European Journal of Medicinal Plants

32(3): 22-33, 2021; Article no.EJMP.67741
ISSN: 2231-0894, NLM ID: 101583475

Comparative Study of the Effect of Five Drying Methods on Bioactive Compounds, Antioxidant Potential and Organoleptic Properties of *Zingiber officinale* (*Ginger*) Rhizome

Yves M. T. Tientcheu[1,2*], Ruth E. K. Dibacto[1,3], Ferdinand L. E. Edoun[1,3], Elsa F. K. Matueno[1], Alex D. K. Tchuenchieu[1], Yadang Germaine[1,4] and Gabriel N. Medoua[1]

[1]Centre for Food and Nutrition Research, Institute of Medical Research and Medicinal Plants Studies, P.O.Box 13 033, Yaoundé, Cameroon.
[2]Laboratory of Plant pathology, Department of Plant Biology and Physiology, Faculty of Sciences, University of Yaoundé 1, P.O.Box 812, Yaoundé, Cameroon.
[3]Laboratory of Nutrition and Nutritional Biochemistry, Department of Biochemistry, Faculty of Sciences, University of Yaoundé 1, P.O.Box 812, Yaoundé, Cameroon.
[4]Department of Food Science and Nutrition, National School of Agro-Industrial Sciences, University of Ngaoundéré, P.O.Box 455, Ngaoundéré, Cameroon.

Authors' contributions

This work was carried out in collaboration among all authors. All members contributed in designing the study. Authors YMTT, REKD, FLEE and EFKM wrote the protocol and managed the analyses of the study. Author ADKT performed the statistical analysis together with authors YMTT and REKD who wrote the first draft of the manuscript. Authors ADKT, YG and GNM supervised the work. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/EJMP/2021/v32i330378
Editor(s):
(1) Dr. N. Karmegam, Government Arts College, India.
(2) Prof. Marcello Iriti, Milan State University, Italy.
Reviewers:
(1) Aurelia Magdalena Pisoschi, University of Agronomic Sciences and Veterinary Medicine of Bucharest, Romania.
(2) Matsuoka, Jissen Women's University, Japan.
Complete Peer review History: http://www.sdiarticle4.com/review-history/67741

Original Research Article

Received 02 March 2021
Accepted 08 May 2021
Published 20 May 2021

ABSTRACT

Aims: Ginger (*Zingiber officinale*) is one of the most popular and widely used spice, known for its health benefits. This study aimed at assessing the potential impact of a Handcrafted dryer (HCD) on the quality of ginger in comparison to the most common drying methods.

**Corresponding author: E-mail: yves.tongue@gmail.com;*

Methodology: Fresh ginger originating from 2 regions were dried using the following techniques: HCD; Air Drying (AD); Ventilator Oven (VO) at 50°C, 60°C and 80°C; Freeze Drying (FD) and Microwave drying (MD) at 700 and 900 W) methods. Dried products were ground and infused in hot water and the total flavonoid contents, and antioxidant potential through different mechanisms (DPPH radical, FRAP and TAC assays) as well as the sensory properties of the infusions were assessed.
Results: TFC of the samples significantly varied with regard to the origin of the Ginger. Infusions deriving from the dried ginger from HCD and VO at 80°C exhibited the highest TPC, TFC and antioxidant activities. While the rise of temperature with VO led to an increase of TPC, it was rather a decrease that was observed with the rise of microwave power level but which did not have a significative effect on the antioxidant potential. No significant difference was noticed in the acceptance of infusions by consumers except MD samples, which received the lowest score by panelists.
Conclusion: Heat-based processes appears to be useful in the optimization of the nutritional value of dried ginger, and HCD appropriate for farmers as it is easy and not expensive to put into practice.

Keywords: Drying methods; ginger; bioactive compounds; antioxidant potential; organoleptic properties.

