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SCIENTIFIC PAPER

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EFFECTS OF DRYING METHOD AND PARTICLE SIZE ON THE ANTIOXIDANT PROPERTIES OF LEAVES AND TEAS OF *Morus alba*, *Lagerstroemia speciosa* AND *Thunbergia laurifolia*

Antioxidant properties (AOP) of leaves and teas of Morus alba L., Lagerstroemia speciosa (L.) Pers. and Thunbergia laurifolia Lindl. as affected by microwave, oven and freeze drying were assessed. Total phenolic content (TPC), radical scavenging ability expressed as ascorbic acid equivalent capacity (AEAC) and ferric reducing power (FRP) were screened using the Folin--Ciocalteu, 2,2-diphenyl-1-picrylhydrazyl (DPPH) and potassium ferricyanide assays, respectively. The effects of particle size were also investigated. Microwave drying resulted in enhanced AOP in M. alba and T. laurifolia. Oven drying resulted in declined AOP in T. laurifolia, with M. alba and L. speciosa relatively unchanged. Significant increase in AOP was observed in freeze-dried leaves of M. alba with L. speciosa and T. laurifolia showing no change or slight increase. TPC, AEAC and FRP of ground microwave-, oven- and freeze-dried leaves of M. alba extracted with 50% methanol were significantly higher than shredded leaves. For tea infusions extracted with hot water, three categories were recognised, i.e., species with shredded leaves yielding stronger AOP (M. alba), species with ground leaves yielding stronger AOP (L. speciosa), and species with ground and shredded leaves yielding comparable AOP (T. laurifolia).

Keywords: antioxidant properties; leaves; teas; drying methods; particle size.

Herbal remedies are often consumed in the form of tea, an infusion of dried leaves or other plant parts, steeped in boiling water [1,2]. Herbal teas have been gaining popularity as consumers believe that they are natural, safe and can promote health and assuage illness [3]. These teas are considered an important alternative source of antioxidants in addition to fruits and vegetables [4]. They are often classified based on their therapeutic actions [5], but their use is not widely advocated by modern medicine as their modes of action and effectiveness are not evidence-based or scientifically-proven [6]. Except for herbs of the family Labiatae, the chemistry and pharmacology of many herbal tea plants are still poorly studied. Baseline information on their pharmacological properties would set the platform for more in-depth research.

Drying of fruits, vegetables and herbs remains an important method of food preservation. It reduces the moisture content of food to a level that allows safe storage over an extended period, and prevents the growth of mould and fungi and thus minimising microbial degradation [7,8]. It brings about substantial reduction in weight and volume, and in packaging, storage and transportation costs. In the production of herbal teas, the drying process may affect antioxidant properties (AOP), and nutritional and physical quality of the herbs. Drying methods can be thermal (*e.g.*, sun, oven and microwave drying) or non-thermal (*e.g.*, air and freeze drying). There is increasing interest in the development of new and more efficient drying methods. The ideal drying method would depend on the

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herbal product of interest, whether cost or quality is a priority for consumer acceptance.

Although extensive research has been conducted on AOP of teas of *Camellia sinensis*, herbal teas are much less studied with the exception of a few studies [9-10]. The effects of drying methods on AOP of herbal teas are poorly studied. In this study, AOP of leaves and teas of three species as affected by microwave, oven and freeze drying were assessed using three different antioxidant assays. Moisture loss and water activity of the various dried samples were determined. The effects of particle size on the AOP of ground and shredded tea infusions were also investigated.

EXPERIMENTAL

Species studied

The three Malaysian species studied were *Morus alba* L. (Moraceae), *Lagerstroemia speciosa* (L.) Pers. (Lythraceae) and *Thunbergia laurifolia* Lindl. (Thunbergiaceae). The locations for sampling of leaves of the species were: *L. speciosa* (Taman Connaught in Cheras, Kuala Lumpur), *M. alba* (Damansara Utama in Petaling Jaya) and *T. laurifolia* (Bandar Sri Menjalara in Kepong).

Extraction

The effects of different drying methods on AOP of leaves were assessed. Fresh leaves (1 g) were powdered with liquid nitrogen in a mortar and extracted with 50 ml of 50% aqueous methanol. Extracts were filtered under suction and stored at 4 °C for analyses which were conducted within a week of extraction. To determine the effects of particle size, AOP of extracts from ground and shredded leaves were compared. Sampled leaves were cleaned, shredded into 2 mm strips with a pasta maker (GCH Retail, Malaysia) and mixed well to minimise heterogeneity of samples.

