Impact of microwave vacuum drying on quality of Liang (Gnetum gnemon var. tenerum) leaves powder

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Abstract

Microwave vacuum drying is gaining popularity to maintain more active compounds compared with conventional drying. Liang (*Gnetum gnemon* var. *tenerum*) is a native plant with high consumer preference in Thailand. However, scientific information on the *tenerum* variety is not well documented. This study analyzed the effect of microwave vacuum drying on the quality of Liang leaves powder. Results showed that microwave vacuum drying at 50–60°C 3600 W for **12** min (G1) preserved better green color and maintained moisture content (%) and water activity (a_w). G1 gave less moisture content and a_w as **5.83 ± 0.07** and **0.42 ± 0.00**, respectively compared to G2 which used lower temperature and longer drying time at **40–50°C**, **2400** W for **15** min. *Salmonella* spp. and *Staphylococcus aureus* were not detected in either sample but pathogenic bacteria such as *Clostridium perfringens*, *Escherichia coli*, *Bacillus cereus*, and Coliforms were reported. The nutritional value of 100 g of powdered Liang leaves provided energy of 348–360 Kcal. G1 contained 25.5 g of protein with high and complete essential amino acids plus branched-chain amino acids and more carotenoids as β-carotenes (3,920 μg/100 g), with total dietary soluble and insoluble fiber 40.7 g/100 g. Consumers generally preferred the commercial green tea matcha drink rather than the Liang leaves drink, which had a strong unfamiliar smell and odor. Nevertheless, Liang leaves exhibited high potential as an ingredient to promote health benefits.

1. Introduction

Drying is the oldest but still the most popular method of preserving agricultural products, particularly vegetables and fruits. Food dehydration involves removing water to prohibit and retard the function of enzymes and bacterial growth. Some dried foods are tasty, nutritious, and easy to prepare and use (Rohini et al., 2021). Recently, the use of microwaves as a drying process has been increasing in both households and industry because this method reduces the drying time and improves the final quality of the dried products. Microwave drying involves dielectric heating by electromagnetic waves. As well as providing a high drying rate within a short time, microwave drying also tends to better preserve the nutritional values of foods (Nisoa et al., 2021). Microwave vacuum drying (MWV) is a new technology in dried food manufacturing as a rapid and efficient dehydration method, with lower temperatures between 40°C and 80°C due to the vacuum phenomenon of reduced pressure Therefore, MWV yields unique characteristics and improves product appearance and quality compared to conventionally dried products by normal microwave heating (Ferenczi et al., 2014). Vacuum drying at lower temperature preserves the original flavor of food and nutrients, enhances the functionality of health foods, increases the value of agricultural products, and retains the physiological activity of the raw materials. Dried fruits and vegetables are classified as sources of high fiber and phytochemicals with low fat, making them healthy food choices (Ahmed et al., 2013). *Gnetum gnemon* var. *tenerum*, an evergreen shrub with Thai names Phak Liang, Phak Kariang, and Phak Miang is a native and popular vegetable in Southern Thailand. The edible stage of the leaves can be cooked with dried fish or pork and coconut milk (Dayana et al., 2011).

Consumption of leafy vegetables is recommended to promote health as a source of fiber, carotenoids, and a variety of vitamins and minerals (Anisong et al., 2022) plus anti-glycaemic properties (Suksanga et al., 2022, 2023). *G. gnemon* var. *tenerum* leaves (100 g) provide fiber 6.8 g, carbohydrates 9.1 g, protein 6.6 g, vitamin A 10889 IU, calcium 151 mg, and iron 2.5 mg (Verheij and Sukendar, 2016). Predominant amino acids found in *G. gnemon* var *tenerum* leaves include branched-chain amino acids (BCAA) such as leucine, isoleucine, and valine (Anisong et al., 2022). *Gnetum gnemon* (Bago) leaves have moisture content of 69. 54 g/ 100 g, protein 17. 96 g/100 g, carbohydrates 32. 59 (g/100 g), and fat 13.101 g/100 g (Mollejon and Gabane, 2019). Liang leaves contain fewer carbohydrates and fat compounds than Bago leaves, possibly due to plant types as shrub and tree. Liang leaves also contain high fiber and protein which is good for diet control.