ABBREVIATIONS

DM : Dry Matter
GAE : Gallic Acid Equivalent
QE : Quercetin Equivalent
AE : Aqueous extract
BA : Bafut
ST : Santchou

1. INTRODUCTION

Zingiber officinale (Ginger) has been widely used as a spice for over 2000 years. There exist 47 genera and 1400 species [1]. Extensively used in cooking for its taste and ability to facilitate digestion, ginger is a good source of nutrients, minerals and essential amino acids. It is particularly known for its high potassium content [2]. Furthermore, this spice is considered to be an important ingredient in herbal medicine for the treatment of various diseases among which cold, stomach upsets, diarrhoea and nausea [3]. Phytochemical studies show that ginger has antioxidant and anti-inflammatory activities, and some of them have anticancer potentials [4]. Recent studies have even shown that ginger phenolics compounds like 8-gingerol, 10-gingerol are significantly active against COVID-19 [5]. Fresh ginger typically contains 85-95% water and is susceptible to microbial and chemical deterioration [6]. Dehydration is the most common process used to limit postharvest losses. The dried product obtained is generally used to make diverse products like ginger powder (spice for cooking), medicines and cosmetics, as well as ginger flavoured foods such as sodas, candies and teas. Dehydration can serve to minimize microbial and chemical deterioration. Nevertheless, the drying process may also lead to high changes in the physical, chemical and organoleptic properties depending on the process used [7,8,9]. In fact, the drying process inhibits microbial growth in plants, influences the change in physicochemical properties (appearance and aroma) and at the same time increases other changes that affect the quality of ginger. The loss of volatile compounds or the formation of new volatile compounds through multiple reactions such as oxidation or esterification, decay of antioxidant compounds, may occur [10]. This process can also lead to the loss of more bioactive compounds that may have antioxidant potential and multiple health properties [11]. Nowadays, many drying methods have been developed and are classified into different groups namely Hot Air Drying (HAD), Oven Drying (OD), Low Temperature Air Drying, Microwave Drying (MD) and Lyophilization (FD) [12]. Drying using a ventilated oven, in a freeze-dryer, in the microwave, is quite often not accessible to farmers. The cost of purchasing these devices and the energy consumption are very high. The open-air drying is the easiest to put into practice and is the most popular. Traditional drying exposes the product to alteration (insects, pests, microbial contamination) and poses a food safety problem for consumers [13]. In 2017, Tchouotaha [14] had developed a charcoal-based combustion dryer which had as advantage to be economically profitable and that could be of interest for ginger drying. This study aims at

studying the potential impact of that novel drying approach on the final quality of ginger in comparison to the most common drying methods.

2. MATERIALS AND METHODS

2.1 Raw Material

Ginger rhizomes originating from two different regions of Cameroon, namely *Santchou* (West, Cameroon) and *Bafut* (North West, Cameroon), were bought in local markets. They were sorted, washed with tap water, and cut into cylindrical slices with a thickness of 4 mm and a diameter of 33 mm for uniformity purposes. The ginger slices were separated into two batches with regards to the two regions of origin. For each drying method, 250 g of sliced ginger from each of the two batches were tested in triplicate. Drying was stopped once the weight became constant.

2.2 Tested Drying Methods

2.2.1 Ventilator oven (VO)

It was carried out in a brand oven *(Venti-line VWR,* USA*)*. The 250 g of sliced ginger was distributed in a single layer on a stainless aluminium foil in the middle of the chamber. Hot air circulated on one side, opposite the chamber, parallel to the surface of the tray. Three different drying temperature levels were used for this study (50, 60 and 80°C).

2.2.2 Microwave drying (MD)

It was performed using brand experimental microwave oven *(SHARP, R77,* Japan*)*. Ginger was spread out on a glass plate and dried at two powers 700 and 900 W.

2.2.3 Freeze drying (FD)

For the FD method, the sliced ginger was put in plastic bags and placed in a refrigerator (*Labcold, Basingstoke Hants*) at -20°C for 24 hours. The frozen samples were then placed in a freeze dryer *(Christ Beta 1-2, Bioblock scientific,* France*)* and dried at −55°C. The operation lasted 48 hours.

2.2.4 Handcrafted dryer (HCD)

A charcoal-based combustion dryer was firstly built based on Tchouotaha's work [14]. It is made of two compartments, a combustion and a drying chamber (Fig. 1), and could reach a maximum temperature of 130°C in the drying chamber. The device does not have a fan, but an opening of 30 cm x 15 cm inside the product drying chamber. With a height 1.20 m and width 0.65 m, it is made from wood (backing plate) for the frame of the device. The entire device is covered with smooth metal sheets for the internal and external coating of the plywood. The ginger samples were distributed in a single layer, on a stainless aluminium foil and inserted in the middle of the chamber for drying.

