Antioxidant properties of ginger leaves: An overview

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ABSTRACT

Past studies on the antioxidant properties (AOP) of ginger species were confined to rhizomes. Although leaves of ginger species have been used for food flavouring and in traditional medicine, little research has been done on their AOP until recent years. This overview is on recent work done on the AOP of ginger leaves. Emphasis is on variation between species, comparison with rhizomes and flowers, altitudinal variation, effects of thermal and non-thermal drying methods, herbal teas, and commercial potentials. Of 26 ginger species, belonging to nine genera and three tribes, AOP of leaves were strongest in *Etlingera* followed by *Alpinia* and *Hedychium*. Eleven out of 14 species (78%) had significantly higher values in leaves than in rhizomes. Similar trends were also observed in other species of *Zingiber*, *Boesenbergia* and *Elettariopsis*. Leaves of highland populations of *Etlingera* had higher values than their lowland counterparts. Thermal drying of leaves of four species led to drastic declines in AOP but freeze drying led to significantly increase for leaves of *Etlingera elatior* and *Alpinia zerumbet*. AOP of hot-water extracts of the freeze-dried tea of *A. zerumbet* were found to be significantly higher than the commercial tea. A protocol to produce a standardised herbal extract of chlorogenic acid (CGA) from *E. elatior* leaves (40% purity) has been developed. With high CGA content of 1.6 times that of commercial extracts from honeysuckle flowers (25% purity), the standardised extract has great potential to be developed into functional foods and other health products.

Keywords: Zingiberaceae, antioxidant properties, leaves, standardised extract

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INTRODUCTION

Gingers are perennial herbs belonging to the family Zingiberaceae. They produce aromatic rhizomes that are subterranean or above ground.[1] Each rhizome can produce erect leafy shoots. Inflorescences are terminal, borne either on leafy shoots or on special erect shoots near the base of the plant. Gingers belong to three tribes, namely, Zingibereae, Alpinieae and Hedychieae.[2] *Zingiber* is the only genus of the tribe Zingibereae. The tribe Alpinieae consists of the genera *Alpinia*, *Amomum*, *Elettaria, Etlingera*, *Elettariopsis, Geocharis*, *Geostachys*, *Hornstedtia* and *Plagiostachys*. The tribe Hedychieae includes *Boesenbergia*, *Camptandra, Curcuma, Haniffia*, *Hedychium*, *Kaempferia* and *Scaphochlamys*.

Ginger plants are widely used as spice, condiment and traditional medicine.[2] The various uses of rhizomes and leaves of cultivated gingers in Peninsular Malaysia have been reviewed.[3] The varied ethno-medicinal uses of gingers in Northeast India have recently been documented.[4]

Rhizomes of ginger plants are eaten raw or cooked as vegetables and used for flavouring food.[2] Species that are widely cultivated are *Alpinia galanga*, *Curcuma longa*, *Etlingera elatior* and *Zingiber officinale* [Figure 1]. Rhizomes of *Z. officinale* are typically used as additives, and flavouring in the food and beverage industry. Rhizomes of *C. longa* are popular as a spice used in curries both for flavouring and colouring. Rhizomes of *A. galanga* are used as spice for meat dishes. As traditional medicine, rhizomes of ginger plants are consumed by women during ailment, illness and confinement. Rhizomes are also taken as a carminative for relieving flatulence. In Thailand, rhizomes of *A. galanga, Z. officinale, C. longa* and *B. rotunda* have been used as local medicine for treating stomachache and diarrhea, and used as a carminative.[5] Rhizomes of *Z. zerumbet* are used as a cure for swelling, sores and loss of appetite, and for de-worming children.[6],[7]

Leaves of ginger plants have also been used for food flavouring and in traditional medicine. In Malaysia, leaves of *C. longa* are used to wrap fish before steaming or

Alpinia galanga *Curcuma longa* *Etlingera elatior*

Figure 1. Some commercial ginger species.

baking.[2] Leaves of *Kaempferia galanga* and *C. longa* are ingredients of curries. Some aborigines in Malaysia flavour their wild meat and fish dishes with leaves of *Elettariopsis slahmong*.[8] In Thailand, its leaves are eaten as salad. Despite their repulsive stinkbug odour, leaves of *E. slahmong* are considered a delicacy. Leaves of *Elettariopsis latiflora* have been used to relieve flatulence, to improve appetite and as antidote to poisons. In Japan, leaves of *Alpinia zerumbet* (Getto) are commonly used to flavour noodles and to wrap rice cakes.[9] Some local companies are producing herbal teas and essential oils from leaves of Getto. Teas of *A. zerumbet* are reported to have hypotensive, diuretic and anti-ulcerogenic properties.[10] Leaves of *Zingiber mioga* have been used to wrap traditional buns with sweetened bean paste (Manjyu).[11] Leaves of *E. elatior*, mixed with other aromatic herbs, are used by post-partum women for bathing to remove body odour.[12] They are also used for cleaning wounds. Leaves of *Kaempferia rotunda* and *K. galanga* are eaten fresh or cooked as vegetables, and used as a cosmetic powder and as a food flavouring agent.[13] In Peninsular Malaysia, boiled leaves of *Hedychium* species are eaten for indigestion.[14] Leaves are sometimes eaten with betel nut to ease abdominal pain. In Thailand, boiled leaves of *Hedychium coronarium* are applied to relieve stiff and sore joints. A decoction of leaves of *A. galanga* is consumed to treat diarrhea.[15] Leaves of *Zingiber spectabile* are used to alleviate swellings, abate inflamed eyelids, and treat headache and backache.[16],[17],[18]

Beside rhizomes and leaves, other plant parts of gingers are consumed as food, spice and condiment. Young inflorescences of *E. elatior* are an essential ingredient of sour curry dishes.[2] In East Malaysia, the hearts of young shoots, inflorescences and fruits of *Etlingera littoralis*, *Etlingera punicea* and *E. elatior* are consumed by indigenous communities as condiment, eaten raw or cooked as vegetable.[19] In Thailand, fruits of *E. littoralis* are edible and young stems, after removing the outer parts, yield an aromatic tender core that is eaten raw or cooked.[16] Flowers of *Etlingera maingayi* are edible. In Malaysia, a decoction of fruits of *E. elatior* is used to treat earache.[12] In Japan, *Z. mioga* is grown for its edible flower buds which are eaten raw or pickled for their pleasant pungent flavour.[11] The buds are finely shredded and used as a garnish in Japanese cuisine.[20] Young shoots and inflorescence of *Z. zerumbet* are used as condiments.[21]

