ANSF APPLIED AND NATURAL SCIENCE FOUNDATION

Journal of Applied and Natural Science
Special Issue: 14 (SI), 119 - 128 (July, 2022)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Optimization of Heat pump-assisted dehumidified air drying (HPD) temperature on phytochemicals, drying characteristics and nutrient compound retention of drumstick by GC-MS and principle component analysis

G. Pandidurai*
Department of Food Science and Nutrition, Community Science College and Research Institute, Tamil Nadu Agricultural University, Madurai, (Tamil Nadu), India
S. Amutha
Department of Food Science and Nutrition, Community Science College and Research Institute, Tamil Nadu Agricultural University, Madurai, (Tamil Nadu), India
S. Kanchana
Department of Food Science and Nutrition, Community Science College and Research Institute, Tamil Nadu Agricultural University, Madurai, (Tamil Nadu), India
S. Vellaikumar
Department of Biotechnology, Agricultural College and Research Institute, Madurai, (Tamil Nadu), India
K. Prabhakaran
Department of Social Science, Agricultural College and Research Institute, Killikulam, (Tamil Nadu), India

*Corresponding author. Email: nanalpandi@gmail.com

Article Info
https://doi.org/10.31018/jans.v14iSI.3577
Received: March 10, 2022
Revised: April 19, 2022
Accepted: May 30, 2022

How to Cite
Pandidurai G. *et al.* (2022). Optimization of Heat pump-assisted dehumidified air drying (HPD) temperature on phytochemicals, drying characteristics and nutrient compound retention of drumstick by GC-MS and principle component analysis. *Journal of Applied and Natural Science*, 14 (SI), 119 - 128. https://doi.org/10.31018/jans.v14iSI.3577

Abstract
Drumstick (*Moringa oleifera* Lam.) is an incredible plant to humans because of its pharmacognostic and nutraceutical properties. *M. oleifera* contains vital nutrients such as minerals, vitamins, and phytochemicals like tannins and flavonoids. The present work aims to study the optimization and quality attributes retention in drumstick through Heat Pump-assisted dehumidified air Dryer (HPD) because the conventional drying process takes more time and energy, affecting the product quality and safety. Different solvents, such as ethanol, chloroform, hexane, acetone and ethyl acetate, were used to determine the presence of phytochemicals (alkaloids, tannins, flavonoids, steroids, terpenoids and saponins) in the drumstick. The phytochemicals were highly present in methanol and ethanol extracts from qualitative screening of drumstick. Dried drumstick powder was prepared by using fresh drumstick pieces, steam blanched for 2-5 min and then sulfated at 0.1 % for 10 min. After that, the dehydration process was performed at different temperatures (45, 55 and 65°C) in an HPD drier. HPD dried drumstick powder at 55°C was found to have maximum physicochemical properties, drying characteristics and higher retention of bioactive compounds with special reference to high powder recovery (97.22 %), excellent flowability and better retention of nutrients like β – carotene (174.49 mg), total antioxidant (266.02 mg), flavonoids (6.207 mg/RE), phenol (229.54 mg/GAE) and vitamin C (253.16 mg). The extract of fresh and HPD dried drumstick powder contained 50 major bioactive compounds such as 2,6-Dihydroxybenzoic acid 3TMS derivative, Butanal 2-ethyl-3-methyl- *etc.,* these bioactive compounds act as various nutraceuticals and therapeutic values.

Keywords: Drumstick, GC – MS, HPD dryer, Nutraceutical, Phytochemicals

INTRODUCTION

Moringa oleifera is also known as the "tree of life" because of its crucial importance. Moringa belongs to the solitary genus from the family *Moringaceae* and contains 13 known species. Among them, *M. oleifera* is a highly exploited species. The other names used for moringa are horse radish tree, mulangay, benzolive, drumstick tree, sajna and kelor. It is also popularly denoted as miracle tree", "natural gift or "mother's best friend" (Mahmood *et al.,* 2010). *M. oleifera* is an important food crop that is gaining much attention as a "tropical natural nutrition*" crop.* Many countries, including India, the Philippines, Pakistan, Hawaii , and Africa, consume moringa's aerial parts (leaves, fruits, flowers , and immature pods) as a nutritive food (Stadtlander and Becker, 2017).