Vitamins are essential nutrients but only very small amounts are required to maintain human health. Concentration of vitamins B1 and B2 in dried *G. gnemon* var. *tenerum* leaves were 0. 17 and 0. 62 mg/ 100 g, respectively while vitamin A content was 3,706 μg/100 g (unpublished data). It is known that vitamins act as co-enzymes and are involved in the synthesis of new cells as well as in the metabolism of fat, protein, and carbohydrates. Vitamin C prevents various diseases by protecting the tissues from oxidative stress through antioxidant activity. Twelve antidepressant nutrients relate to the prevention and treatment of depressive disorders including folate, long-chain omega-3 fatty acids (EPA and DHA), magnesium, potassium, selenium, thiamine, vitamin A, vitamin B6, and vitamin B12 (LaChance and Ramsey, 2018). The highest-scoring plant foods showing potential for antidepressant activity were leafy greens, lettuce, peppers, and cruciferous vegetables (LaChance and Ramsey, 2018). However, no scientific study has investigated the utilization and processing of Liang leaves. Therefore, this research investigated microwave vacuum drying of Liang leaves and evaluated leaf quality for further utilization.

2. Materials and methods

2.1 Plant material preparation

Gnetum leaves (*Gnetum gnemon* var. *tenerum* Linn.) were collected from a farm located near Tone Pliow Waterfall, Hat Yai, Songkhla, Thailand. The harvesting was performed from April to October 2020 and samples were transported to the Faculty of Agro-Industry, PSU. To control the quality of raw material, only edible light green leaf samples called Bai pe-salat (order No. 3–4) with lengths 10.0 to 14.0 cm and width 4.0 to 6.0 cm were used, as shown in Fig. 1.

The selected leaves were soaked in 100 ppm chlorine solution for 5 min for disinfection before washing and rinsing with running tap water twice to reduce the chlorine residue to less than 1 ppm (Ministry of Public Health. Notifications of Ministry of Public Health, 2019). The samples were then drained before the drying process and initial quality determination. Ministry of Public Health. Notifications of Ministry of Public Health: washing agent and microbial decontaminated substance for food, 2019. https://www.ratchakitcha.soc.go.th/DATA/PDF/2562/E/278/T_0034.PDF (accessed on 27 September 2023).

2.2 Drying process

The samples were drained before an initial quality check followed by drying and biological activity analyses. The washed and drained leaves were dried using a microwave vacuum dryer (March Cool Industry Co., Ltd., Thailand) at the Food Innovation and Research Institute, Prince of Songkla University (FIRIN, PSU). The microwave vacuum dryer consisted of three pairs of magnetrons with a 360∘ rotating load basket, with 400 g of *Gnetum* leaves loaded for each batch. High temperature runs were performed at 3600 Watts (600 W X 6 magnetrons) for 12 min (high power with short time, G1), or at 2400 Watts (600 W X 4 magnetrons) for 15 min (low power with longer time, G2) at a controlled pressure of 13.33 kPa, to reach moisture content of less than 10%. The dried samples were then ground to obtain fine powders (230 mesh).

2.3 Initial quality analysis

The Liang leaves powder was analyzed for physical, chemical, and microbiological quality as follows:

2.3.1 Physical Quality

The Liang leaves powder was measured for moisture content (%), water activity (a_w), pH, and color values by the AOAC (2000) procedure.

2.3.1.1 Moisture content

An empty moisture can and lid were dried in the oven at 105°C for 3 h, transferred to a desiccator to cool, and then weighed. Three grams of the sample were placed in the dish and spread uniformly before drying in the oven at 105°C until constant weight. The dish containing the dried sample, partially covered with the lid, was placed in a desiccator to cool before closing the lid and weighing. The moisture content was calculated using the equation below.

Moisture (%) = $((W_1-W_2) \times 100)/W_1$

where

W_1 = weight (g) of sample before drying

W_2 = weight (g) of sample after drying

2.3.1.2 Water activity (a_w)

Water activity of Liang leaves powder was determined using a Novasina water activity meter (Thermoconstanter Novasina TH200, Switzerland).