In recent years, gingers have become popular ornamental plants as their inflorescences and foliage are colourful and attractive.[2] Plants of *Alpinia*, *Curcuma*, *Etlingera*, *Hedychium*, *Kaempferia* and *Zingiber* are cultivated for their attractive leaves and/or flowers. They include *Alpinia mutica*, *Alpinia purpurata*, *Alpinia zerumbet* 'Variegata', *E. elatior*, *Etlingera fulgens*, *Hedychium coronarium*, *Kaempferia pulchra* and *Z. spectabile* [Figure 2]. Farms in Australia and Hawaii are cultivating *E. elatior* and selling its inflorescences as cut flowers.[12] In Thailand, plants of *Curcuma alismatifolia* and *Curcuma roscoeana* have been cultivated and exported for the aesthetics of their flowers.[16]

Commercial products have been developed from ginger species. In western countries, rhizomes of *Z. officinale* are used in the production of alcoholic beverages such as ginger beer, ginger ale and ginger wine.[22] They are also widely used to make ginger bread, biscuits, cakes, puddings and pickle. Xanzwhite™ is a Malaysian skin-lightening product made from a blend of *Curcuma zanthorrhiza* and *Zingiber zerumbet* rhizomes[23] Rhizomes of *K. galanga* and *C. longa* have strong tyrosinase inhibition properties, rendering them useful for cosmetic applications.[24] As curcumin is a yellow colouring substance, its hydrogenated colourless form (tetrahydrocurcumin) is often used in skin care preparations in India.[25] In Northeast Thailand, a tonic drink made from the rhizomes of *Kaempferia parviflora* is commercially available, and is believed to relieve impotent symptoms.[26]

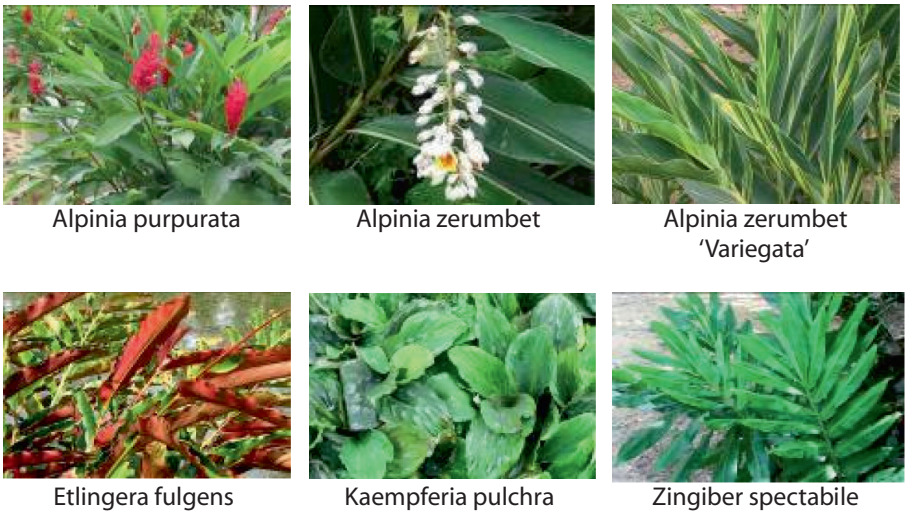

Figure 2. Some ornamental ginger species.

Phytochemical studies of ginger leaves have been undertaken mainly on *Alpinia* species.[27] Compounds found in leaves of *Alpinia* include flavonoids,[10],[28] phenolic acids,[29] labdane-type diterpenes,[30] diarylheptanoids,[31] phenylbutanoids[32] and kava pyrones.[10],[33],[34] From the leaves of *A. zerumbet*, flavonoids (rutin, kaempferol 3-*O*-rutinoside, kaempferol 3-*O*-glucuronide, (+)-catechin and (-)-epicatechin), and kava pyrones (dihydro-5,6-dehydro kawain and 5,6-dehydrokawain) have been identified.[10] Ferulic acid and p-hydroxybenzoic acid are major phenolic acids in ethyl acetate leaf extracts of *A. zerumbet*.[29] A 3-methoxyflavone (kumatakenin), and two steroidal glycosides (sitosteryl-3-*O*-6-palmitoyl-β-D-glucoside and β-sitosteryl galactoside) were isolated from hexane and dichloromethane leaf extracts of *A. purpurata*.[35] From the leaves of *Etlingera*, three caffeoylquinic acids (CQA) including chlorogenic acid have been isolated from leaves of *E. elatior*.[36] These compounds were reported for the first time in Zingiberaceae. Besides CQA, flavonoids of isoquercitrin, quercitrin and (+)-catechin were also isolated.[37] Flavonoids of kaempferol 3-glucuronide, quercetin 3-glucuronide, quercetin 3-glucoside and quercetin 3-rhamnoside have earlier been reported from leaves of *E. elatior*.[28] Leaves of *Hedychium*, *Kaempferia* and *Globba* were found to be mainly flavonoids and flavonoid glycosides.

Past studies on the antioxidant properties (AOP) of ginger species were confined to rhizomes. Rhizome extracts from various species of *Alpinia*, *Curcuma* and *Zingiber* have been reported to possess antioxidant activity comparable with or stronger than α-tocopherol and butylated hydroxytoluene.[38],[39],[40],[41] Screening of 18 ginger species belonging to five genera from Taiwan, rhizomes of *Curcuma zedoaria* and *C. longa* had the highest phenolic content, and rhizomes of *C. longa* and *H. coronarium* had the strongest antioxidant capacity, radical scavenging and reducing power.[42]

AOP of different chemical constituents isolated from ginger rhizomes have also been studied. Antioxidants from rhizomes included gingerol-related compounds and diarylheptanoids in *Z. officinale*,[43] and curcuminoids in *C. longa*[44],[45] and *Zingiber cassumunar*.[46],[47] From rhizomes of *Z. officinale*, gingerol, shogaol, gingerdiol, gingerdione, dihydrogingerdione, hexahydrocurcumin and octahydrocurcumin have been identified.[48] The gingerol-related compounds and diarylheptanoids can be classified into four groups, namely, 5-hydroxy-3-one, 4-en-3-one, 3,5-diol and 3,5-diacetate.[49]. Depending on the substitution pattern of the side chain and benzene ring, and on the length of the side chain, their AOP can be stronger than α-tocopherol. From rhizomes of *C. longa* and *Z. cassumunar*, curcuminoids of curcumin, demethoxylated curcumin, cassumunin and cassumunarin have been identified.[47] From rhizomes of *Alpinia nutans*, 5,6-dehydrokawain and (-)-pinocembrin have AOP comparable to α-tocopherol.[50]

Very little research is done on the AOP of seeds and fruits of Zingiberaceae. Some work has been conducted on seeds of *Alpinia katsumadai*[51] and *A. zerumbet*.[52] 2',3',4',6'-Tetra hydroxychalcone isolated from fruits of *Alpinia rafflesiana* showed significant radical scavenging activity.[53]

Although leaves of ginger species have been used for food flavouring and in traditional medicine, little research has been done on their AOP until recent years. This overview is on recent work done on the AOP of ginger leaves. Emphasis is on species variation, comparison with rhizomes and flowers, altitudinal variation, effects of thermal and non-thermal drying methods, herbal teas, and commercial potentials.

