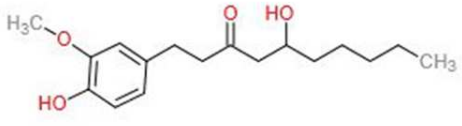
Sample	6-Gingerol (mg/g extract)	Moisture content (g/100 g powder)	Gallic acid equivalents (GAE: mg/g solid)	Trolox content (µmol/g solid)
DMD4GA1	2.4 ± 0.1[a]	3.1 ± 1.6[a]	1.9 ± 0.1[a]	5.7 ± 0.3[b]
DMD1GA4	2.0 ± 0.3[a]	8.2 ± 3.0[a]	1.8 ± 0.1[a]	5.6 ± 0.2[b]
DMD5	2.1 ± 0.2[a]	3.7 ± 2.4[a]	2.2 ± 0.2[a]	6.5 ± 0.1[a]
DGA5	2.3 ± 0.3[a]	5.3 ± 0.5[a]	2.0 ± 0.2[a]	5.9 ± 0.1[ab]

Values are means ± SD of triplicate determination. [a,b]Means with same letters in each column are not significantly different ($p<0.05$). GE = ginger extract; MD = maltodextrin; GA = gum arabic; DMD4GA1 = microencapsulated GE with MD:GA mixed at a weight ratio of 4:1 g:g, DMD1GA4 = microencapsulated GE with MD:GA mixed at a weight ratio of 1:4 g:g, DMD5 = microencapsulated GE with MD, DGA5= microencapsulated GE with GA.

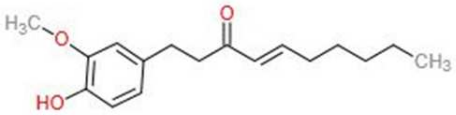
Table 2. Particle size data of microencapsulated ginger extract powders

Sample	Mean particle size per diameter (µm)	*L**	Chroma	Hue angle
DMD4GA1	8.2 ± 0.1[b]	84.1 ± 0.01[b]	8.58 ± 0.008[d]	78.8 ± 0.07[a]
DMD1GA4	15.3 ± 2.2[a]	85.0 ± 0.01[a]	10.91 ± 0.002[b]	76.5 ± 0.06[c]
DMD5	10.4 ± 0.4[b]	80.7 ± 0.01[c]	10.05 ± 0.014[c]	77.8 ± 0.05[b]
DGA5	14.3 ± 1.6[a]	79.5 ± 0.01[d]	14.55 ± 0.010[a]	74.5 ± 0.01[d]

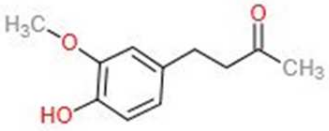
*Values are means ± SD of triplicate determination. [ab]Means with same letters in each column are not significantly different ($p<0.05$). GE = ginger extract; MD = maltodextrin; GA = gum arabic; DMD4GA1 = microencapsulated GE with MD:GA mixed at a weight ratio of 4:1 g:g; DMD1GA4 = microencapsulated GE with MD:GA mixed at a weight ratio of 1:4 g:g; DMD5 = microencapsulated GE with MD; DGA5= microencapsulated GE with GA.



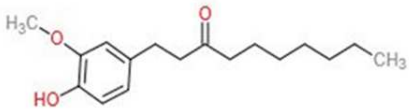
6-gingerol



6-shogaol



zingerone



6-paradol

Figure 1.

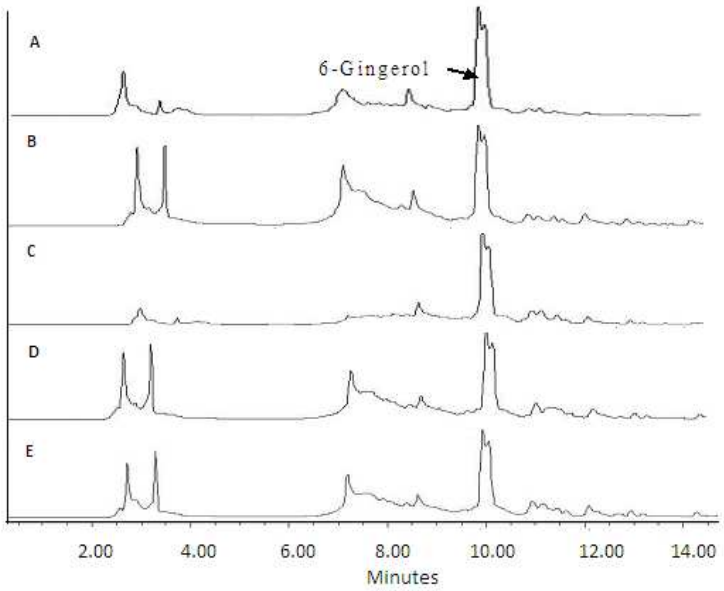


Figure 2.