Hot water was used to extract teas infusions. Dried leaves (0.6 g) were extracted using 100 ml of boiling water (100 °C) with continuous shaking (150 rpm) for 1 h. The boiling water was allowed to cool throughout the period to mimic tea brewing. Extracts were then filtered and stored at 4 °C for further analysis. To determine the effects of particle size, AOP of extracts from ground and shredded tea infusions were also investigated.

Drying methods

Shredded leaf samples were divided into batches and subjected to thermal treatments of microwave drying and oven drying, and non-thermal treatment of freeze drying. Microwave drying involved drying 12 g of leaves placed in the centre of the turntable of a microwave oven (Sharp R-397JS, 230-240 V, 50 Hz, Malaysia) for 1.5 min. Oven drying involved drying 15 g of leaves placed in stackable baskets inside a universal oven (Memmert UFB500, Germany) for 3 h at 50 °C with the vent restrictor flap open. Baskets were positioned in front of the fan to allow for good air circulation. Freeze drying involved drying 30 g of leaves in 500 ml Florentine flasks (Favorit, Malaysia) using a freeze dryer (Martin Christ-Alpha 1-4 LD plus, Germany) for 5 h, at less than 1.0 mbar pressure and ice condenser at -40 °C. The flasks provide uniform heat transfer from the surrounding laboratory environment with ambient temperature of 24 °C to the samples for sublimation. All dried leaves were vacuum-packed (Vacuum Packager - DZQ400/500, China) and kept in a freezer at -20 °C for further analysis. For each species, the different drying methods were all conducted on the same day. One batch of fresh leaves was extracted as control for comparison with dried leaves.

Moisture loss and water activity

Moisture loss (%) of microwave-, oven- and freeze-dried leaves was determined by weighing fresh and dried leaves. Water activity of the dried leaves was measured using a water activity meter (Masteraw, Navasina Lab, Switzerland).

Antioxidant assays

Total phenolic content (TPC) was determined using the Folin-Ciocalteu (FC) assay [11,12]. Samples (300 ml, in triplicate) were introduced into test tubes followed by 1.5 ml of FC reagent (10 times dilution) and 1.2 ml of sodium carbonate (7.5%, w/v). The tubes were allowed to stand for 30 min before absorbance at 765 nm was measured. TPC was expressed as mg gallic acid equivalent (GAE)/100 g of sample. The calibration equation for gallic acid (GA) was $y = 0.0111x - 0.0148$ ($R^2 = 0.9998$), where y is the absorbance and x is the GA concentration in mg/l.

Radical scavenging activity (RSA) was assessed using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay [11,12]. Different dilutions of extracts (1 ml) were added to 2 ml of DPPH (5.9 mg per 100 ml methanol). As RSA was calculated using IC_{50}, different dilutions of extracts were necessary to give a range of concentrations to ensure that the DPPH scavenging curve passed through 50%. After 30 min, absorbance was measured at 517 nm. RSA was expressed as ascorbic acid equivalent antioxidant capacity (AEAC) in mg ascorbic acid (AA)/100 g and calculated as $10^5 \times IC_{50}(AA)/IC_{50}(extract)$. IC_{50} of ascorbic acid was 0.00387 mg/ml.

Ferric reducing power (FRP) was measured using the potassium ferricyanide assay [11,12]. Different dilutions of extracts (1 ml) were added to 2.5 ml phosphate buffer (0.2 M, pH 6.6) and 2.5 ml of potassium ferricyanide (1%, w/v). Different dilutions of extracts were used to obtain a curve of absorbance against concentration. The gallic acid equivalent (GAE) was calculated by comparing the slope of this curve with that of gallic acid. Care was taken to ensure that absorbance did not exceed 0.7 as high concentrations would cause precipitation of the Prussian blue (ferric ferrocyanide) complex. The mixture was incubated at 50 °C for 20 min. After adding trichloroacetic acid solution (2.5 ml, 10%, w/v), the mixture was separated into aliquots of 2.5 ml, and diluted with 2.5 ml of water. To each diluted aliquot, 500 ml of ferric chloride solution (0.1%, w/v) was added. After 30 min, absorbance was measured at 700 nm. FRP of extracts was expressed as mg GAE/100 g. The calibration equation for gallic acid was $y = 16.767x$ ($R^2 = 0.9974$), where y is the absorbance and x is the GA concentration in mg/ml.