ANTIOXIDANT PROPERTIES

Variation between species

AOP of ginger leaves were evaluated in terms of total phenolic content, radical scavenging, ferric reducing power, ferrous ion chelating and lipid peroxidation inhibition.[37],[54] Fresh leaves were extracted with methanol. Total phenolic content (TPC) was determined using the Folin-Ciocalteu assay. Radical scavenging activity, expressed as ascorbic equivalent antioxidant capacity (AEAC), was measured using the 2,2-dipheny1-1-picrylhydrazyl (DPPH) assay. Ferric reducing power (FRP), ferrous ion chelating (FIC) ability and lipid peroxidation inhibition (LPI) activity were assessed using the potassium ferricyanide, ferrous-ferrozine and β-carotene bleaching assays, respectively.

Of five *Etlingera* species screened for AOP, *E. elatior* and *Etlingera rubrostriata* had the highest TPC, AEAC and FRP.[54] Values ranged from 3480-3550 GAE/100 g, 3540-3750 mg AA/100 g and 17-20 GAE/g, respectively. Moderately high values were found in the leaves of *E. littoralis* and *E. fulgens*. Lowest values were found in the leaves of *E. maingayi*. It is evident that *Etlingera* species with high leaf TPC also have high AEAC and FRP. Ranking was in the order: *E. elatior* ~ *E. rubrostriata* > *E. littoralis* ~ *E. fulgens* > *E. maingayi*.

In terms of FIC ability, the trend was reversed with leaves of *E. maingayi* and *E. fulgens* having the highest values which were superior to that of young leaves of *Camellia sinensis*, used as positive control.[54] It can be seen that leaves of *Etlingera* species with high TPC, AEAC and FRP have low FIC and *vice versa*. This would mean that phenolic compounds in the leaves responsible for antioxidant activities of scavenging free radicals and reducing ferric ions might not be directly involved in ferrous ion chelation. The compounds responsible for ferrous ion chelation could be nitrogen-containing compounds, which are generally better chelators than are phenols.

In terms of LPI activity, leaves of *E. maingayi* had the highest values.[54] With the exception of *E. fulgens*, leaves of all *Etlingera* species studied showed higher LPI than leaves of *C. sinensis* and this reflects their ability to strongly inhibit lipid peroxidation. There appears to be no correlation between LPI activity and antioxidant activities as measured by the other assays.

Screening of AOP of five *Alpinia* species revealed three categories, namely, strong, moderate and weak.[55] The strong category included *A. zerumbet* and *Alpinia malaccensis* with TPC, AEAC and FRP values ranging from 1850-2230 GAE/100 g, 2180-2600 mg AA/100 g and 11 GAE/g, respectively. The moderate category included *A. purpurata* and *A. zerumbet* 'Variegata' and the weak category included *A. galanga*. Ranking was in the order: *A. zerumbet* ~ *A. malaccensis* > *A. purpurata* ~ *A. zerumbet* 'Variegata' > *A. galanga*.

Leaves of 26 ginger species belonging to nine genera and three tribes were screened for TPC and AEAC.[9] *Etlingera* had the highest values followed by *Alpinia* and *Hedychium* [Table 1]. Species of *Boesenbergia*, *Curcuma*, *Elettariopsis*, *Kaempferia*, *Scaphochlamys* and *Zingiber* had much lower values.

Foliage of tropical forest plants produces more antioxidants when exposed to elevated light conditions.[56] Plants growing along seashores, which receive much sunlight, have efficient AOP to prevent oxidative damage.[57] These observations may also apply to leaves of *Etlingera* and *Alpinia*, which have high TPC and AEAC. *Etlingera* species are the largest of the ginger plants and can grow up to 6 m in height.[58],[59] They grow in gaps of disturbed forest and are continually exposed to direct sunlight. *Alpinia* species are medium-sized to large forest plants.[2] The other genera are small- to medium-sized herbs. Among the various tribes and genera of gingers, there appears to be a positive correlation between the phenolic content and radical scavenging activity of leaves with plant size and site conditions.[9] Larger ginger plants growing in exposed forest sites have stronger AOP properties than have smaller plants growing in shaded sites.

Comparison with rhizomes and flowers

TPC and AEAC of fresh leaves and rhizomes of 14 species from the same plant or location were also assessed for comparison.[9] Results showed that 11 species (78%) had significantly higher TPC and/or AEAC in leaves than in rhizomes [Table 2]. Leaves of *E. elatior* and *E. maingayi* which had the highest TPC and AEAC were 7-8 times

Table 1. Total phenolic content (TPC) and ascorbic acid equivalent antioxidant capacity (AEAC) of fresh leaves of 26 ginger species[9]

Species	TPC (mg GAE/100 g)	AEAC (mg AA/100 g)
Alpinia zerumbet	1990 ± 62	2180 ± 42
A. purpurata	1190 ± 174	1100 ± 113
A. zerumbet 'Variegata'	1150 ± 41	1250 ± 184
A. malaccensis	744 ± 61	800 ± 62
A. galanga	392 ± 50	90 ± 36
Boesenbergia rotunda	260 ± 8	157 ± 2
Curcuma zanthorrhiza	503 ± 57	287 ± 39
C. aeruginosa	282 ± 78	140 ± 47
C. mangga	275 ± 36	118 ± 11
C. longa	230 ± 19	113 ± 18
Elettariopsis latiflora	423 ± 26	395 ± 27
E. slahmong	346 ± 45	269 ± 67
E. smithiae	303 ± 18	147 ± 21
Etlingera elatior	2390 ± 329	2280 ± 778
E. rubrostriata	2250 ± 113	2290 ± 118
E. littoralis	2150 ± 94	1990 ± 87
E. fulgens	1280 ± 144	845 ± 158
E. maingayi	1110 ± 93	963 ± 169
Hedychium coronarium	820 ± 55	814 ± 116
Kaempferia galanga	146 ± 9	77 ± 7
K. rotunda	140 ± 48	46 ± 15
K. pulchra	112 ± 9	30 ± 3
Scaphochlamys kunstleri	203 ± 21	171 ± 33
Zingiber officinale	291 ± 18	96 ± 7
Z. spectabile	242 ± 7	121 ± 24
Z. ottensii	162 ± 13	52 ± 6

Values of TPC and AEAC are means ± SD (n = 3). GAE = gallic acid equivalent and AA = ascorbic acid.

higher than those of rhizomes. The trend is less evident with *Alpinia* species. TPC and AEAC of leaves and rhizomes of *A. malaccensis* were comparable while leaves of *A. galanga* had higher TPC but lower AEAC than rhizomes.