2.2.5 Air drying (AD)

The sliced ginger was simply placed on a rack and dried under the sun till the weight became constant.

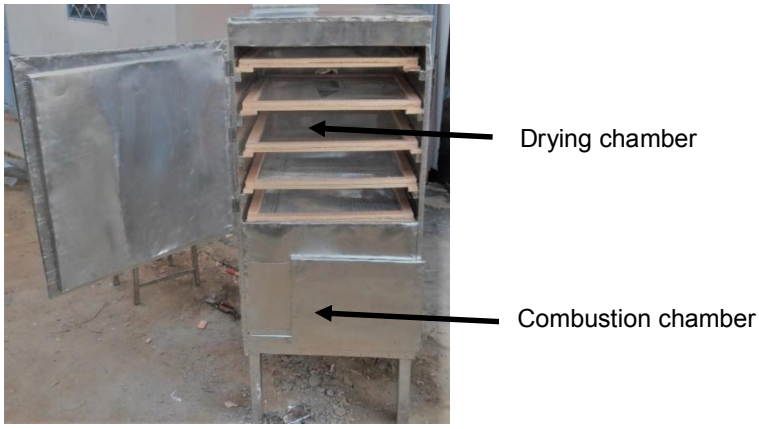

Fig. 1. The built charcoal-based combustion dryer

2.3 Quality Analyses of the Obtained Products

2.3.1 Sample preparation

In order to simulate a household herbal tea preparation, 1 g of each grounded sample obtained from the different drying methods, was infused in 100 mL of boiled distilled water (100°C) and stirred continuously for 5 min using a magnetic stirrer (*Agimatic-S, J.P. Selecta S.A.*, *Barcelona,* Spain). The infusion was left to cool before being filtered using a filter paper (*Wathman* N° 4) for analyses.

2.3.2 Biochemical analyses

2.3.2.1 Assessment of total phenolic content

The total phenolic content (TPC) in ground ginger extracts was determined using the Folin-Ciocalteu method [15]. A volume of 50 µL of ginger extracts was mixed with 575 µL of distilled water and 125 µL of the Folin-Ciocalteu Reagent (1:16). After 5 min, 1250 µL of a 7% sodium carbonate ($NaCO_3$) solution was added and the volume was adjusted to 3 mL with distilled water. The absorbances were read at 760 nm (*UVmini-1240, UV-Vis Spectrophotometer*, *Shimadzu-Japan*) against the blank. The calibration curve was obtained using standard gallic acid with a concentration range of 20 to 600 mg/mL. The TPC were expressed in milligram (mg) gallic acid equivalents per gram (g) of dry matter (mg GAE/g DM). (r^2=0.9881).

2.3.2.2 Assessment of total flavonoid content

The total flavonoid content (TFC) was estimated by the method described by Bahorun et al. [16]. To 1 mL of ginger extracts was added 1 mL of aluminium trichloride ($AlCl_3$) solution dissolved in methanol (2% w/v) and 1 mL of potassium acetate solution (CH_3COOK, 1M). After 10 minutes of incubation at 25°C, the absorbances were read at 430 nm against the blank. The flavonoid contents were expressed in milligram (mg) quercetin equivalents per gram (g) of dry matter (mg QE/g DM) considering the standard quercetin calibration curve *(r^2*=0.991).

2.3.2.3 Evaluation of antioxidant potential

2.3.2.3.1 DPPH Free-Radical Scavenging assay

The radical scavenging activity was assessed using the 2, 2′-diphenyl-1-picrylhydrazyl (DPPH) test as described by Sanchez-Moreno et al. [17]. A volume of 50 µL of the ginger extract was added to 1950 µL of a freshly prepared methanolic DPPH solution (0.025 g/L). After 30 minutes of incubation at room temperature (25 ± 1°C) in the dark, the absorbances were read at 517 nm. Methanol was used as a control and ascorbic acid (vitamin C) as standard. The capacity of the extracts to trap the DPPH radical was expressed as a percentage of inhibition of the DPPH radical using the following formula:

$$Percentage\ DPPH\ Scavenging\ Activity = \frac{Absorbance\ of\ Control - Absorbance\ of\ Sample}{Absorbance\ of\ Control}\ X\ 100$$