Data analysis

All antioxidant analyses were conducted in triplicate and results were expressed as mean ± standard deviation. Analysis of variance (ANOVA) was done using Tukey's Honestly Significant Difference (HSD) test at $P < 0.05$.

AOP of fresh leaves were analysed in terms of fresh weight as they were not subjected to any drying treatments. For comparison, the fresh weight equivalent of dried samples was calculated from the moisture loss. AOP of ground and shredded dried leaves and tea infusions were analysed in terms of dry weight.

RESULTS AND DISCUSSION

Effects of thermal drying

Moisture loss (%), water activity, and AOP of microwave- and oven-dried leaves of *M. alba*, *L. speciosa* and *T. laurifolia* with comparisons to fresh leaves are shown in Table 1. Moisture loss was 61-79% and 63-79%, and water activity was 0.41-0.65 and 0.23--0.54 for microwave drying and oven drying, respectively.

Microwave drying resulted in significant increase in the AOP of leaves of *M. alba* and *T. laurifolia*. Increase in TPC, AEAC and FRP was 20, 48 and 23% for *M. alba*, and increase in TPC and AEAC was 25 and 40% for *T. laurifolia*, respectively. In contrast, microwave-dried leaves of *L. speciosa* showed significant declines of 15, 41 and 38% in TPC, AEAC and FRP, respectively.

An earlier study on the effects of microwave drying on leaves of *T. laurifolia* using the half-leaf test has been reported [13]. The half-leaf test was specifically designed to verify whether microwave treatment does indeed increase antioxidant activity. Fresh leaves were cut in half along the central vein. One half was microwave-dried for 4 min while the other half was retained as control. The half leaves were weighed before and after drying. This would effectively rule out inter-leaf variation. Results based on two leaves showed an increase of 41 and 50% in TPC and AEAC for the first leaf, and an increase of 38 and 51% for the second leaf, respectively.

Table 1. Moisture loss, water activity and antioxidant properties of microwave-, oven- and freeze-dried leaves of Morus alba, Lagerstroemia speciosa and Thunbergia laurifolia with comparisons to fresh leaves (fresh weight); MD = microwave drying, OD = oven drying, FD = freeze drying; TPC = total phenolic content (mg gallic acid equivalent/100 g), AEAC = ascorbic acid equivalent antioxidant capacity (mg ascorbic acid/100 g), FRP = ferric reducing power (mg gallic acid equivalent/100 g), NA = not available. Values are means ± standard deviation (n = 3). For each column, values followed by the same superscript (a-d) are not statistically different at P < 0.05, as measured by the Tukey's HSD test. Analysis of variance does not apply between species and between drying methods

Species (family)	Drying method	Moisture loss, %	Water activity	Phenolic content and antioxidant activity		
				TPC	AEAC	FRP
M. alba (Moraceae)	Fresh	-	-	688±22^{c}	508±6^{c}	335±11^{c}
	MD	61.3	0.41	855±11^{a}	970±31^{a}	437±7^{a}
	OD	63.3	0.23	711±21^{c}	644±19^{b}	336±21^{c}
	FD	63.3	0.03	799±8^{b}	639±18^{b}	403±8^{b}
L. speciosa (Lythraceae)	Fresh	-	-	4147±21^{a}	6119±330^{ab}	2963±27^{b}
	MD	61.3	0.65	2583±141^{c}	3601±279^{c}	1833±127^{c}
	OD	66.3	0.42	3536±217^{c}	5253±669^{b}	2837±126^{b}
	FD	65.6	0.19	4220±181^{a}	6379±277^{a}	3208±121^{a}
T. laurifolia (Thunbergiaceae)	Fresh	-	-	675±60^{b}	579±79^{c}	NA
	MD	79.3	0.41	902±12^{a}	968±32^{a}	NA
	OD	79.3	0.54	424±15^{c}	434±16^{d}	NA
	FD	80.9	0.23	700±52^{b}	708±88^{b}	NA

A likely cause for the increase in antioxidant activity following microwave drying was the production of additional phenolic compounds from precursors already present in the samples [13]. Another possible explanation is the rapid inactivation of polyphenol oxidase (PPO) activity in samples due to microwave irradiation [14]. The enzyme is therefore unable to generate oxidation products that would reduce the phenollic content.