India is a leading moringa producer in the world, with a yearly production of 2.2 million tons and productivity of 51 tons of tender pods per hectare. Tamil Nadu is the leading moringa-producing state in India, with an average production of 6.71 lakh tonnes of tender pods annually from a cultivated area of 13042 ha (Sekhar *et al.,* 2018). *M. oleifera* is frequently regarded as a curative for all health issues or diseases (Panacea). Indians and Africans have traditionally employed *M. oleifera* in herbal medicine, as it has a high potential to treat deficiency disorders (Lakshmipriya *et al.,* 2016).

Drumsticks are essential for human health due to their medicinal and therapeutic properties. Presently, the demand for moringa has increased by 19 % per annum due to off-season availability, increased utilization by people, and improper postharvest practices. One-fourth of moringa produce is spoiled during storage and transport (Nithyapriya *et al.,* 2013). To prevent postharvest losses in the moringa, there is a need for processing, and it will meet the demand of the market throughout the year (Arun Prabhu *et al.,* 2011).

Dehydration is a method of preservation; hot air is used to dry food and plant materials. The weight and volume of the product are minimized during drying, resulting in lower packaging, storage and transportation costs. The quality of the dried products is influenced by drying time, temperature and water activity. A higher temperature can lower the flavour, colour, heat-sensitive nutrients, and bioactive compounds during the drying process. The quality of the dried products can be improved by reducing the process temperature when compared to higher ones. Based on the product type, availability of dryer, cost, time and energy consumption desired drying techniques (Kinki *et al.,* 2020)

The conventional drying process takes more time and energy than advanced techniques, and it also results in microbial contamination of food products due to prolonged processing time and improper handling, which will also affect the organoleptic properties and product quality in terms of mould growth during storage. Alternatives to conventional drying advanced dryers, *viz*., freeze- or vacuum-drying and heat pump-assisted dehumidified air drying (HPD), are used for dry heat-sensitive materials. Klungboonkrong *et al.* (2018) designed an HPD dryer, which resulted in the retention of bioactive compounds in dried products.

The efficiency of drying in the HPD system is enhanced by the heat pump in which an evaporator removed heat and the humidity of the drying air was reduced. The absorbed heat is used to raise the temperature of the dry air in the condenser (Potisate *et al.,* 2014). The HPD dryer saves time and energy (15 -20 %) along with low temperatures. HPD dried products have higher retention of sensory and nutritional properties. The combination of the heat pump with a closed circle for drying ensures exhaust-free operation, which is an advantage. This also implies that the use of heat pump drying makes the task independent of ambient air humidity **(**Yohana *et al.,* 2018).

Compared to conventional and mechanical drying, heat pump drying technology achieves maximum recovery of volatile components and better product quality under a wide range of drying conditions. Various types of HPD dried products *viz.,* grapes (Aktas *et al.,* 2019), Rose (Xu *et al.,* 2022), banana (Tunckal and Doymaz, 2020), sweet basil leaves (Trirattanapikul *and* Phoungchandang 2012) and mushroom (Zhao *et al.,* 2019).

Keeping the above mentioned points study was framed with the objective of optimizing drying characteristics, retention of nutrients and phytochemicals in drumstick by adopting HPD drying technique.

MATERIALS AND METHODS

Physico-chemical properties of drumstick

A fresh and fully mature drumstick (PKM - 2) procured from a farmer producer organization in Madurai was used in the study. Fresh drumsticks were analysed for their physicochemical characteristics, *viz.,* moisture and ascorbic acid, using AOAC (1990) and Ranganna (1995). The protein-Kjeldahl method was used to measure total nitrogen content and fat by the Soxhlet extraction method (AOAC 1995). Carbohydrate and crude fiber (Abbas *et al.,* 2018), β – carotene – HPLC method (Chen *et al.,* 2017), total antioxidant activity (TAA) (Lim *et al.,* 2007), total flavonoids (Meda *et al.,* 2005), total phenols (TP) (Quettier-deleu *et al.,* 2000) and minerals (Boudieb *et al.,* 2019) were analysed.

Phytochemical screening of fresh drumstick

Bioactive compounds were extracted from fresh drumsticks using different solvents (methanol, ethanol, chloroform, hexane, acetone and ethyl acetate). Twenty grams of the fresh drumstick samples were taken by weighing them in an electronic balance and transferred into a 250 ml beaker. After that, 150 ml of the different solvents was added and centrifuged at 1000 rpm for 2 hr until agitation. Then, the samples were allowed to continue the extraction process at room temperature for 48 hr. Finally, each sample solvent mixture was filtered, and the crude extract was taken for phytochemical screening (Marcel *et al.,* 2016). Qualitative phytochemical analysis was performed with each solvent extract of the drumstick to determine the presence of alkaloids, tannins, flavonoids, steroids, terpenoids and saponins **(**Andzouana and Mombouli 2012).