2.3.2.3.2 Determination of Total Antioxidant Capacity (TAC)

The TAC was performed based on the reduction of molybdenum Mo (VI) as described by Prieto et al. [18]. For that, 0.3 mL of each extract was mixed with 3 mL of reagent solution [equivolume mixture of sulfuric acid (H_2SO_4, 0.6 M); sodium phosphate (NaH_2PO_4, 28 mM) and ammonium molybdate ($(NH_4)_6Mo_7O_{24}$, 4 mM)]. The tubes were screwed and incubated at 95°C for 90 minutes in a water bath (*PolyScience*, USA). After cooling, the absorbances were read at 695 nm against the blank (3 mL of the reagent solution and 0.3 mL of methanol). The TAC was expressed in milligrams of ascorbic acid equivalent per gram of dry matter (mg AAE/g DM) considering a standard curve generated with different concentrations of ascorbic acid (0.01 – 0.5 mg/mL).

2.3.2.3.3 Evaluation of Ferric Reducing Antioxidant Power (FRAP)

The Oyaizu method [19] was used. In fact, 1 mL of ginger extract was mixed with 2.5 mL of 0.2 M sodium phosphate buffer (0.2 M, pH 6.6) and 2.5 mL of potassium ferrocyanide ($K_3Fe(CN)_6$, 1%), after which it was incubated in a water bath at 50°C (*PolyScience*, USA) for 20 min. Then, 2.5 mL of trichloroacetic acid (TCA, 10%) was added to the mixture which was centrifuged at 650g for 10 min. From the obtained supernatant, 2.5 mL was mixed with 2.5 mL of distilled water and 0.5 mL of ferric chloride solution ($FeCl_3$, 0.1%). The intensity of the blue-green colour was measured at 700 nm. Ascorbic acid was used as a positive control at a concentration ranging from 0 to 0.30 mg/mL.

2.3.3 Organoleptic analysis

Sensory analysis was performed by a panel constituted of 15 persons between the age range of 25-45 years. Scores on a 9-point hedonic scale (1= dislike extremely to 9=like extremely) where attributed with regards to the colour, turbidity, taste and odour.

2.4 Statistical Analysis

Experiment data were analysed using *Statistica* software. A one-way ANOVA test (Least Squared Difference) was performed to assess the significance of the differences between the mean values obtained.

3. RESULTS

3.1 Effect of Drying Methods on Total Phenolic and Flavonoid Contents of Ginger

Table 1 shows the total phenolic and flavonoid contents of the different ginger infusion extracts obtained from the different drying methods. Ginger from *Santchou (ST Ginger)* globally tended to have a higher content when compared to that from *Bafut* (BA Ginger) but this difference was not significative when comparing TPC. The use of the air drying (AD) and handcrafter drying (HCD) methods led to products with the lowest and highest TPC, respectively. This was not the case with TFC where the lowest values were obtained with ginger dried at 60°C in a ventilated oven (VO) and the highest with sample from ventilated oven 50°C (BA Ginger) and handcrafter dryer (ST Ginger). The statistical analysis reveals no significant difference in the TPC of sample dried through HCD, VO 80, MD 700W, VO 60 for the case of BA ginger, and only between the first two methods for ST ginger. On the other side, a statistically similar TFC was observed with ginger dried through VO 50 and MD 700W for BA ginger, and through HCD, FD, VO 80 and MD 90. While the increase in the power of microwave from 700 to 900 W led to a decrease of the TPC and TFC of ginger, the rise of the drying temperature from 50°C to 80°C when using a ventilated oven rather led to an increase of TPC. This was not the case with TFC where a down hyperbolic tendency appeared. Samples made with ginger dried at 60°C exhibited a lower content compared to those coming from ginger dried at 50 and 80°C.