2.3.1.3 Color values

Color values of the Liang leaves powder were measured using a color meter (Hunter Lab Universal Software). The color values were expressed as CIE Lab* coordinates where L* represents the luminosity

(0 = black; 100 = white), a* the redness (a* > 0), b* the blueness (b*>0) or yellowness (b*<0).

2.4 Microbiological quality

The Liang leaves powder was subjected to analysis for total plate count (BAM 2001), Coliforms (BAM 2017), *Bacillus cereus* (BAM 2012), yeast and mold (BAM 2001).

2.5 Nutritional composition

The Liang leaves powder was analyzed for proximate composition including protein, fat, carbohydrate, and fiber according to the method of AOAC (2000), while vitamins and mineral contents were analyzed following AOAC (2003).

2.6 Sensory evaluation

The two dried leaves powders from medium power (2400 W, 15 min) and high power (3600 W, 12 min) as well as green tea matcha (commercial) as the reference were infused using 3 g of each product powder with water at 80°C 30 ml/cup. During the sensory evaluation test, the panelists received water to rinse the mouth between samples and recorded attributes of appearance, color, odor, flavor mouthfeel, aftertaste and overall using a 9-point hedonic scale ranging from 1 = dislike much to 9 = like much. The samples were served in random order to 50 panelists consisting of scientists and students at the Faculty of Agro-Industry, Prince of Songkla University who were familiar with drinking vegetable juice or tea.

2.7 Statistical analysis

A completely randomized design (CRD) was used throughout the study, except for the sensory testing which used a randomized completely block design (RCBD). All experimental data were presented as mean ± standard deviation of three replications. The mean values of each sample were analyzed using analysis of variance (ANOVA). with significant differences among means determined by Tukey's test ($p < 0.05$) using SPSS for Windows (SPSS Inc, Chicago, IL, USA).

3. Results and Discussion

Fresh Liang leaves had a moisture content of 78.65 ± 1.01, water activity (a_w) 0.978, and pH 6.2 ± 0.03. Using microwave vacuum drying at the higher temperature condition of 50–60°C (3600 W for 12 min) gave reduced parameter values of 5.83 ± 0.07, 0.42 ± 0.00, and 5.9 ± 0.02, respectively compared with the lower temperature condition of 40–50°C (2400 W for 15 min) as 7.15 ± 0.09, 0.48 ± 0.00, and 5.9 ± 0.00. According to dried product regulations, both Liang products met the moisture content (< 10%) and a_w (≤ 0.6) (Table 1.), while the commercial Japanese green tea (M) gave moisture content 1.10 ± 0.07, water activity (a_w) 0.24 ± 0.01, and pH 5.85 ± 0.02 suggesting that moisture content may be a good sensitive parameter to differentiate drying process performance compared to a_w. However, using both moisture content and a_w would be better for predicting product shelf life.

Table 1
Quality analysis of Liang leaves after microwave drying (color value, moisture content (%), water activity, pH value)

Sample	Color value			Moisture content (%)	Water activity (a_w)	pH value
	L* (lightness)	a* (redness to greenness)	b* (yellowness to blueness)			
Liang leaves powder; G1 (3600 W 12 min)	49.86 ± 0.2 ^{b}	-11.88 ± 0.07 ^{b}	29.77 ± 0.25 ^{b}	5.83± 0.07 ^{b}	0.42 ± 0.00 ^{b}	5.9 ± 0.02 ^{b}
Liang leaves powder; G2 (2400 W 15 min)	46.19 ± 0.08^{c}	-9.64 ± 0.09^{c}	25.36± 0.14 ^{c}	7.15± 0.09 ^{c}	0.48 ± 0.00^{c}	5.9± 0.00^{b}
Commercial Japanese green tea matcha powder (M)	56.09 ± 0.03^{a}	-12.93 ± 0.02^{a}	33.45± 0.09 ^{a}	1.10 ± 0.07^{a}	0.24 ± 0.01 ^{a}	5.85 ± 0.02^{a}