Other related studies showed variable effects of microwave drying on the AOP of leaves of herbal plants. Species of *Alpinia zerumbet*, *Curcuma longa*, *Etlingera elatior* and *Kaempferia galanga* (Zingiberaceae) [12] and *Phyllanthus amarus* (Euphorbiaceae) [15] showed substantial declines of 27-71% while *Vitex negundo* (Labiatae) [16] showed little or no change. Research on broccoli showed that antioxidant activity of florets and stems declined gradually when cooked in a domestic microwave oven for 0.5--5.0 min [17]. Similarly, there was significant decrease in antioxidant activity of fresh strawberries when subjected to vacuum-microwave drying [18].

Oven drying resulted in significant declines in the AOP of leaves of *T. laurifolia* with loss of 37% in TPC and 25% in AEAC. Leaves of *M. alba* and *L. speciosa* showed little or no change with the exception of AEAC of *M. alba* (significant increase) and TPC of *L. speciosa* (significant decrease). Related studies similarly reported declines in AOP following oven drying. Leaves of *A. zerumbet*, *C. longa*, *E. elatior* and *K. galanga* showed drastic declines of 42-81% [12]. Loss of 17-39% was displayed by *P. amarus* and *V. negundo* [15,16].

Processing methods such as drying are known to have variable effects on AOP of plant samples. Effects include little or no change, significant declines or enhancement in AOP [19]. Food processing can improve the properties of antioxidants or induce the formation of new antioxidant compounds, so that the overall antioxidant activity increases or remains unchanged [20]. There are changes in chemical composition caused by the drying process and the best method of drying enhances AOP or leads to the least alteration in phenolic content and antioxidant activity of the sample.

Increase in antioxidant activity following thermal treatments has been reported in tomato [21], sweet corn [22], mushroom [23] and ginseng [24]. A green tea produced by drying young leaves of *C. sinensis* in a microwave oven showed significantly higher AOP than four brands of commercial green and black tea [25]. Increase in antioxidant activity following thermal treatments has been attributed to the release of bound phenolic compounds due to the breakdown of cellular constituents and the formation of new compounds with enhanced AOP [20-22].

Many studies have reported losses in AOP of plant samples following thermal treatments. Losses were mainly reported in vegetables [26-29]. Losses in AOP of heat-treated samples have been attributed to thermal degradation of phenolic compounds, to degradative enzymes, and to loss of antioxidant enzyme activities [15,29]. Declines in AOP are often accompanied by the loss of other bioactive properties [28].

Studies have also showed that thermal treatments had little or no effect on AOP of plant samples. Microwave drying did not modify AOP of selected herbs and spices as most of the differences between treated and non-treated samples were statistically insignificant [30]. RSA of garlic, onion and egg plant was unaffected by microwave cooking [31].

A drying treatment applied onto a given plant sample could have variable effects on AOP. Depending on the assays used, antioxidant activities may show gains, result in losses or remain unchanged. This was found in tomatoes [32], purple wheat bran [33] and vegetables [26,34]. Involving a different process from drying, the effects of cooking on AOP have been much studied. It was reported that the effects on AOP depend on the type of vegetable and not on the type of cooking [35]. However, another related study on 10 types of vegetables and six methods of cooking showed that the type of cooking has strong influence of AOP [31]. Microwave cooking and griddling resulted in the lowest losses in RSA, while boiling and pressure cooking led to the greatest losses. The effects on thermal treatments on AOP of vegetables have recently been reviewed [36]. Phenolic contents and antioxidant activity of fruits and vegetables are known to vary between cultivars and between growing seasons [37,38]. Invariably, these factors would have an influence on the effects of different drying methods.

Effects of non-thermal drying

Moisture loss, water activity and AOP of freeze--dried leaves with comparisons to fresh leaves are shown in Table 1. Moisture loss was 63-81% and water activity was 0.03-0.23 for freeze drying. Significant increase in AOP was observed in freeze-dried leaves of *M. alba* with increments of 14% for TPC, 21% for AEAC and 17% for FRP. AOP of *L. speciosa* and *T. laurifolia* showed no change or slight increase. There was significant increase in FRP of *L. speciosa* and in AEAC of *T. laurifolia.* Related studies have shown similar AOP enhancement of freeze drying in ginger species of *A. zerumbet* and *E. elatior* but not so for *C.*

longa and *K. galanga* which declined slightly or remained unchanged [12].