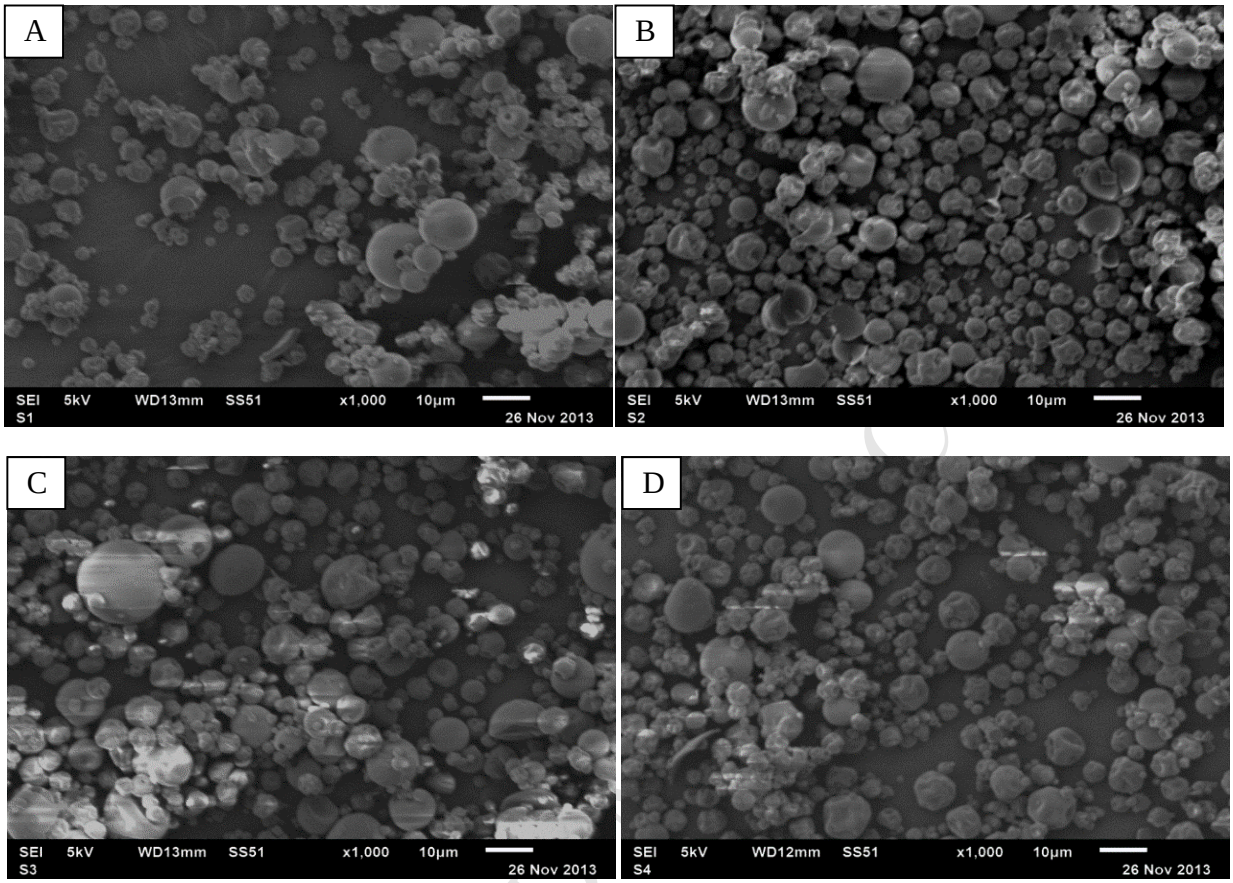


Figure 3.

- Ginger (*Zingiber officinale* Roscoe) extract (GE) contains high levels of 6-gingerol.
- Microencapsulation process can reduce the concentration of 6-gingerol in GE.
- Microencapsulation process can influnce the antioxidant activity of GE.