3.2 Antioxidant potential of ginger

The results obtained from the analysis of the antioxidant potential of the different ginger samples are presented in Table 2. Regardless of the drying method, it globally tended to be no significant difference between the antioxidant potential of ginger from *Bafut* and *Santchou* when considering DPPH scavenging and FRAP values obtained. In five cases out of the eight tested conditions, *BA* ginger samples rather showed a significative higher TAC. Drying at VO of 50 and 60°C led to samples with the lowest DPPH* scavenging potential. The remaining samples showed no significant difference between their scavenging activities. Besides, HCD and VO 80 appeared as the drying methods leading to the highest TAC and FRAP of the samples. At the opposite of what was previously noted with TPC and TFC, the rise of microwave power from 700 to 900 W did not lead to significant changes of the antioxidant potential of the samples. An increase of the antioxidant potential with the rise of temperature was rather noticed when performing drying with a ventilated oven.

3.3 Effect of Drying Methods on Organoleptic Properties

No significant difference was observed with respect to the sensory analysis of the ginger originating from *Santchou* and *Bafut*. Samples obtained from the ginger dried with microwave (MD) at 900W received a negative appreciation (below 5); all the other samples had a score ranging from 5 to 7 whatever the evaluated parameters. Overall, MD at either 700 or 900 W led to products with the less appreciated colour, turbidity, taste and smell. No significant difference in the appreciation of these parameters was observed when comparing score given to samples made using the other drying methods.

Table 1. Total phenolic content and total flavonoid content of the different ginger samples

Drying Methods	Total Phenolic contents (mg QE/g DM)		Total Flavonoid contents (mg GAE/g DM)	
	BA Ginger	ST Ginger	BA Ginger	ST Ginger
Air drying (AD)	$^{a}690.20 \pm 83.00^{a}$	$^{abc}867.97 \pm 18.11^{a}$	$^{a}69.06 \pm 4.94^{a}$	$^{c}131.28 \pm 3.56^{b}$
Freeze drying (FD)	$^{ab}839.22 \pm 54.90^{a}$	$^{abc}875.82 \pm 47.28^{a}$	$^{b}95.32 \pm 5.50^{a}$	$^{d}158.11 \pm 8.62^{b}$
Handcrafted dryer (HCD)	$^{c}1092.81 \pm 106.49^{a}$	$^{e}1286.27 \pm 81.51^{a}$	$^{b}101.03 \pm 0.00^{a}$	$^{d}165.53 \pm 3.56^{b}$
Ventilated oven 50°C (V0 50)	$^{a}724.18 \pm 65.31^{a}$	$^{ab}742.48 \pm 81.63^{a}$	$^{f}173.52 \pm 5.23^{a}$	$^{c}132.42 \pm 2.62^{b}$
Ventilated oven 60°C (VO 60)	$^{bc}1035.29 \pm 141.39^{a}$	$^{cd}977.78 \pm 78.95^{a}$	$^{a}66.21 \pm 5.50^{a}$	$^{ab}112.44 \pm 4.31^{b}$
Ventilated oven 80°C (VO 80)	$^{C}1090.42 \pm 45.96^{a}$	$^{de}1173.86 \pm 44.60^{a}$	$^{bc}103.31 \pm 4.94^{a}$	$^{d}159.82 \pm 5.23^{b}$
Microwave drying 700 W (MD 700)	$^{c}1087.58 \pm 86.04^{a}$	$^{cd}1035.29 \pm 109.80^{a}$	$^{ef}160.39 \pm 4.31^{b}$	$^{c}130.14 \pm 3.42^{a}$
Microwave drying 900W (MD 900)	^{ab} 823.53 ± 35.94^{a}	$^{bcd}954.25 \pm 32.65^{a}$	$^{d}132.42 \pm 4.31^{b}$	$^{d}115.87 \pm 3.56^{a}$

BA: Bafut; ST: Santchou, Values are means ± SD (n = 3). Within the same column, values that are not preceded by the same letter are significantly different; within the same line, values that are not followed by the same letter are significantly different at P < 0.05