There is no thermal degradation in freeze drying as the process does not allow degradative enzymes to function. Freeze drying is known to have high extraction efficiency because ice crystals formed within the plant matrix can rupture cell structure which allows exit of cellular components and access of solvent, and consequently better extraction [10]. The HPLC chromatogram of leaves of *E. elatior* showed greater amounts of minor compounds following freeze drying than fresh leaves [12].

The retention of AOP after freeze drying has often been reported. Freeze-dried yam flours displayed the highest antioxidant activity compared to hot air- and drum-dried flours [39]. Freeze-dried marionberry, strawberry and corn yielded higher TPC than air-dried samples [10]. Freeze-dried leaves of water hyacinth had higher antioxidant activity than sun- and oven-dried leaves [40]. Higher antioxidant values have been reported in freeze-dried than hot air-dried daylily flowers [41]. The effect of AOP enhancement after freeze drying has seldom been reported. Total antioxidant activity of freeze-dried asparagus was 50% higher than fresh samples [42]. Ferrous ion chelating ability gained, but TPC, FRP and RSA remained unchanged for freeze-dried tomatoes [32].

This study has demonstrated AOP enhancement following freeze drying in *M. alba* with *L. speciosa* and *T. laurifolia* showing no change or slight increase. Findings support the view that freeze drying remains the best method of drying foods as the quality of freeze-dried products is comparable to that of fresh products [43].

Effects of particle size

AOP of ground and shredded leaves of *M. alba* extracted with 50% methanol are shown in Table 2. Antioxidant values in terms of TPC, AEAC and FRP of ground microwave-, oven- and freeze-dried leaves were significantly higher than shredded leaves. For the microwave-dried tea, values of ground leaves were 3.1, 6.6 and 3.3 times those of shredded leaves, respectively. For the oven-dried tea, values were 1.6, 1.5 and 1.4 times higher, and for the freeze-dried tea, values were 1.9, 2.4 and 1.9 times higher.

Findings on AOP of ground and shredded leaves of *M. alba* extracted with aqueous methanol support the general consensus that particle size of samples is an important parameter that influences extraction yield, *i.e.*, smaller particle size would increase the extraction surface and enhance extraction efficiency [44-47]. Diffusivity of solute to solvent phase increases as the extracted material becomes smaller. Consequently, greater amount of antioxidant active compounds from the finer particles could be gained, resulting in stronger antioxidant capacity of the extract. This has been reported in culinary herbs [44], ginger [45], tea [46] and fruits [47] that smaller particle size yielded higher phenolic content and antioxidant activity.

However, when AOP of ground and shredded tea infusions of selected species extracted with hot water (100 °C) were compared, variations emerged. Values of AOP of tea infusions from shredded microwave-, oven- and freeze-dried leaves were significantly higher than those of ground tea infusions for *M. alba*, and *vice versa* for *L. speciosa* (Table 3). For *T. laurifolia*, AOP of tea infusions from ground and shredded leaves were comparable.

While ground microwave-, oven- and freeze-dried *M. alba* leaves extracted with aqueous methanol had stronger AOP than shredded leaves, this does not apply for tea infusions extracted with hot water. Three categories were recognized i.e. species with shredded leaves yielding stronger AOP (*M. alba*), species with ground leaves yielding stronger AOP (*L. speciosa*), and species with ground and shredded leaves yielding comparable AOP (*T. laurifolia*). Findings in this study suggested that particle size of microwave-, oven- and freeze-dried dried leaves is not

Table 2. Antioxidant properties of ground and shredded leaves of Morus alba extracted with 50% methanol (dry weight); MD = microwave drying, OD = oven drying, FD = freeze drying, G = ground, S = shredded, TPC = total phenolic content (mg gallic acid equivalent/100 g), AEAC = ascorbic acid equivalent antioxidant capacity (mg ascorbic acid/100 g), FRP = ferric reducing power (mg gallic acid equivalent/100 g). Values are means ± standard deviation (n = 3). For each column, values followed by the same superscript (a-b) are not statistically different at P < 0.05, as measured by the Tukey's HSD test. Analysis of variance does not apply between drying methods

Drying method	Particle size	Phenolic content and antioxidant activity		
		TPC	AEAC	FRP
MD	G	2209±28[a]	2506±80[a]	1129±18[a]
	S	718±41[b]	380±21[b]	344±18[b]
OD	G	1937±57[a]	1755±52[a]	916±57[a]
	S	1210±27[b]	1202±33[b]	662±30[b]
FD	G	2177±22[a]	1741±49[a]	1098±22[a]
	S	1147±5[b]	728±11[b]	572±22[b]