Color is one of the major parameters of dried food products. The L* coordinate indicates darkness or lightness and ranges from black (0) to white (100). Coordinates, a* and b*, indicate color directions: +a* is the red direction, -a* is the green direction, +b* is the yellow direction, and -b* is the blue direction. Results in Table 1 showed that the lightness (L*) of Liang leaves powder increased when using 3600 W for 12 min, with a higher green color value compared with using 2400 W for 15 min, while moisture content and water activity of the powder decreased. The a* and b* values were high in the 3600 W for the 12 min microwave vacuum drying process. Both Liang leaves powders and the commercial Japanese green tea (M) powder exhibited a green-blue color. The main compound response to green color is chlorophyll, while yellow to red color reflects lutein, α-carotene, β-carotene, and total carotenoids (Itle and Kabelka, 2009). The color of the two Liang leaf powders compared with commercial Japanese green tea (matcha) powder is shown in Fig. 2.

For microbial quality, the dried product gave total plate counts higher than the standard regulation (< 100 CFU/g). Interestingly, the dried sample was significantly contaminated with *Bacillus cereus* at 15–18 times higher than the standard regulation (Table 2). Total aerobic plate count, yeast and mold, and *Escherichia coli* were 6.4 120x 10^4 CFU/g, 50–120 CFU/g, and < 3.0 MPN/g, respectively. Pathogenic bacteria including *Bacillus cereus* were 1500–1800 CFU/g while *Clostridium perfringens* were < 10 CFU/g. Spore-forming bacteria such as *Bacillus cereus* and *Clostridium perfringens* can survive in harsh environments.

Table 2
Effect of microwave vacuum drying on microbial quality of Liang leaves powder

Type	**Microwave** **3600 W 2400 W** **12 min 15 min**		**Method**	**Community product standardM.P.1441/2013 (Herbs mixed with instant powder) ; The Ministry of Public Health (No. 426) 2021 (Plant-based Tea)**
Total plate count	6.4×10^4 CFU/g	120×10^4 CFU/g	BAM (2001), Chap. 3	< 1×10^4 CFU/ g
Yeast and mold	50 CFU/g	120 CFU/g	BAM (2001), Chap. 18	< 100 CFU/ g
Coliforms	2.4×10^4 MPN /100 g	2.4×10^4 MPN /100 g	BAM (2017), Chap. 4	< 2.2 MPN/ 100 g
Escherichia coli	< 3.0 MPN/g	< 3.0 MPN/g	BAM (2017), Chap. 4	Not detected
Salmonella spp.	Not detected in 25 g	Not detected in 25 g	BAM (2018), Chap. 5	Not detected
Staphylococcus aureus	Not detected in 0.1 g	Not detected in 0.1 g	BAM (2016), Chap. 12	≤ 100 CFU/ 1 g
Bacillus cereus	1500 CFU/g	1800 CFU/g	BAM (2012), Chap. 14	≤ 100 CFU / 1 g
Clostridium perfringens	< 10 CFU/g	< 10 CFU/g	BAM (2001), Chap. 16	≤ 100 CFU / 1 g

In-depth interviews recorded that farmers used chicken manure as fertilizer, which may be a source of *Bacillus sp*. (Haque et al., 2022). Therefore, specific detergents or a washing step may require further investigation. Another possibility is coating the leaves with wax to protect against microbial. However, *Salmonella* spp. and *Staphylococcus aureus* were not found in all samples. Therefore, the controversial result between *Bacillus cereus* and other pathogenic bacteria including *Escherichia coli* and *Salmonella* spp. required further investigation. Commercial probiotics as *Bacillus* species are now used including *B. cereus*, *B. clausii*, *B. coagulans*, *B. licheniformis*, *B. polyfermenticus*, *B. pumilus*, and *B. subtilis* (Lee et al., 2019). Generally, Bacillus bacteria are mainly found in chicken, mouse, and pig (Jacquier *et al.*, 2009; Ma et al., 2018). Therefore, detecting *Bacillus cereus* in the dried product may not only infer a negative meaning as a food pathogen but also the beneficial side of being a probiotic agent. Health-beneficial strains require further investigation to ensure the safety of their phenotypes and genotypic characteristics. This experiment also revealed the disadvantage of using microwave vacuum drying in terms of reduced efficiency for microbial reduction, which should be noted as a safety warning for food or product processing.