Gas Chromatography-Mass Spectrometry (GC- MS) analysis

GC–MS analysis of drumsticks was performed by Kumaravel *et al.* (2010) and Vijayakumari *et al.* (2015). GC–MS analysis was carried out using the Shimadzu GCMS-QP2010 Ultra system. The temperature of the injector was 280°C. The samples were injected as splits with a split ratio of 1/25. The injection volume of the sample was `1 l. A capillary column with dimensions 30 m x 0.25 mm x 0.25 m Rtx-5MS was utilized. Helium was used as a career gas with a constant flow rate of 1.00 ml min-1. The oven temperature was set to 60°C for the first 2 minutes and then increased to 260° C for another 10 minutes. The MS ionization potential was 70 eV, and the temperatures were as follows: 260° C interface and 280°C ion source. The mass scan was fixed from 40 to 550.

Processing for the preparation of dried drumstick powder

Healthy mature PKM-2 moringa pods were selected. Then, fresh drumstick pieces were steam blanched for 2-5 min until tender and sulphated at 0.1 % for 10 min to preserve the color and improve storage durability. After that, a dehydration process was performed with heat-pump dehumidified-air drying by Klungboonkrong *et al.* (2018). The HPD drying unit heat pump system consists of a compressor, evaporator, condenser and expansion valve. The dimensions of the drying chamber were 0.90 x 1.80 x 1.70 m. When air flowed over an electric heating coil with a maximum capacity of 1800 W, the compressor moved back and forth in a straight line with a capacity of 300 W. The air was passed into the drying chamber to dry the materials where placed in inner trays (each tray 50 kg) and drying temperature was regulated by a thermostat. The drumstick pieces were dried at 45(A), 55(B), and 65(C) °C with a 0.5 m/s airspeed.

The dehydration characteristics of drumstick powder were analysed, *viz.,* powder recovery, water solubility index (Grabowski *et al*., 2006), flowability (Seeranguraya*r et al.,* 2017), bulk and tap density (Chegini and Ghobadian 2005), Hausner ratio, Carr index (Seeranguraya*r et al.,* 2017), hygroscopicity (Cai and Corke 2000), water and oil absorption capacity (Rosario and Flores 1981), rehydration ratio and dehydration ratio (Ranganna, 1986).

Statistical analysis

Data analysis was performed in a completely randomized design (CRD) using SPSS 14.0 for Windows (SPSS, 2005). Multivariate analysis (principal component analysis - PCA) was performed on the significant variables according to the varied drying temperatures.

RESULTS AND DISCUSSION

Physicochemical characteristics of fresh and HPD dried drumstick

The physicochemical characteristics of fresh drumsticks are mentioned in Table 1. The selected moringa pod had a weight of 100.73 to 250.80 g, 59.62 to 110.80 cm length, 4.75 to 6.32 cm breadth and 5.04 to

Table 1. Physicochemical characteristics of fresh and dried drumsticks

Particulars	Fresh Drumstick	Different drying temperature		
		45°C	55°C	65°C
Moisture (%)	86.12±1.52^{d}	4.08±0.05^{a}	4.048±0.10^{b}	4.103±0.10^{a}
Protein (g)	2.71±0.06^{a}	23.98±0.09^{a}	24.26±0.75^{e}	23.30±0.52^{e}
Crude fibre (g)	4.5±0.11^{b}	19.12±0.19^{b}	19.28±0.36^{c}	18.71±0.42^{d}
β – carotene (mg)	6.57±0.14^{b}	166.51±5.32^{g}	174.49±4.86^{h}	163.31±1.02^{f}
Ascorbic acid (mg)	146.5±1.99^{e}	240.12±6.04^{h}	253.16±0.51^{d}	234.90±5.59^{i}
Total Phenol content (mg/GAE)	26.87±0.73^{c}	226.94±6.33^{i}	229.54±5.15^{i}	220.46±0.30^{c}
Total Flavonoid content (mg/RE)	6.15±0.11^{b}	6.12±0.15^{b}	6.207±0.03^{a}	5.90±0.14^{a}
Total antioxidant activity (mg)	188.60±0.75^{e}	260.44±0.06^{a}	266.02±0.09^{a}	258.22±0.32^{e}
Calcium (mg)	37±0.75^{c}	175.19±4.64^{f}	175.97±1.91^{f}	173.22±2.23^{h}
Iron (mg)	1.18±0.08^{a}	293.53±1.99^{d}	294.55±2.20^{g}	290.96±1.97^{g}
Phosphorus (mg)	108.5±3.61^{f}	7.15±0.03^{a}	7.51±0.07^{a}	7.01±0.21^{b}
Potassium (mg)	360.8±9.99^{g}	346.36±2.12^{e}	371.62±12.38^{j}	346.36±8.48^{j}
Magnesium (mg)	36.01±0.39^{c}	35.98±0.78^{c}	36.18±0.54^{d}	35.86±0.53^{e}