Table 3. Antioxidant properties of ground and shredded tea infusions of Morus alba, Lagerstroemia speciosa and Thunbergia laurifolia extracted with hot water (dry weight); MD = microwave drying, OD = oven drying, FD = freeze drying, G = ground, S = shredded, TPC = total phenolic content (mg gallic acid equivalent/100 g), AEAC = ascorbic acid equivalent antioxidant capacity (mg ascorbic acid/100 g), FRP = ferric reducing power (mg gallic acid equivalent /100 g), NA = not available. Values are means ± standard deviation (n = 3). For each column, values followed by the same superscript (a-b) are not statistically different at P < 0.05, as measured by the Tukey's HSD test. Analysis of variance does not apply between drying methods of each species

Species	Drying method	Particle size	Phenolic content and antioxidant activity		
			TPC	AEAC	FRP
M. alba	MD	G	1500±26^{b}	1350±79^{b}	635±29^{b}
		S	1870±44^{a}	1920±23^{a}	865±25^{a}
	OD	G	1500±43^{b}	735±32^{b}	644±11^{a}
		S	1640±130^{a}	1320±90^{a}	695±49^{a}
	FD	G	1660±36^{b}	615±32^{b}	745±18^{b}
		S	1850±68^{a}	1560±68^{a}	807±26^{a}
L. speciosa	MD	G	5270±145^{a}	7480±109^{a}	3880±117^{a}
		S	4170±227^{b}	5940±524^{b}	2880±110^{b}
	OD	G	5920±191^{a}	7150±443^{a}	3900±240^{a}
		S	3520±53^{b}	4350±134^{b}	2080±63^{b}
	FD	G	7180±197^{a}	11000±404^{a}	5940±45^{a}
		S	3490±296^{b}	9690±1320^{a}	2160±234^{b}
T. laurifolia	MD	G	3230±107^{a}	3350±159^{a}	NA
		S	3080±202^{a}	3450±273^{a}	NA
	OD	G	1730±140^{a}	1560±8^{a}	NA
		S	1800±57^{a}	1590±55^{a}	NA
	FD	G	3850±127^{a}	4520±100^{a}	NA
		S	3960±384^{a}	4350±277^{a}	NA

the sole factor influencing AOP of tea infusions. Other factors include the type and volume of extraction solvent used, pH of extraction medium, extraction temperature and time, and number of extraction steps [48,49].

CONCLUSION

Both thermal and non-thermal drying methods had variable effects on the AOP of leaves and tea infusions of the species studied. Microwave drying resulted in enhanced AOP in leaves of *M. alba* and *T. laurifolia.* Oven drying resulted in significant declines in AOP of *T. laurifolia* with *M. alba* and *L. speciosa* relatively unchanged. Significant increase was observed in freeze-dried leaves of *M. alba* with *L. speciosa* and *T. laurifolia* showing little or no change. Freeze drying appears to be a sound method for producing herbal teas. Due to its high operation cost, freeze drying can be applied to produce high-value specialty tea with enhanced AOP.

AOP values of ground microwave-, oven- and freeze-dried leaves of *M. alba* were significantly higher than shredded leaves, implying that smaller particle size yielded higher phenolic content and antioxidant activity. For tea infusions extracted with hot water, three categories were recognised, *i.e.*, species with shredded leaves yielding stronger AOP (*M. alba*), species with ground leaves yielding stronger AOP (*L. speciosa*), and species with ground and shredded leaves yielding comparable AOP (*T. laurifolia*). Beside particle size, other factors can also influence AOP of tea infusions.

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REFERENCES

[1] W.J. Craig, Am. J. Clin. Nutr. **70** (1999) 491S-499S

[2] M.A. Lazar, J. Clin. Invest. **113** (2004) 23-25

[3] C. Thomson, R.B. Lutz, In: Nutrition in the Prevention and Treatment of Disease, A.M. Coulston, C.L. Rock, E.R. Monsen, Eds., Academic Press, London, 2001, pp. 261-275

[4] H. Speisky, C. Rocco, C. Carrasco, E.A. Lissi, C. López-Alarcón, Phytother. Res. **20** (2006) 462-467

[5] A. Romm, L. Ganora, D. Hoffmann, E. Yarnell, K. Abascal, M. Coven, In: Botanical Medicine for Women's

Health, A. Romm, M.L. Hardy, S. Mills, Eds., Churchill Livingstone/Elsevier, Oxford, 2010, pp. 24-74