Using microwave vacuum drying at 3600 W provided higher vitamin and mineral values than using 2400 W. Drying at a higher power (3600 W) for a shorter time retained more β-carotene and folic contents compared with a lower power (2400 W) for a longer time (Table 3).

Table 3
Effect of microwave vacuum drying on vitamin contents of Liang leaves powder

Vitamin	**Unit/ 100 g**	**Content**		**Method**
		Dry basis weight (dry sample weight)		
		Microwave drying condition		
		3600 W 12 min	**2400 W 15 min**	
Vitamin A (Beta-carotene)	µg	4162.68 (3920)	3991.38 (3706)	Based on JAOAC (1997)
Vitamin B1 (Thiamine)	mg	0.23 (0.22)	0.18 (0.17)	Based on Food Chemistry, Vol.56, No.1, 1996, P.81–86
Vitamin B2 (Riboflavin)	mg	0.46 (0.43)	0.67(0.62)	Based on Food Chemistry, Vol.56, No.1, 1996, P.81–86
Vitamin B5 (Pantothenic acid)	mg	6.64(6.25)	7.49(6.95)	Based on AOAC (2016), 945.74
Vitamin B6 (Pyridoxine)	mg	Not Detected	0.41(0.38)	Based on Food Chemistry, Vol.56, No.1, 1996, P.81–86
Vitamin B9 (Folic acid)	µg	1016.25 (957)	898.22 (834)	USFDA (1996)
Vitamin C	mg	405.65 (382)	435.11 (404)	Based on Bull. Dept.Med.Sci., Vol.40, No., 1998, P.347–357
Vitamin K	µg	2208.77 (2080)	1367.80 (1270)	Based on AOAC (2016), 999.15

The sample temperature in the basket tank was 40–50 ºC and 50–60 ºC when using 2400 W and 3600 W, respectively indicating that heating time may also play a role in destroying some chemical compounds, possibly due to O_2 tension activity. Interestingly, Liang leaves had high zinc content at

5.07(4.77)-5.01(4.65) mg/100 g (Table 4), similar to oysters, red meat or animal products (Firouzi et al., 2022).

Table 4
Effect of microwave vacuum drying on mineral contents of Liang leaves powder

Mineral	Unit/ 100 g	Content Dry basis weight (dry sample weight)		Method
		Microwave drying condition		
		3600 W 12 min	2400 W 15 min	
Calcium	mg	367.42 (346)	328.49 (305)	Based on AOAC (2016), 984.27
Copper	mg	0.66(0.62)	0.69(0.64)	Based on AOAC (2016), 2011.19
Iron	mg	5.63(5.30)	5.73(5.32)	Based on AOAC (2016), 2011.19
Magnesium	mg	234.68 (221)	197.09 (183)	Based on AOAC (2016), 984.27
Potassium	mg	2763.09 (2602)	3208.40 (2979)	Based on AOAC (2016), 984.27
Selenium	µg	< 5	21.32 (19.8)	Based on AOAC (2016), 2011.19
Sodium	mg	31.64 (29.8)	30.37 (28.2)	Based on AOAC (2016), 984.27
Zinc	mg	5.07(4.77)	5.01(4.65)	Based on AOAC (2016), 2011.19

The Recommended Dietary Allowance (RDA) of zinc is 8 mg/day for women and 11 mg/day for men. Zinc is necessary for adequate innate and adaptive immune system function and is an effective therapeutic strategy for strengthening the immune system in patients with COVID-19 (Firouzi et al., 2022). Liang leaves revealed both water-soluble (vitamin C, B) and fat-soluble vitamins (vitamin A, K) associated with health benefits. Dark green Liang leaves provide high β-carotene, the most potent precursor of vitamin A, which is an important nutrient for vision and preventing night blindness, improving the ability of the immune system to resist infections, and functional development of the gastrointestinal and reproductive systems (Gul et al., 2015).

The consumption of Liang leaves powder provides energy of 348–360 Kcal, with higher energy (360 Kcal) obtained from 3600 W drying reflecting the higher total fat content (Table 5). Interestingly, higher microwave power destroyed protein but not dietary fiber compared with lower power drying. This result requires further investigation for nutritional management.