6.17 cm pulp thickness. Drumstick fruit has a bright green colour, smooth surface, strong drumstick flavour and firm texture. The chemical characteristics of moringa fruit included moisture - 86.12 g, protein - 2.71 g, crude fiber - 4.5 g, β - carotene - 6.57 mg and ascorbic acid - 146.5 mg. The drumstick contains much valued nutraceutical properties, where the total antioxidant activity, total flavonoids and total phenols were 188.60 mg 100 g^{-1}, 6.15 mg RE g^{-1} extract and 26.87 mg GAE g^{-1} extract, respectively, and with mineral contents of calcium - 37, iron - 1.18, phosphorous - 108.5, potassium - 360.8 and magnesium 36.01 mg 100 g^{-1}.

Similar results were recorded by Lakshmipriya *et al.* (2016) through the chemical characteristics of the drumstick which shows the protein 2.5 g, carbohydrate 3.7 g, fibre 4.8 g, vitamin C 120 mg, calcium 30 mg, magnesium 24 mg, phosphorus 110 mg, potassium 259 mg and iron 5.3 mg per 100 g. Shailendra *et al.,* (2016) analyzed the moringa pod and it contains moisture - 89.99 percent, ascorbic acid - 127.39 mg per 100 g, calcium - 31.95 mg per 100 g, iron - 5.35 mg per 100 g, phosphorus - 107.85 mg per 100 g, crude fiber - 4.00 percent and vitamin A - 185.06 IU and his results were accordance with the present investigation.

The physico-chemical composition of the HPD dried drumstick powder is presented in Table 1. The moisture content of the drumstick powder varied between 4.08 (45°C) and 4.103 % (65°C). The protein and crude fibre contents of HPD-dried moringa powder were 23.30-24.26 and 18.71-19.28 per 100 g, respectively, at different temperatures. The β – carotene content of powder dried at 55°C was higher (174.49 mg per 100 g) than those dried at 45°C and 65°C (166.51 and 163.31 mg per 100 g). Similarly, the ascorbic acid content was also higher (253.16 mg per 100 g) in drumstick powder dried at 55°C, followed by 45°C and 65°C. The total phenol, flavonoid and antioxidant activities were 220.46 to 229.54 mg/GAE, 5.90 to 6.207 mg/RE and 258.22 to 266.02 mg per 100 g, respectively, at different temperature levels. The maximum retention of calcium, iron, phosphorus, potassium and magnesium was found at drying temperatures of 45°C and 55°C compared with 65°C.

The same results were recorded by Potisate *et al.,* 2015 in HPD dried moringa and shows moisture content (4.65), crude fibre (18.90), β – carotene content (170.22), total phenolics (187.39 mg GAE) and total antioxidant activity (236.87 mg QE g). Klungboonkrong *et al.,* (2018) also reported the same results in HPD dried *Orthosiphon aristatus* leaves in different temperatures 40°C, 50°C and 60°C and their results were moisture content (3.91 to 4.32), total phenolics (125 to 188.3 mg GAE) and total antioxidant activity (178 to 215.2 mg QE g).

The present study results revealed that increasing air drying temperature (65°C) led to an increasing reduction of heat sensitivity nutrients like β - carotene and ascorbic acids due to thermal degradation and oxidation. Low moisture with higher temperature for a longer time resulted in a higher reduction of TP and TAA. The higher phenolic content correlated to high antioxidant activity at optimum temperature due to high hydrogen atom-donating ability of phenolic compound. When drying temperature was above the optimum level, the drumstick cell walls were disrupted and triggered the release of oxidative and hydrolytic enzymes to destroy the antioxidants properties.