Significantly higher TPC and AEAC in leaves than rhizomes of five wild and six cultivated ginger species have been reported earlier.[60] Similar results were obtained when the total flavonoid content (TFC) and radical scavenging activity (RSA) of leaves and rhizomes of two varieties of *Z. officinale* harvested 8, 12 and 16 weeks after planting were compared.[61] Leaves of both varieties had significantly higher TFC and stronger RSA than rhizomes although leaves showed a declining trend while rhizomes showed an increasing trend. It can be inferred that older rhizomes of *Z. officinale* have higher phenolic content and stronger antioxidant activity than younger rhizomes. In *Boesenbergia armeniaca* and *Boesenbergia pulchella* var. *attenuata*, leaves and stems had higher TPC and TFC, and stronger RSA and FRP than rhizomes.[62] Similarly, methanol extracts of leaves of *Elettariopsis curtisii* exhibited higher TPC, and stronger radical scavenging ability and reducing power than rhizomes.[63]

Antioxidants are secondary metabolites produced by plants to protect against oxidative damage by free radicals.[64] In gingers, it is generally believed that antioxidants produced by the plant are transported to the rhizomes where they are accumulated.[9] This implies that rhizomes would have higher antioxidant activity than other plant parts. However, results showed that this might not be true

Table 2. Total phenolic content (TPC) and ascorbic acid equivalent antioxidant capacity (AEAC) of fresh leaves (L) and rhizomes (R) of 14 ginger species[9]

Ginger species	Plant part	TPC (mg GAE/100 g)	AEAC (mg AA/100 g)
Alpinia galanga	L	392 ± 50a	90 ± 36a
	R	214 ± 20b	214 ± 20b
A. malaccensis	L	744 ± 61a	800 ± 62a
	R	564 ± 209a	745 ± 342a
Boesenbergia rotunda	L	260 ± 8a	157 ± 2a
	R	197 ± 50a	89 ± 7b
Curcuma aeruginosa	L	282 ± 78a	140 ± 47a
	R	145 ± 31b	55 ± 11b
C. longa	L	230 ± 19a	113 ± 18a
	R	534 ± 205b	390 ± 127b
C. mangga	L	275 ± 36a	118 ± 11a
	R	112 ± 21b	33 ± 1b
C. zanthorrhiza	L	503 ± 57a	287 ± 39a
	R	250 ± 52b	134 ± 21b
Elettariopsis slahmong	L	346 ± 45a	269 ± 67a
	R	219 ± 57b	197 ± 76a
Etlingera elatior	L	2390 ± 329a	2280 ± 778a
	R	326 ± 76b	295 ± 96b
E. maingayi	L	1110 ± 93a	963 ± 169a
	R	160 ± 52b	122 ± 53b
Kaempferia galanga	L	146 ± 9a	77 ± 7a
	R	57 ± 1b	17 ± 1b
Scaphochlamys kunsteri	L	203 ± 21a	171 ± 33a
	R	73 ± 3b	14 ± 2b
Zingiber officinale	L	291 ± 18a	96 ± 7a
	R	157 ± 18b	84 ± 3a
Z. spectabile	L	242 ± 7a	121 ± 24a
	R	157 ± 100a	124 ± 109a

Values of TPC and AEAC are means ± SD (n = 3). GAE = gallic acid equivalent and AA = ascorbic acid. For each column, values followed by the same letter (a–b) are not statistically different at $P < 0.05$ as measured by the Tukey HSD test. ANOVA compares values of leaves and rhizomes of each species and does not apply between species.

as the majority of the species studied had significantly higher phenolic content and antioxidant activity in leaves than in rhizomes. It has been reported much greater concentrations of flavones and flavonols in leaves of vegetables which are exposed to sunlight.[65] Only trace amounts were found in unexposed parts below the soil surface which include roots and rhizomes. This could explain why leaves have significantly higher phenolic content and antioxidant activity than rhizomes in ginger plants.

Analyses of different plant parts of *E. elatior* showed that leaves had significantly higher TPC, AEAC and FRP than inflorescences and rhizomes.[54] Values of leaves were 3550 mg GAE/100 g, 3750 mg AA/100 g and 19.6 mg GAE/g; inflorescences were 295 mg GAE/100 g, 268 mg AA/100 g and 1.5 mg GAE/g; and rhizomes were 187 mg GAE/100 g, 185 mg AA/100 g and 0.9 mg GAE/g; respectively. Analyses of *A. purpurata* and *A. galanga* showed that leaves and flowers had comparable TPC, AEAC and FRP values.[66]

Altitudinal variation

Leaves of all highland populations of *Etlingera* species were found to have higher TPC and AEAC than lowland counterparts.[52] Leaves of *E. rubrostriata*, *E. elatior* and *E. fulgens* showed significantly higher values with greater altitude, while leaves of *E. littoralis* were marginally higher.

Higher altitudes seem to trigger an adaptive response in *Etlingera* species. Higher leaf TPC and AEAC of highland populations over lowland counterparts might be due to environmental factors, such as higher UV-B radiation and lower air temperature.[54] There is increasing evidence that enhanced UV-B radiation induces production of phenolic compounds in plants.[67] Enzymes associated with the synthesis of phenolics are produced in greater quantities or show increased activity.[68] Phenylalanine ammonia lyase (PAL) is up-regulated, resulting in the accumulation of flavonoids and anthocyanins, which have antioxidant ability.[69] Low temperatures have also been shown to enhance PAL synthesis in a variety of plants, leading to increased production of flavonoids and other phenolics.[68]

Thermal drying methods

All methods of thermal drying (microwave, oven and sun drying) of leaves of *A. zerumbet*, *E. elatior*, *C. longa* and *K. galanga* resulted in drastic declines in TPC, AEAC and FRP.[70] Declines ranged from 36-91%, 27-86% and 43-88%, respectively. Similar declines have been reported for leaves of *A. galanga*, *A. purpurata* and *A. zerumbet*.[55] Many studies have reported losses in AOP of plant samples following thermal treatments. Losses in AOP of heat-treated samples have been attributed to degradative enzymes, thermal degradation of phytochemicals and loss of antioxidant enzyme activities.[71],[72] Declines in AOP are often accompanied by loss of other bioactive properties.[73]

An interesting finding is the effect of microwave drying on AOP of leaves of *E. elatior*.[70] Leaves microwave-dried for 2, 4, 6 and 8 min, which resulted in same weight loss (75%), showed significant but comparable declines in TPC, AEAC and FRP. A likely explanation is that microwave drying for 2 min is sufficient to remove the moisture content and to decompose all heat-labile antioxidants and subsequent heating would have no effect.