Table 5
Nutritional composition of Liang leaves powder processed by microwave vacuum drying

Composition g/100 g	Content: Dry basis weight (dried sample weight) Microwave drying condition 3600 W 12 min	Content: Dry basis weight (dried sample weight) Microwave drying condition 2400 W 15 min	Method
Calories (Including dietary fiber) kcals	382.29(360)	374.80(348)	Method of Analysis for Nutrition labeling (1993)
Fat	2.21(2.08)	1.55(1.44)	Based on AOAC (2016), 996.06
Saturated fat	0.72(0.68)	0.44(0.41)	
Unsaturated fat	1.34(1.26)	0.98(0.91)	
Polyunsaturated fat	1.03(0.97)	0.80(0.74)	
Monounsaturated fat	0.30(0.28)	0.18(0.17)	
Protein: Nx6.25	27.08(25.5)	29.08(27)	Based on AOAC(2016), 981.10
Carbohydrate (Including dietary fiber)	63.40(59.7)	61.17(56.8)	Method of Analysis for Nutrition labeling (1993)
Dietary fiber (Total)	43.22(40.7)	39.10(36.3)	AOAC(2016), 985.29
Insoluble dietary fiber Soluble dietary fiber	33.34(31.4) 9.85(9.28)	33.49(31.1) 5.58(5.18)	AOAC(2016), 991.42 AOAC(2016), 993.19

Amino acid profiles of Liang leaves powder produced by vacuum microwave drying are shown in Table 6. Crude protein obtained from 3600 W drying retained essential amino acids better than using 2400 W. Results indicated that proteins and amino acids were easily destroyed by vacuum microwave drying. Most amino acids are heat-sensitive except for glutamic acid and methionine. Therefore, at higher drying temperatures lower amino acid values were found, concurring with Hendriks (2018). The heat-sensitive amino acids in this experiment were histidine, lysine isoleucine, valine, and tryptophan while threonine, methionine, leucine, and phenylalanine were not heat sensitive. The heat labile, non-enzymatic reaction or Maillard reaction between carboxylic and amino groups, particularly for lysine, may also be involved (Yokoyama et al., 2021). Methionine and cystine can be oxidized at the sulfur atom leading to functional loss (Ahmad et al., 2017).

Table 6
Essential amino acid composition of *G. gnemon* var *tenerum* powder affected by microwave vacuum drying

Amino acid (mg/100g)	**Microwave drying condition**			
	3600 W 12 min		**2400 W 15 min**	
	Dry basis weight mg (%)	**Dry sample weight mg (%)**	**Dry basis weight mg (%)**	**Dry sample weight mg (%)**
Isoleucine	769.88 (8.93)	725 (8.79)	986.54 (9.35)	916 (9.35)
Leucine	1784(20.70)	1680 (20.38)	2078.62 (19.7)	1930 (19.7)
Lysine	1699(19.71)	1600(19.41)	2272.48 (21.54)	2110 (21.54)
Methionine	363.17 (4.21)	342 (4.15)	338.18 (3.21)	314 (3.21)
Phenylalanine	1008.81 (11.70)	950 (11.52)	1141.63 (10.82)	1060 (10.82)
Threonine	1060 (12.30)	1125.62 (13.65)	1061.93 (10.07)	986 (10.07)
Tryptophan	200.7 (2.33)	189 (2.29)	274.64 (2.60)	255 (2.60)
Valine	1136 (13.18)	1070 (12.98)	1421.65 (13.48)	1320 (13.48)
Histidine	597.85 (6.94)	563 (6.83)	974.69 (9.24)	905 (9.24)

Non-essential amino acids are not as important as essential amino acids but their reduction impacts heat stability. Results showed that cystine, l-arginine, tyrosine, and glycine were the four most heat-sensitive amino acids, while glutamic acid, aspartic acid, serine, l-alanine, and proline were not heat-sensitive. Interestingly, glutamic acid did not reduce at higher power microwave energy. Changing both essential and non-essential amino acids may partially impact the sensory evaluation. Using higher energy increased amino acid reduction while using lower energy retained amino acid quantity (Table 7).