[6] S. Wachtel-Galor, I.F.F. Benzie, in: Herbal Medicine: Biomolecular and Clinical Aspects, I.F.F. Benzie, S. Wachtel-Galor, Eds., CRC Press, Boca Raton, FL, 2011, pp. 1-10

[7] İ. Doymaz, Chem. Ind. Chem. Eng. Q. **17** (2011) 199-205

[8] C.H. Chong, C.L. Law, in: Drying of Exotic Fruits, Vegetables and Fruits - Vol. 2, S.V. Jangam, C.L. Law, A.S. Mujumdar, Eds., Singapore, pp. 1-42

[9] A.K. Atoui, A. Mansouri, G. Boskou, P. Kefalas, Food Chem. **89** (2005) 27-36

[10] D.K. Asami, Y.J. Hong, D.M. Barrett, A.E. Mitchell, J. Agric. Food Chem. **51** (2003) 1237-1241

[11] E.W.C. Chan, Y.Y. Lim, K.L. Chong, J.B.L. Tan, S.K. Wong, J. Food Compos. Anal. **23** (2010) 185-189

[12] E.W.C. Chan, Y.Y. Lim, S.K. Wong, K.K. Lim, S.P. Tan, F.S. Lianto, M.Y. Yong, Food Chem. **113** (2009) 166-172

[13] E.W.C. Chan, Y.Y. Lim, J. Trop. Forest Sci. **18** (2006) 130-136

[14] J.N. Rodríguez-López, L.G. Fenoll, J. Tudela, C. Devece, D. Sánchez-Hernández, E. de los Reyes, F. García-Cánovas, J. Agric. Food Chem. **47** (1999) 3028-3035

[15] Y.Y. Lim, J. Murtijaya, LWT - Food Sci. Technol. **40** (2007) 1664-1669

[16] K.L. Chong, Y.Y. Lim, J. Food Qual. **35** (2012) 51-59

[17] D. Zhang, Y. Hamauzu, Food Chem. **88** (2004) 503-509

[18] A. Wojdyło, A. Figiel, J. Oszmiański, J. Agric. Food Chem. **57** (2009) 1337-1343

[19] M.C. Nicoli, M. Anese, M. Parpinel, Trends Food Sci. Tech. **10** (1999) 94-100

[20] A. Tomaino, F. Cimino, V. Zimbalatti, V. Venuti, V. Sulfaro, A. de Pasquale, A. Saija, Food Chem. **89** (2005) 549-554

[21] V. Dewanto, X.Z. Wu, K.K. Adom, R.H. Liu, J. Agric. Food Chem. **50** (2002) 3010-3014

[22] V. Dewanto, X.Z. Wu, R.H. Liu, J. Agric. Food Chem. **50** (2002) 4959-4964

[23] Y. Choi, S.M. Lee, J. Chun, H.B. Lee, J. Lee, Food Chem. **99** (2006) 381-387

[24] K.S. Kang, H.Y. Kim, J.S. Pyo, T. Yokozawa, Biol. Pharm. Bull. **29** (2006) 750-754

[25] E.W.C. Chan, Y.Y. Lim, Y.L. Chew, Food Chem. **102** (2007) 1214-1222

[26] A. Ismail, Z.M. Marjan, C.W. Foong, Food Chem. **87** (2004) 581-586

[27] R.K. Toor, G.P. Savage, Food Chem. **94** (2006) 90-97

[28] M.K. Roy, M. Takenaka, S. Isobe, T. Tsushida, Food Chem. **103** (2007) 106-114

[29] J.A. Larrauri, P. Rupérez, F. Saura-Calixto, J. Agric. Food Chem. **45** (1997) 1390-1393

[30] D. Bertelli, M. Plessi, F. Miglietta, Italian J. Food Sci. **16**(1) (2004) 97-103

[31] A.M. Jiménez-Monreal, L. García-Diz, M. Martínez-Tomé, M. Mariscal, M.A. Murcia, J. Food Sci. **74** (2009) H97--H103

[32] C.H. Chang, H.Y. Lin, C.Y. Chang, Y.C. Liu, J. Food Eng. **77** (2006) 478-485

[33] W. Li, M.D. Pickard, T. Beta, Food Chem. **104** (2007) 1080-1086

[34] T. Yamaguchi, T. Mizobuchi, R. Kajikawa, H. Kawashima, F. Miyabe, J. Terao, H. Takamura, T. Matoba, Food Sci. Technol. Res. **7** (2001) 250-257