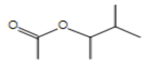
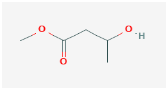
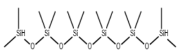
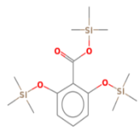
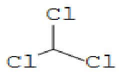
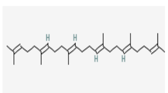
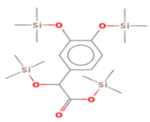
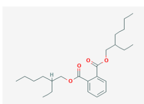
Qualitative phytochemical screening of fresh drumsticks

The present qualitative screening results indicate (Table 2), phytochemicals were highly present in methanol and ethanolic extracts, and a lower amount of phytochemicals was noticed in the chloroform extract. The same results were recorded by Bamishaiye *et al.* (2011) and Nweze *et al.* (2014) in methanol and ethanolic moringa extracts, respectively. Intracellular ingredients are extracted from the cellular membrane by methanol and ethanol solvents due to their high penetration capacity (Wang *et al.,* 2009). In diluted ethanol,

Table 2. Qualitative phytochemicals screening of fresh drumstick

Phytochemicals	Different extracts					
	Methanol + Drumstick	**Ethanol + Drumstick**	**Chloroform + Drumstick**	**Hexane + Drumstick**	**Acetone + Drumstick**	**Ethyl acetate + Drumstick**
Alkaloids	+	+	-	+	-	+
Tannins	+++	+++	+	+	+	+
Flavonoids	++	+++	+	+	+	+
Steroids	++	+	+	+	+	-
Terpenoids	+	+	-	+	-	+
Saponin	+	+	-	+	+	+

Table 3. Total ionic chromatogram (GC–MS) of methanol extract of drumstick obtained with 70 eV using a VF-5MS fused silica capillary column with He gas as the carrier

S. No	RT	Name of the compound	Molecular formula	MW (g/mol)	Peak area %	Structure	Biological activity	Citation
1	4.984	1-Dodecanol	$C_{12}H_{26}O$	186	2.56		Flavouring agent	(Muñoz *et al.*, 2021)
2	5.486	Butanal, 2-ethyl-3-methyl-	$C_7H_{14}O$	116.20	23.56		Flavouring agent	(Muñoz *et al.*, 2021)
3	5.990	Ethanone, 1-(3 -ethyloxiranyl)-	$C_6H_{10}O_2$	114.14	5.10		Antioxidant, antimicrobial	(Jusuf *et al.*, 2020)
4	7.602	Hexadecanoic acid, methyl ester(lauric palmitic)	$C_{17}H_{34}O_2$	270.45	6.03		Antibacterial activity, Antioxidant, Antiandrogenic flavor,	(Mazumder *et al.*, 2020)
5	11.675	Butanoic acid, 3-hydroxy-3-methyl-, methyl es	$C_6H_{12}O_3$	132.11	2.04		Flavouring agent	(Muñoz *et al.*, 2021)
6	15.113	Cyclohexasiloxane, dodecamethyl-	$C_{12}H_{36}O_6Si_6$	444.92	4.86		Skin care, cosmetics products, breast implantation, Antimicrobial	(Pinto *et al.*, 2017)
7	16.532	Eicosane	$C_{20}H_{42}$	282.54	2.18		Antitumour activity against the human gastric SGC-7901 cell line antifungal.activity	(Adnan *et al.*, 2019)
8	20.226	Heneicosane	$C_{21}H_{44}$	296.57	3.54		Antimicrobial	(Sivakumar *et al.*, 2011)
9	23.281	Hexasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11-dodecamethyl	$C_{12}H_{38}O_5Si_6$	430	8.02		Antioxidative, Anti-allergic, Anti-hyperuricemic, Activities.	(Nalawade *et al.*, 2015)
10	25.933	2,6-Dihydroxybenzoic acid, 3TMS derivative	$C_{16}H_{30}O_4Si_3$	370	29.90		Antioxidant and Anti-inflammatory Antimicrobial Antibacterial Activities,	(Lu *et al.*, 2012)
11	29.542	Tetratetracontane	$C_{44}H_{90}$	619.20	4.02		Antioxidant and cytoprotective activities	(Melappa *et al.*, 2014)
12	30.651	Squalene	$C_{30}H_{50}$	410.73	4.58		Antibacterial, Antioxidant, Antitumor, Anti-inflammatory,	(Chandrasekaran *et al.*, 2011)
13	32.598	3,4-Dihydroxymandelic acid, 4TMS derivative	$C_{20}H_{40}O_5Si_4$	472	8.45		Antitumor, analgesic, Antimicrobial, Therapeutic activities.	(Altameme *et al.*, 2017)
14	35.754	(E)-9-Octadecenoic acid ethyl ester	$C_{18}H_{32}O_2$	310.5	2.95		Cancer preventive, Anti-inflammatory, Hepatoprotective,	(Bukhari *et al.*, 2017)
15	43.682	Bis(2-ethylhexyl) phthalate	$C_{24}H_{38}O_4$	394.6	3.63		Antibacterial and antifungal activity	(Abubakar *et al.*, 2018)