Table 7
Non-essential amino acid composition of *G. gnemon* var *tenerum* powder affected by microwave vacuum drying

Non-essential amino acid (mg/100g)	Microwave drying condition			
	3600 W 12 min		2400 W 15 min	
	Dry basis weight mg (%)	Dry sample weight mg (%)	Dry basis weight mg (%)	Dry sample weight mg (%)
Aspartic acid	2591.06 (22.58)	2440 (22.58)	2714.05 (18.70)	2520 (18.70)
Cystine	58.19 (0.51)	54.8 (0.51)	1058.70 (7.29)	983 (7.29)
Glutamic acid	2176.91 (18.97)	2050 (18.97)	1992.46 (13.73)	1850 (13.73)
Glycine	789 (6.88)	743 (6.88)	1109.32 (7.64)	1030 (7.64)
L-Alanine	1741.53 (15.18)	1640 (15.18)	1960.15 (13.50)	1820 (13.50)
L-Arginine	1125.62 (9.81)	1060 (9.81)	2078.62 (14.32)	1930 (14.32)
Proline	1327.39 (11.57)	1250 (11.57)	1486.27 (10.24)	1380 (10.24)
Serine	1338.01 (11.66)	1260 (11.66)	1324.72 (9.13)	1230 (9.13)
Tyrosine	328.13 (2.86)	309 (2.86)	790.52 (5.45)	734 (5.45)

Interestingly, using 3600 Watts for 12 min retained fatty acid composition profiling better than using 2400 Watts for 15 min shown in Table 8. Reduction of fatty acids from intact plant organelles may be induced by oxidation (O_2 exposure) and temperature. The fat content in the leaves was not high and not in a free form; therefore, the stability may be longer. Dąbrowska et al. (2015) reported that unsaturated fatty acids were most sensitive to O_2 tension and time. Interestingly, omega-3, 6 and 9 unsaturated fatty acids were found in the Liang leaves. This may be the first documented data concerning the nutritional composition of the most popular highly priced Liang leaves, *G. gnemon* var. *tenerum*.

Table 8
Fatty acid composition of *G. gnemon* powder under various microwave vacuum drying conditions

Fatty acid (mg/100g)	Content Dry basis weight (dry sample weight)	
	Microwave drying condition	
	3600 W 12 min	2400 W 15 min
Alpha-linolenic acid (C18:3,ALA, Omega-3)	0.71(0.67)	0.54(0.50)
Arachidonic acid (C20:0)	(< 0.01)	Not Detected
Capric acid (C10:0)	0.02	0.02
Docosahexaenoic acid (C22:6, DHA Omega-3)	Not Detected	0.02
Lauric acid (C12:0)	0.05	0.02
Lignoceric acid (C24:0)	0.02	0.01
Linoleic acid (C18:2, Omega-6)	0.32(0.30)	0.24(0.22)
Myristic acid (C14:0)	0.02	<0.01
Oleic acid (C18:1,Omega-9)	0.29(0.27)	0.17(0.16)
Omega-3	0.71(0.67)	0.56(0.52)
Omega-6	0.32(0.30)	0.24(0.22)
Omega-9	0.29(0.27)	0.17(0.16)
Palmitic acid (C16:0)	0.50(0.47)	0.32(0.30)
Palmitoleic acid (C16:1)	0.01	0.01
Stearic acid (C18:0)	0.11(0.10)	0.08(0.07)

The sensory acceptability of Liang leaves drink prepared using two conditions was compared with commercial Japanese matcha based on appearance, color, aroma, flavor, mouthfeel, aftertaste, and acceptability with results shown in Table 9. Consumers preferred the matcha drink to the Liang leaves drink, possibly because the latter had a strong smell and unfamiliar odor compared with the commercial green tea.