Table 2. Antioxidant potential of the different ginger samples

Drying Methods	DPPH (%)		TAC (mg AAE/g DM)		FRAP (mg AAE/g DM)	
	BA Ginger	ST Ginger	BA Ginger	ST Ginger	BA Ginger	ST Ginger
Air drying (AD)	^{b}43,16 ±3,33^{a}	^{b}42.07 ± 2.9^{a}	^{ab}150.21 ± 3,43^{a}	^{a}124.63 ± 6.61^{b}	^{cde}1863.47 ±178.83^{a}	^{cde}1937.89±143.08^{a}
Freeze drying (FD)	^{b}36,05 ±2,16^{a}	^{b}35.61 ± 1.66^{a}	^{ab}153.92 ± 1.78^{a}	^{ab}127.50 ±6.32^{b}	^{bc}1591.46 ± 78.45^{a}	^{ab}1395.96 ±85.17^{a}
Handcrafted dryer (HCD)	^{b}44,38 ±0,25^{a}	^{b}44.99 ± 0,74^{a}	^{e}182.88 ± 7.87^{a}	^{g}188.13 ± 6.92^{a}	^{f}2349.84 ± 201,42^{a}	^{de}2035.38 ± 38.61^{a}
Ventilated oven 50 (V0 50)	^{a}4.01 ± 0,86^{a}	^{a}13.47 ± 6.4^{a}	^{de}172.54 ± 6.82^{a}	^{bc}141.63 ±0.45^{b}	^{a}1187.89 ± 166.38^{a}	^{bcd}1677.94 ±65.63^{b}
Ventilated oven 60°C (VO 60)	^{a}12,42 ± 4,38^{a}	^{a}15.95 ± 2.22^{a}	^{cde}170.50 ± 3.04^{a}	^{def}170.33 ± 3.5^{a}	^{bcd}1669.03 ± 74.88^{a}	^{bcd}1756.03±74.88^{a}
Ventilated oven 80°C (VO 80)	^{b}38,67 ±7,21^{a}	^{b}39.76 ± 4.32^{b}	^{e}183.50 ± 0.66^{a}	^{fg}178.58 ±5.62^{a}	^{def}2036.43 ± 22.91^{a}	^{e}2209.38 ± 64.18^{a}
Microwave drying 700W (MD 700)	^{b}47.47 ±0.92^{a}	^{b}44.51 ± 5.12^{a}	^{bcd}159.50 ± 5.63^{a}	^{ab}128.42 ±5.51^{b}	^{ef}2104.04 ±177.73^{a}	^{de}1987.16 ± 96.88^{a}
Microwave drying 900W (MD 900)	^{b}36.75 ± 6.1^{a}	^{b}38.75±10.54^{a}	^{abc}156.08 ± 0.59^{a}	^{ab}127.33 ± 3,82^{b}	^{bcde}1750.26±40,16^{a}	^{bcd}1769.65±254.56^{a}

BA: Bafut; ST: Santchou. Values are means ± SD (n = 3). Within the same column, values that are not preceded by the same letter are significantly different; within the same line, values that are not followed by the same letter are significantly different at P < 0.05