Non-thermal drying methods

Air drying resulted in significant losses in TPC, AEAC and FRP were observed in air-dried leaves of *A. zerumbet*, *E. elatior*, *C. longa* and *K. galanga*.[70] Declines ranged from 49-80%, 48-84% and 50-83%, respectively. Declines in AOP resulting from air drying could be due to enzymatic degradation as the process was carried out at room temperature and takes several days for samples to dry. Contrary to results of this study, air drying of temperate herbs of lemon balm, oregano and peppermint had variable effects on AOP which ranged from significant increase to significant decline.[74]

On the contrary, freeze drying resulted in significant gains in TPC, AEAC and FRP of leaves of *A. zerumbet* and *E. elatior*.[70] Gains were 26%, 45% and 36% for *E. elatior*, and 28%, 16% and 9% for *A. zerumbet*, respectively [Table 3]. Unlike leaves of *A. zerumbet* and

Table 3. Total phenolic content (TPC), ascorbic acid equivalent antioxidant capacity (AEAC) and ferric reducing power (FRP) of fresh and freeze-dried (FD) leaves of four ginger species[70]

Species	Treatment	Water loss (%)	TPC (mg GAE/100 g)	AEAC (mg AA/100 g)	FRP (mg GAE/g)
Alpinia zerumbet	Fresh		1990 ± 62a	2180 ± 42a	11 ± 0.2a
	FD	61 ± 2	2550 ± 55b	2530 ± 45b	12 ± 0.2b
Etlingera elatior	Fresh		2420 ± 210a	2960 ± 362a	14 ± 0.7a
	FD	76 ± 4	3050 ± 226b	4280 ± 55b	19 ± 1.3b
Curcuma longa	Fresh		399 ± 15a	243 ± 28a	2.1 ± 0.1a
	FD	82 ± 2	357 ± 20b	222 ± 12a	1.8 ± 0.1b
Kaempferia galanga	Fresh		133 ± 5a	42 ± 3a	0.7 ± 0.1a
	FD	86 ± 3	112 ± 11b	38 ± 5a	0.6 ± 0.1a

Values of TPC, AEAC and FRP of leaves are means ± SD ($n = 3$). GAE = gallic acid equivalent and AA = ascorbic acid. For each column, values followed by the same letter (a–b) are not statistically different at $P < 0.05$ as measured by the Tukey HSD test. ANOVA does not apply between species and between drying methods.

E. elatior, which showed significant gains, freeze drying led to slight declines of 11%, 9% and 14% for leaves of *C. longa*, and 16%, 10% and 14% for leaves of *K. galanga*, respectively. After one-week storage, AOP of freeze-dried *E. elatior* leaves remained significantly higher than those of fresh control leaves. Recently, similar effects of non-thermal drying on the AOP of leaves of *A. galanga*, *A. purpurata* and *A. zerumbet* were reported.[55]

Freeze drying resulted in slight declines in TPC and FRP for *C. longa* and in TPC for *K. galanga*.[70] Freeze-dried leaves of *A. zerumbet* and *E. elatior* were thick, powdery and easy to extract while leaves of *C. longa* and *K. galanga* were thin, papery and difficult to extract. Variation in the ease of extractability due to modification of the matrix could explain why freeze drying has different effects on these two groups of species. Results of the study showed that freeze drying had three major effects on the AOP of ginger leaves. Firstly, freeze-dried leaves of *C. longa* and *K. galanga* had the least decline in AOP compared with leaves dried using other drying methods (microwave, oven, sun and air drying). Secondly, leaves of *A. zerumbet* and *E. elatior* showed enhancement in AOP following freeze drying. Thirdly, freeze-dried leaves of *E. elatior* remained stable following one week of storage under sealed conditions and room temperature.

TPC and antioxidant activity of freeze-dried inflorescences of *E. elatior* have been reported to be 8-9 times that of fresh samples.[75] There is no thermal degradation in freeze drying and neither does the process allow degradative enzymes to function.[70] Furthermore, 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, access of solvent and consequently better extraction.[76] The HPLC chromatogram (254 nm) of leaves of *E. elatior*, which showed greater amounts of minor compounds following freeze drying, supported this inference [Figure 3].

Herbal teas

AOP of the freeze-dried tea of *A. zerumbet* produced in the laboratory were compared with the commercial *A. zerumbet* (Getto) tea purchased from Okinawa, Japan. TPC, AEAC and FRP of hot-water extraction of the freeze-dried tea were found to be significantly higher than the commercial tea.[55],[70] Variability in AOP of the commercial and freeze-dried teas may be due to number of factors. They include drying methods, type of extraction solvents and antioxidant assays used.[70] The significantly lower TPC, AEAC and FRP of the commercial tea could be due to the use of conventional drying methods where heat is applied during the manufacturing process. Consequently, much of the antioxidant compounds are lost through enzymatic degradation and/or heat decomposition. On the contrary, much AOP are retained in the freeze-dried tea as freeze drying is non-thermal. Freeze drying remains the best method of drying foods as the quality of freeze-dried products is comparable to fresh products.[77]

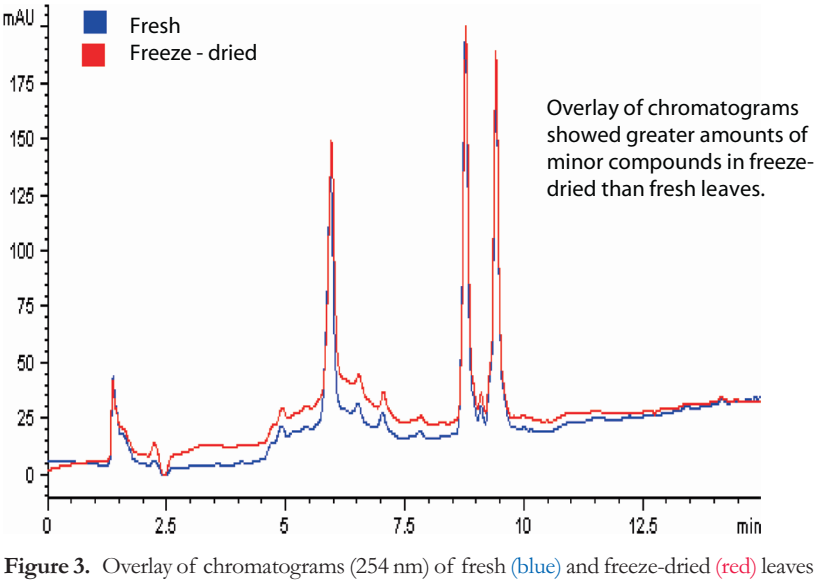

Figure 3. Overlay of chromatograms (254 nm) of fresh (blue) and freeze-dried (red) leaves of *Etlingera elatior*[70].