[35] N. Turkmen, F. Sari, Y.S. Velioglu, Food Chem. **93** (2005) 713-718

[36] B. Chipurura, M. Muchiweti, F. Manditseraa, Asian J. Clin. Nutr. **2** (2010) 93-100

[37] B. Łata, M. Przeradzka, M. Bińkowska, J. Agric. Food Chem. **53** (2005) 8970-8978

[38] M.N. Mitić, M.V. Obradović, D.A. Kostić, R.J. Micić, E.T. Pecev, Chem. Ind. Chem. Eng. Q. **18** (2012) 53-62

[39] C.L. Hsu, W. Chen, Y.M. Weng, C.Y. Tseng, Food Chem. **83** (2003) 85-92

[40] R. Bodo, A. Azzouz, R. Hausler, Plant Sci. **166** (2004) 893-899

[41] L.C. Mao, X. Pan, F. Que, X.H. Fang, Eur. Food Res. Technol. **222** (2006) 236-241

[42] C.I. Nindo, T. Sun, S.W. Wang, J. Tang, J.R. Powers, LWT - Food Sci. Technol. **36** (2003) 507-516

[43] C. Ratti, J. Food Eng. **49** (2001) 311-319

[44] M.S. Gião, C.I. Pereira, S.C. Fonseca, M.E. Pintado, F.X. Malcata, Food Chem. **117** (2009) 412-416

[45] G.F. Zhang, Z.B. Yang, Y. Wang, W.R. Yang, S.Z. Jiang, G.S. Gai, Poult. Sci. **88** (2009) 2159-2166

[46] Q.V. Vuong, J.B. Golding, M. Nguyen, P.D. Roach, J. Sep. Sci. **33** (2010) 3415-3428

[47] R. Pumklam, P. Siriwongwilaichat, in: Proc. 12th ASEAN Food Conf., 2011, Bangkok, Thailand, 2011, pp. 728-732

[48] M. Escribano-Bailon, C. Santos-Buelga, In: Methods in Polyphenol Analysis, C. Santos-Buelga, G. Williamson, Eds., RSC Publishing, Cambridge, 2003, pp. 1-16

[49] G. Spigno, L. Tramelli, D.M. De Faveri, J. Food Eng. **81** (2007) 200-208.

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NAUČNI RAD

UTICAJ METODE SUŠENJA I VELIČINE ČESTICE NA ANTIOKSIDATIVNA SVOJSTVA LIŠĆA I ČAJA KOD *Morus alba, Lagerstroemia speciosa* I *Thunbergia laurifolia*

Procenjivan je uticaj sušenja mikrotalasima, u peći i zamrzavanjem na antioksidativna svojstva (AOP) lišća i čajeva vrste Morusalba L., Lagerstroemia speciosa (L.) Pers. i Thunbergia laurifolia Lindl. Ukupan sadržaj fenola (TPC), sposobnost hvatanja radikala, izražena kao ekvivalentni kapacitet askorbinske kiseline (AEAC), i moć redukcije gvožđa (FRP) određeni su metodom Folin-Ciocalteu, pomoću 2,2-difenil-1-pikrilhidrazila (DPPH) i kalijumheksacijanoferata(II), respektivno. Takođe, ispitivan je uticaj veličine čestica. Mikrotalasno sušenje poboljšava AOP kod M. alba i T. laurifolia. Sušenjem u peći vrednost AOP se smanjuje kod T. laurifolia, dok kod M. alba i L. speciosa ostaje relativno nepromenjena. Značajno povećanje AOP je primećeno prilikom zamrzavanja sušenog lišća M. alba, dok L. speciosa i T. laurifolia ne pokazuju nikakvu promenu ili blago povećanje. TPC, AEAC i FRP su kod lišća sušenog mikrotalasima, u peći i zamrzavanjem kod M. alba i ekstrahovanih pomoću 50% metanola znatno veći nego kod iseckanog lišća. Prilikom ektrakcije toplom vodom i pripreme infuzije za čaj, primećeno je da vrste sa seckanim lišćem dovode do jačeg AOP (M. alba), vrsta sa mlevenim lišćem daje jaču AOP (L. speciosa), i vrste sa mlevenim i iseckanim lišćem dovode do komparativnog AOP (T. laurifolia).

Ključne reči: antioksidativne osobine; lišće; čaj; metode sušenja; veličina čestice.