Table 9
Sensory evaluation of the Liang leaves powder drink produced by microwave vacuum drying

Characteristic	Liang leaves powder drink		
	3600 W 12 min	2400 W 15 min	Matcha powder
Appearance	5.82 ± 1.49^{a}	6.10 ± 1.37^{a}	7.42 ± 0.91^{b}
Color	6.42 ± 1.37^{a}	6.68 ± 1.08^{a}	7.38 ± 0.92^{b}
Aroma	5.30 ± 1.80^{a}	5.46 ± 1.72^{ab}	7.06 ± 1.33^{b}
Flavor	5.26 ± 1.74^{a}	5.58 ± 1.69^{a}	6.38 ± 1.65^{b}
Mouthfeel	5.36 ± 1.82^{a}	5.58 ± 1.69^{a}	6.54 ± 1.47^{b}
Aftertaste	5.36 ± 1.88^{a}	5.54 ± 1.73^{ab}	6.26 ± 1.56^{b}

Each value was expressed as the mean ± standard deviation (n = 3). Different letters in the same column indicated significant differences($p < 0.05$).

This aroma could be resolved by modification with some fragrant spices, fruits, and flowers. Many panelists also noted that Liang powder showed promise as an alternative source for soups, sauces, and functional ingredients for other products due to its nutritive value and savory property with a meaty taste and flavor.

4. Conclusions

Microwave vacuum drying at 3600 Watts for 12 minutes was selected to produce Liang leaves powder, giving better color value, moisture content, a_w and fatty acid composition. However, using lower magnetron power retained both essential and non-essential amino acids. Some minerals and vitamins are heat sensitive compounds. The sensory acceptability of the Liang leaves powder was lower than the commercial Japanese green tea but Liang leaves powder may be suitable for addition to savory products. The Liang leaves powder showed high potential as a functional food ingredient. However, odor modification may be needed to increase consumer acceptance of the drink.

Declarations

Informed consent (human ethical approval)

The ethical permission was approved with reference number PSU-HREC-2023-005-1-1 by the Human Research Ethics Committee, Prince of Songkla University

CRediT authorship contribution statement

Nata Anisong: Methodology, Experiment, Formal analysis, Writing – original draft, Draft manuscript. Sunisa Siripongvutikorn: Conceptualization, Facility and protocol support, Formal analysis, Supervision, Writing - review & editing, Editing, revising manuscript. Panupong Puttarak: Formal analysis, Granting. Santad Wichienchot: Formal analysis.

Declaration of competing interest

We confirm that there was no conflict of interest in this study.

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Author Contribution

Nata Anisong: Methodology, Experiment, Formal analysis, Writing – original draft, Draft manuscript. Corresponding author:Sunisa Siripongvutikorn: Conceptualization, Facility and protocol support, Formal analysis, Supervision, Writing - review & editing, Editing, revising manuscript. Panupong Puttarak: Formal analysis, Granting. Santad Wichienchot: Formal analysis.

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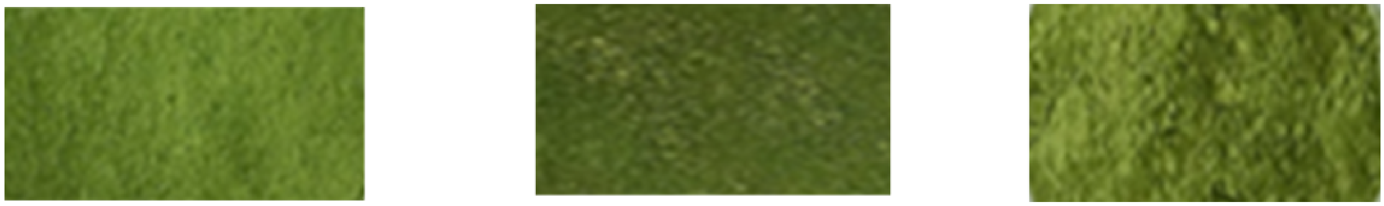
Figures

Figure 1

The edible stage of the light green leaves called Bai pe-salat (order number 3-4) was used in this experiment as quality control of raw material. The top leaves are also edible but were not used in this experiment.



(G1) (G2) (M)

Figure 2

Color of Liang leaves powder processed by different microwave vacuum drying conditions as 3600 Watts (600 W x 6 magnetrons 12 min) (G1), 2400 Watts (600 W x 4 magnetrons 15 min) (G2), and commercial Japanese green tea (matcha) powder (M).