Table 3. Global appreciation of the prepared infusion samples

Drying Method	Mark (/9)							
	Colour		Turbidity		Taste		Odour	
	BA	ST	BA	ST	BA	ST	BA	ST
Air drying (AD)	$^{b}5.87\pm1.06^{a}$	$^{bc}5.80\pm1.26^{a}$	$^{bc}5.27\pm1.49^{a}$	$^{bc}5.07\pm1.58^{a}$	$^{b}5.40\pm1.92^{a}$	$^{bc}5.33\pm1.68^{a}$	$^{bc}5.73\pm1.44a$	$^{bc}5.60\pm1.59^{a}$
Freeze drying (FD)	$^{b}6.60\pm1.50^{a}$	$^{c}6.93\pm1.44^{a}$	$^{b}6.67\pm1.18^{a}$	$^{b}6.67\pm1.50^{a}$	$^{b}6.27\pm1.33^{a}$	$^{bc}6.53\pm1.55^{a}$	$^{c}6.40\pm1.06^{a}$	$^{c}6.73\pm1.16^{a}$
Handcrafted dryer (HD)	$^{b}6.13\pm1.06^{a}$	$^{bc}6.40\pm0.83^{a}$	$^{ab}5.67\pm1.45^{a}$	$^{ab}5.60\pm1.35^{a}$	$^{b}6.4\pm1.50^{a}$	$^{bc}6.33\pm1.45^{a}$	$^{bc}6.13\pm1.36^{a}$	$^{bc}6.20\pm1.37^{a}$
Ventilated oven 50°C (V0 50)	$^{b}5.87\pm1.19^{a}$	$^{bc}6.13\pm1.36^{a}$	$^{ab}5.67\pm1.40^{a}$	$^{b}6.07\pm0.88^{a}$	$^{b}5.93\pm1.33^{a}$	$^{bc}5.87\pm1.19^{a}$	$^{bc}6.20\pm1.01^{a}$	$^{bc}5.73\pm1.16^{a}$
Ventilated oven 60°C (VO 60)	$^{b}6.20\pm0.94^{a}$	$^{bc}6.47\pm1.13^{a}$	$^{b}6.00\pm0.85^{a}$	$^{b}5.93\pm1.49^{a}$	$^{b}6.40\pm1.06^{a}$	$^{bc}5.80\pm1.52^{a}$	$^{bc}6.20\pm0.77^{a}$	$^{c}6.60\pm0.99^{a}$
Ventilated oven 80°C(VO 80)	$^{b}6.47\pm1.06^{a}$	$^{c}6.93\pm1.03^{a}$	$^{b}6.27\pm1.16^{a}$	$^{b}6.53\pm1.41^{a}$	$^{b}6.33\pm1.29^{a}$	$^{c}6.67\pm1.45^{a}$	$^{c}6.40\pm1.30a$	$^{c}6.60\pm1.35^{a}$
Microwave drying (MD 700)	$^{ab}5.40\pm1.18a$	$^{ab}5.20\pm1.37a$	$^{b}5.07\pm1.49^{a}$	$^{ab}4.93\pm1.39^{a}$	$^{b}4.93\pm1.16^{a}$	$^{bc}5.00\pm1.25^{a}$	$^{c}4.60\pm1.59a$	$^{ab}4.87\pm1.55^{a}$
Microwave drying (MD 900)	$^{a}5.07\pm1.28^{a}$	$^{a}4.07\pm1.91^{a}$	$^{a}4.93\pm1.44^{a}$	$^{a}4.07\pm1.87^{a}$	$^{a}4.71\pm1.20^{a}$	$^{a}2.93\pm1.79^{a}$	$^{ab}4.53\pm1.60^{a}$	$^{a}3.33\pm1.84^{a}$

BA: Bafut; ST: Santchou. Values are means ± SD (n = 3). Within the same column, values that are not preceded by the same letter are significantly different; Within the same line, values that are not followed by the same letter are significantly different at $P < 0.05$

4. DISCUSSION

The health benefits of ginger are attributed to its antioxidant activity linked to its rich phytochemistry. Its roots total antioxidants have even been reported to be above the ones of pomegranate and some berries [20]. Strengthening the body's defences by improving the antioxidant status helps to protect humans against many chronic diseases [21]. As observed in this study, ginger contains bioactive compounds that are able to scavenge free radicals and this antioxidant potential had already been established through *in vitro* and *in vivo* studies [21]. Ginger is well known to decrease age-related oxidative stress markers [20]. 6-gingerol, 6-shogaol, zingerone beside other phenolics and flavonoids are the most abundant bioactive compounds found in ginger with 6-gingerol being the most abundant and 6-shogaol being less abundant but more biologically active [22].

Different factors, such as plant genetics and cultivar, soil composition and growing conditions, maturity state, and post-harvest conditions, among others determine the phytochemical contents of plants/foods and their concentration [23,24]. This was the case when comparing the total flavonoids content of extracts deriving from ginger rhizomes of *Santchou* and *Bafut*. On the other hand, no significative difference in the TPC was noticed, but Pawar et al. [25] had already reported a variation of phenolics, especially 6-gingerol content, in 12 ginger cultivars from different agro-climatic zones of India and mainly established a linear relationship between DPPH-radical scavenging activity and total phenolic. The correlation was always assumed to be strong when phenolics were grouped with flavonoids. Ghafoor et al. [26] also observed a clear correlation between total phenolics and antioxidant activity of ginger rhizomes (R^2= 0.973, p<0.001), the main phenolics of dried ginger being catechin, gallic acid and 3, 4-dihydroxybenzoic acid.