Commercial potentials

Chlorogenic acid (CGA) is the dominant phenolic compound in leaves of *E. elatior*.[36] CGA content (294 mg CGA/100 g) was found to be significantly higher than flowers of *Lonicera japonica* or Japanese honeysuckle (173 mg CGA/100 g), the commercial source. Leaves of *E. elatior* which currently have no economic value, could serve as an alternative source of CGA. Unlike flowers of *L. japonica* which are small and seasonal, leaves of the widely cultivated *E. elatior* are large and available in abundance. Furthermore, harvesting of leaves is non-destructive to the plants.

A protocol to produce a standardised herbal extract of CGA from leaves of *E. elatior* using column chromatography was developed.[37] Freeze drying of leaves followed by extraction with 30% ethanol, and sequential fractionation using Diaion HP-20 and Sephadex LH-20 yielded a CGA extract with 40% w/w purity. CGA fractions had antioxidant, antibacterial and tyrosinase inhibition properties. The entire fractionation process took only 6.5 h, using gravity flow. From 50 g of leaves, the final yield of CGA extract was 0.2 g (0.4%). CGA content of the standardised extract from leaves of *E. elatior* (40%) is 1.6 times that of commercial extracts from honeysuckle flowers (25%). With high CGA content, the extract has great potential to be developed into functional food and other health products.

CONCLUSION

Recent studies showed that leaves of ginger species had higher antioxidant activity than rhizomes and flowers. Of 26 ginger species screened, AOP of leaves were strongest in *Etlingera* followed by *Alpinia* and *Hedychium*. Eleven out of 14 species had significantly higher values in leaves than in rhizomes. Similar trends were also observed in other species of *Zingiber*, *Boesenbergia* and *Elettariopsis*. Leaves of highland populations of *Etlingera* had higher values than their lowland counterparts. Thermal drying of leaves of four species led to drastic declines in AOP but freeze drying led to significantly increase for leaves of *E. elatior* and *A. zerumbet*. AOP of hot-water extracts of the freeze-dried tea of *A. zerumbet* were found to be significantly higher than the commercial tea. A protocol to produce a standardised herbal extract of chlorogenic acid (CGA) from *E. elatior* leaves (40% purity) has been developed. Its CGA content is 1.6 times that of commercial extracts from honeysuckle flowers (25% purity). The standardised extract has great potential to be developed into functional foods and other health products.

REFERENCES

1. Soepadmo E. Ginger plants. Nat Malay 1976;1:32-9.
2. Larsen K, Ibrahim H, Khaw SH, Saw LG. Gingers of Peninsular Malaysia and Singapore. Kota Kinabalu: Natural History Publications (Borneo); 1999.
3. Ibrahim H, Khalid N, Hussin K. Cultivated gingers of Peninsular Malaysia: utilization, profiles and micropropagation. Gard Bull Sing 2007;59:77-88.
4. Tushar, Basak S, Sarma GC, Rangan L. Ethnomedical uses of Zingiberaceous plants of Northeast India. J Ethnopharmacol 2010;132:286-96.
5. Oonmetta-aree J, Suzuki T, Gasaluck P, Eumkeb G. Antimicrobial properties and action of galangal (*Alpinia galanga* Linn.) on *Staphylococcus aureus*. LWT - Food Sci Technol 2006;39:1214-20.
6. Somchit MN, Shukriyah MHN. Anti-inflammatory property of ethanol and water extracts of *Zingiber zerumbet*. Indian J Pharmacol 2003;35:181-2.
7. Faizah S, Somchit MN, Shukriyah MH. *Zingiber zerumbet* (Lempoyang): A potential anti-inflammatory agent. In: Omar R, Ali Rahman Z, Latif MT, Lihan T, Adam JH, Editors. Proceedings of Regional Symposium on Environment and Natural Resources; 2002 Apr 10-11; Hotel Renaissance, Kuala Lumpur, Malaysia. p. 516-20.
8. Lim CK. Taxonomic notes on *Elettariopsis* Baker and new taxa from Peninsular Malaysia and Thailand. Folia Malay 2003;4:205-26.
9. Chan EWC, Lim YY, Wong LF, Lianto FS, Wong SK, Lim KK, *et al*. Antioxidant and tyrosinase inhibition properties of leaves and rhizomes of ginger species. Food Chem 2008;109:477-83.
10. Mpalantinos MA, de Moura RS, Parente JP, Kuster RM. Biologically active flavonoids and kava pyrones from the aqueous extract of *Alpinia zerumbet*. Phytother Res 1998;12:442-4.
11. Abe M, Ozawa Y, Uda Y, Yamada F, Morimitsu Y, Nakamura Y, *et al*. Antimicrobial activities of diterpene dialdehydes, constituents from myoga (*Zingiber mioga* Roscoe), and their quantitative analysis. Biosci Biotechnol Biochem 2004;68:1601-4.
12. Ibrahim H, Setyowati FM. *Etlingera*. In: de Guzman CC, Siemonsma JS, Editors. Plant Resources of South-East Asia, Vol. 13. Backhuys Publisher, Leiden, Netherlands. 1999. p. 123-6.
13. Ibrahim H. *Kaempferia*. In: de Padua LS, Bunyapraphatsara N, Lemmens RHMJ, Editors. Plant Resources of South-East Asia Vol. 12. Backhuys Publisher, Leiden, Netherlands. 1999. p. 331-5.
14. Ibrahim H. *Hedychium*. In: van Valkenburg JLCH, Bunyapraphatsara N, Editors. Plant Resources of South-East Asia Vol. 12. Backhuys Publisher, Leiden, Netherlands. 2001. p. 290-5.
15. Ong HC, Nordiana M. Malay ethno-medico botany in Machang, Kelantan, Malaysia. Fitoterapia 1999;70:502-13.
16. Sirirugsa P. Thai Zingiberaceae: species diversity and their uses. Paper presented at the International Conference on Biodiversity and Bioresources: Conservation and Utilization; 1997 Nov 23-27; Phuket, Thailand. Available from: http://old.iupac.org/ symposia/ proceedings/phuket97/sirirugsa.html.
17. Theilade I. Revision of the genus *Zingiber* in Peninsular Malaysia. Gard Bull Sing 1996;48:207-36.
18. Wolff XY, Astuti IP, Brink M. *Zingiber*. In: De Guzman CC, Siemonsma JS, Editors. Plant Resources of South-east Asia, Vol. 13, Backhuys Publisher, Leiden, Netherlands. 1999. p. 233-8.

19. Noweg T, Abdullah AR, Nidang D, 2003. Forest plants as vegetables for communities bordering the Crocker Range National Park. ASEAN Rev Biodiv Environ Conser, Jan-Mar 2003;1-18.
20. Gracie AJ, Brown PH, Burgess SW, Clark RJ. Rhizome dormancy and shoot growth in myoga (*Zingiber mioga* Roscoe). Sci Hortic 2000;84:27-36.
21. Nakamura Y, Yoshida C, Murakami A, Ohigashi H, Osawa T, Uchida K. Zerumbone, a tropical ginger sesquiterpene, activates phase II drug metabolizing enzymes. FEBS Lett 2004;572:245-50.
22. Vasala PA. Ginger. In: Peter KV, Editor. Handbook of Herbs and Spices. Woodhead Publishing Ltd. and CRC Press. 2001. p. 195-206.
23. Rozanida AR, Nurul Izza N, Mohd Helme MH, Zanariah H. Xanzwhite™ - a cosmeceutical product from species in the family Zingiberaceae. In: Mazura MP, Chang YS, Subramaniam V, Khoo MGH, Ong BK, Editors. Proceedings of the Seminar on Medicinal and Aromatic Plants. 2006. p. 31-6.
24. Majeed M, Prakash L. Fighting acne and more: Effective natural approaches to skin care. Cosmet Toiletries Manuf, April 2004;215-9.
25. Kole PI, Jadhav HR, Thakurdesai P, Nagappa AN. Cosmetics potential of herbal extracts. Nat Prod Rad 2005;4:315-21.
26. Yenjai C, Prasanphen K, Daodee S, Wongpanich V, Kittakoop P. Bioactive flavonoids from *Kaempferia parviflora*. Fitoterapia 2004;75:89-92.
27. Pancharoen O, Prawat U, Tuntiwachwuttikul PT. Phytochemistry of Zingiberaceae. Stud Nat Prod Chem 2000;23:797-865.
28. Williams CA, Harborne JB. The leaf flavonoids of Zingiberales. Biochem System Ecol 1977;5:221-9.
29. Elzaawely AA, Xuan TD, Tawata S. Essential oils, kava pyrones and phenolic compounds from leaves and rhizomes of *Alpinia zerumbet* (Pers.) B.L. Burtt. & R.M. Sm. and their antioxidant activity. Food Chem 2007;103:486-94.
30. Sy LK, Brown GD. Labdane diterpenoids from *Alpinia chinensis.* J Nat Prod 1997; 60:904-8.
31. Ngo KS, Brown GD. Stilbenes, monoterpenes, diarylheptanoids, labdanes and chalcones from *Alpinia katsumadai.* Phytochemistry 1998;47:1117-23.
32. Kikuzaki H, Tesaki S, Yonemori S, Nakatani N. Phenylbutanoid dimers from the leaves of *Alpinia flabellata.* Phytochemistry 2001;56:109-14.
33. Fujita T, Nishimura H, Kaburagi K, Mizutani J. Plant growth inhibiting alpha-pyrones from *Alpinia speciosa.* Phytochemistry 1994;36:23-7.
34. Kuster RM, Mpalantinos MA, de Holanda MC, Lima P, Brand ET, Parente JP. GC-MS determination of kava-pyrones in *Alpinia zerumbet* leaves. J High Res Chrom 1999;22:129-30.
35. Villaflores OB, Macabeo AG, Gehle D, Krohn K, Franzblau SG, Aguinaldo AM. Phytoconstituents from *Alpinia purpurata* and their *in vitro* inhibitory activity against *Mycobacterium tuberculosis*. Phcog Res 2009;1:261-9
36. Chan EWC, Lim YY, Ling SK, Tan SP, Lim KK, Khoo MGH. Caffeoylquinic acids from leaves of *Etlingera* species (Zingiberaceae). LWT - Food Sci Technol 2009;42:1026-30.
37. Chan EWC. Bioactivities and chemical constituents of leaves of some *Etlingera* species (Zingiberaceae) in Peninsular Malaysia. Selangor, Malaysia. PhD thesis, Monash University Sunway Campus, Malaysia. (2009). Available from: http://arrow. monash. edu.au/hdl/1959.1/149589.
38. Jitoe A, Masuda T, Tengah IGP, Suprapta DN, Gara IW, Nakatani N. Antioxidant activity of tropical ginger extracts and analysis of the contained curcuminoids. J Agric Food Chem 1992;40;1337-40.
39. Habsah M, Amran M, Mackeen MM, Lajis NH, Kikuzaki H, Nakatani N, *et al*. Screening of Zingiberaceae extracts for antimicrobial and antioxidant activities. J Ethnopharmacol 2000;72(3):403-10.
40. Zaeoung S, Plubrukarn A, Keawpradub N. Cytotoxic and free radical scavenging activities of Zingiberaceous rhizomes. Songkla J Sci Technol 2005;27:799-812.
41. Vankar PS, Tiwari V, Singh LW, Swapana N. Antioxidant properties of some exclusive species of Zingiberaceae family of Manipur. Electron J Environ Agric Food Chem 2006;5:1318-22.
42. Chen IN, Chang CC, Ng CC, Wang CY, Shyu YT, Chang TL. Antioxidant and antimicrobial activity of Zingiberaceae plants in Taiwan. Plant Food Hum Nutri 2008;63:15-20.
43. Kikuzaki H, Nakatani N. Antioxidant effects of some ginger constituents. J Food Sci 1993; 58:1407-10.
44. Sreejayan N, Rao MNA. Free radical scavenging activity of curcuminoids. Drug Res 1996; 46:169-71.
45. Song EK, Cho H, Kim JS, Kim NY, An NH, Kim JA, *et al*. Diarylheptanoids with free radical scavenging and hepatoprotective activity *in vitro* from *Curcuma longa*. Planta Med 2001;67:876-7.
46. Masuda T, Jitoe A. Antioxidative and anti-inflammatory compounds from tropical gingers: isolation, structure determination, and activities of cassumunins A, B, and C, new complex curcuminoids from *Zingiber cassumunar*. J Agric Food Chem 1994; 42:1850-6.
47. Jitoe A, Masuda T, Mabry TJ. Novel antioxidants, cassumunarin A, B, and C from *Zingiber cassumunar*. Tetrahedron Lett 1994;35:981-4.
48. Nakatani N, Kikuzaki H. Antioxidants in ginger family. In: Ho CT, Zheng QY, Editors. Quality Management of Nutraceuticals. ACS Sympo Series 2001;803:230-40.
49. Kikuzaki H, Kawasaki Y, Nakatani N. Structure of antioxidative compounds in ginger. In: Ho CT, Osawa T, Huang MT, Rosen RT, Editors. Food Phytochemicals for Cancer Prevention II. ACS Sympo Series 1994;547:237-43.
50. Habsah M, Lajis NH, Ali AM, Sukari MA, Hin YY, Kikuzaki H, *et al*. The antioxidative components from *Alpinia nutans*. Pharm Biol 2003;41:7-9.
51. Lee SE, Shin HT, Hwang HJ, Kim JH. Antioxidant activity of extracts from *Alpinia katsumadai* seed. Phytother Res 2003;17:1041-7.
52. Elzaawely AA, Xuan TD, Koyama H, Tawata S. Antioxidant activity and contents of essential oil and phenolic compounds in flowers and seeds of *Alpinia zerumbet* (Pers.) BL Burtt. & RM Sm. Food Chem 2007;104:1648-53.
53. Habsah M, Faridah A, Permana D, Lajis NH, Ali AM, Sukari MA, *et al*. DPPH free radical scavenger components from fruits of *Alpinia rafflesiana* Wall. ex. Bak. (Zingiberaceae). Z Naturforsch C 2004;59:811-5.
54. Chan EWC, Lim YY, Omar M. Antioxidant and antibacterial activity of leaves of *Etlingera* species (Zingiberaceae) in Peninsular Malaysia. Food Chem 2007;104:1586-93.
55. Wong SK, Wong LF, Lim YY, Chan EWC. Effects of drying treatments on the antioxidant properties of leaves and teas of *Alpinia* species (Zingiberaceae). J Trop Med Plant 2010;11:97-105.
56. Frankel S, Berenbaum M. Effects of light regime on antioxidant content of foliage in a tropical forest community. Biotropica 1999;31:422-9.
57. Masuda T, Yonemori S, Oyama Y, Takeda Y, Tanaka T, Andoh T, *et al.* Evaluation of the antioxidant activity of environmental plants: activity of the leaf extracts from seashore plants. J Agric Food Chem 1999;47:1749-54.
58. Khaw SH. The genus *Etlingera* (Zingiberaceae) in Peninsular Malaysia including a new species. Gard Bull Sing 2001;53: 191-239.
59. Poulsen AD. *Etlingera* Giseke of Java. Gard Bull Sing 2007;59: 145-72.