In the present study, the antioxidant potential of the samples was evaluated using 3 methods (DPPH, FRAP, TAC) in order to test different antioxidant reactional mechanisms. Infusions deriving from HCD and VO 80 dried ginger showed the highest TAC and FRAP but not DPPH. A difference in the nature of the compounds present after the different treatment therefore appears obvious, some being more reactive to an antioxidant pathway than to another. This change induced by the drying process could be appreciated with MD where the rise of microwave power from 700 to 900 W led to a significant reduction of samples TPC and TFC but not in their antioxidant potential. Samples with the highest DPPH* scavenging were confirmed to be the ones with the highest TPC and secondly TFC (cf HCD, VO80 and MD 700W). However, this was not always valid when considering the DPPH* inhibition percentage in AD, which was significantly higher than the one in VO60 especially for BA Ginger. This therefore suggests that the drying processes led to a difference in the nature of the phenolics compounds. As reported by Mao et al. [27], gingerols such as 6-gingerol, 8-gingerol, and 10-gingerol are the major polyphenols of fresh ginger and with heat treatment or long-time storage, they can be transformed into corresponding shogaols, which have different antioxidant potential. After hydrogenation, shogaols can be also transformed into paradols.

FD is one of the processes generally used in laboratories to preserve food samples on a long period. It is considered as the best method of postharvest drying for the conservation of phenolic compounds because it changes microstructure of the plant tissue so that the extraction of flavonoid compounds can be made easier [26,28,29] Comparing oven, microwave, freeze and room-air drying, Ghafoor et al. [26] observed that FD ginger had higher total phenolics, antioxidant activity and total carotenoids, and OD ginger an improved phenolic compounds availability. An increase in the TPC and antioxidant potential of samples from OD ginger was noticed in this study, TFC values being higher than with FD samples. Drying at temperatures up to 80°C therefore enhance phenolics extraction from ginger. On the other hand the reduction of the TFC observed with microwave power level from (700 to 900 W) contrast with Kubra et al. [30] who stated the maximum power level they tested (800W) as optimal for drying of ginger slices with respect to retention of non-volatiles such as TPC including [6]-gingerol. The HCD is a drying method that does not have a ventilation device, making this technic a hybrid method of the Hot Air Drying (HAD) method (HCD is a non-convective drying method). The high levels of polyphenols and flavonoids obtained with HCD could be supported by certain studies which have shown that, HAD drying method (a convective air current system) induces volatilization of the antioxidant compounds. The non-ventilation of

the HCD, favoured a non-volatilization of the bioactive compounds through mechanisms such as glycosylation [31]. Moreover, the heat source could also be singled out, as the heat produced by the HCD coal has a very high intensity compared to the HAD with temperature ranges from 60 to 90°C. These strong intensities of heat produced by the HCD would cause a major rupture of the plant walls cell of the ginger, resulting in a greater release of antioxidant compounds like TPC and TFC as noticed with VO. Another explanation of the high level of polyphenol in samples from HCD could result from the smoke generated during drying process. Indeed, charcoal used as heat source, generated polyphenols during its combustion. These polyphenols present in smoke might interact with the food matrix and lead to an increase of the polyphenol contents of the dry food matrix. The presence of polyphenols in smoke from some tropical hardwoods was highlighted by Sokamte et al. [32].

From a sensorial point of view, MD appears as the worst drying process in comparison to the other tested drying methods. No significant difference was observed in the acceptance of infusions by consumers except MD samples, which received the lowest score from panelists. These results confirm a denaturation of ginger characteristics when using this drying method at a high-power level. Testing a microwave assisted convective dryer at power level up to 240 W, Mohanta et al. [33] rather obtained accepted infusions. This power level is therefore a key parameter to take into consideration when performing such treatment.

5. CONCLUSION

The use of a heat based drying process (HCD/VO80) helps in enhancing the extraction of phenolics and flavonoids from Ginger. Those processes appear of interest in the perspectives of optimizing the antioxidant potential of drinks made with dried ginger and therefore their nutritional value. They can be appropriate for farms as they are easy to perform and less expensive than microwave drying, which may even have acceptability of the obtained dried ginger as limitation.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/67741