60. Chan EWC, Lim YY, Lim TY. Total phenolic content and antioxidant activity of leaves and rhizomes of some ginger species in Peninsular Malaysia. Gard Bull Sing 2007;59:47-58.
61. Ghasemzadeh A, Jaafar HZE, Rahmat A. Identification and concentration of some flavonoid components in Malaysian young ginger (*Zingiber officinale* Roscoe) varieties by a high performance liquid chromatography method. Molecules 2010; 15:6231-43;
62. Jing LJ, Mohamed M, Rahmat A, Abu Bakar MF. Phytochemicals, antioxidant properties and anticancer investigations of the different parts of several gingers species (*Boesenbergia rotunda*, *Boesenbergia pulchella* var *attenuata* and *Boesenbergia armeniaca*). J Med Plant Res 2010;4:27-32.
63. Chairgulprasert V, Prasertsongskun S, Junpra-ob S, Sangjun M. Chemical constituents of essential oil, antioxidant and antibacterial activities from *Elettariopsis curtisii* Baker. Songkla J Sci Technol 2008;30:591-6.
64. Larson RA. The antioxidants of higher plants. Phytochemistry 1998;27:969-78.
65. Herrmann K. On the occurrence of flavonol and flavone glycoside in vegetables. Eur Food Res Technol A 1988;186:1-5.
66. Wong LF, Lim YY, Omar M. Antioxidant and antimicrobial activities of some *Alpinia* species. J Food Biochem 2009;33:835-51.
67. Bassman JH. Ecosystem consequences of enhanced solar ultraviolet radiation: secondary plant metabolites as mediators of multiple trophic interactions in terrestrial plant communities. Photochem Photobiol 2004;79:382-98.
68. Chalker-Scott L, Scott JD. Elevated ultraviolet-B radiation induces cross-protection to cold in leaves of *Rhododendron* under field conditions. Photochem Photobiol 2004; 79:199-204.
69. Jansen MAK, Gaba V, Greenberg BM. Higher plants and UV-B radiation: balancing damage, repair and acclimation. Trends Plant Sci 1998;3:131-5.
70. Chan EWC, Lim YY, Wong SK, Lim KK, Tan SP, Lianto FS, *et al.* Effects of different drying methods on the antioxidant properties of leaves and tea of ginger species. Food Chem 2009;113:166-72.
71. Larrauri JA, Rupérez P, Saura-Calixto F. Effect of drying temperature on the stability of polyphenols and antioxidant activity of red grape pomace peels. J Agric Food Chem 1997;45:1390-3.
72. Lim YY, Murtijaya J. Antioxidant properties of *Phyllanthus amarus* extracts as affected by different drying methods. LWT – Food Sci Technol 2007;40:1664-9.
73. Roy MK, Takenaka M, Isobe S, Tsushida T. Antioxidant potential, anti-proliferative activities, and phenolic content in water-soluble fractions of some commonly consumed vegetables: Effects of thermal treatment. Food Chem 2007;103:106-14.
74. Capecka E, Mareczeek A, Leja M. Antioxidant activity of fresh and dry herbs of some Lamiaceae species. Food Chem 2005;93:223-6.
75. Yan SW, Asmah R. Comparison of total phenolic contents and antioxidant activities of turmeric leaf, pandan leaf and torch ginger flower. Int Food Res J 2010;17:417-23.
76. Asami DK, Hong YJ, Barrett DM, Mitchell AE. Comparison of the total phenolic and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry, and corn grown using conventional, organic, and sustainable agricultural practices. J Agric Food Chem 2003;51:1237-41.
77. Ratti C. Hot air- and freeze-drying of high-value foods: a review. J Food Eng 2001; 49:311-9.