the concentration of flavonoids was higher due to amplified polarity (Aliyu *et al.,* 2016). Extraction of bioactive compounds from medicinal plants is limited in solvents (chloroform and hexane) with very low strength and polarity (Liu *et al.,* 2000).

Among the phytochemicals, tannins and flavonoids were highly detected in methanol and ethanol extracts when compared to other solvent extracts such as chloroform, hexane, acetone and ethyl acetate. Okwu DE and Okwu ME 2004 stated the higher concentration of flavonoids in moringa parts it will also helps to protect against allergies, platelet aggregation, inflammation, free radicals, viruses, microbes, ulcers and tumors.

Identification of bioactive components in drumsticks by GC–MS

Fresh and HPD-dried drumstick powder analysed for bioactive compounds by GC–MS showed that the extracts of both fresh and dried powder contained 50 major bioactive compounds, of which the maximum quantum was found in 15 compounds (Table 3), including 2,6-dihydroxybenzoic acid 3TMS derivative (29.90 %), butanal 2-ethyl-3-methyl (23.56 %), 3,4-dihydroxymandelic acid 4TMS derivative (8.45 %) and hexasiloxane, and 1,1,3,3,5,5,7,7,9,9,11,11-dodecamethyl (8.02 %). These bioactive compounds act as various nutraceuticals and have therapeutic value, such as hair growth promoters, hydroxylation of liver enzymes during phase I metabolism, and preventing the production of uric acid and arachidonic acid inhibitors in the human system (Bernhard *et al.,* 2014).

Hexadecanoic acid-methyl ester (6.03 %) has antibacterial and antioxidant activity and hypocholesterolemic and alpha-reductase inhibitor properties (Mazumder *et al.,* 2020). Ethanone 1-(3-ethyloxiranyl) - (5.10 %) has strong antimicrobial and antioxidant properties and helps to destroy food-borne pathogens and prevent diseases (Jusuf *et al.,* 2020). Cyclohexasiloxane dodecamethyl (4.86 %) compound used for skincare, cosmetics products, breast implantation and antimicrobial agent (Pinto *et al.,* 2017). Squalene (4.58 %) bioactive compound contains antibacterial, hypoglycemic, hypolipidemic effects and cancer preventing and immunostimulant properties (Chandrasekaran *et al.,* 2011). Tetratetracontane (4.02 %) had antioxidant and anti-inflammatory properties and beneficial therapeutic value in humans (Melappa *et al.,* 2014). Bis (2-ethylhexyl) phthalate (3.63 %) helps to prevent food-borne disease, as it has antibacterial and antifungal activity (Abubakar *et al.,* 2018). Heneicosane (3.54 %) and (E)-9-octadecenoic acid ethyl ester (2.95 %) have cancer preventive, anti-inflammatory, antihistaminic and antieczemic properties (Sivakumar *et al.,* 2011 ; Bukhari *et al.,* 2017). 1-Dodecanol (2.56 %) and eicosane (2.18 %) compounds have antitumor activity against the human gastric SGC-7901 cell line (Muñoz *et al.,* 2021;Adnan *et al.,* 2019) and butanoic acid, 3-hydroxy-3-methyl-, methyl (2.04 %) behave as flavouring agents in moringa fruit (Muñoz *et al.,* 2021).

The results revealed that the above said the drying temperature did not influence bioactive compounds due to processing of minimal temperature at short duration in HPD drying processes.

Optimization of HPD drying for the production of drumstick powder by PCA

The principal component analysis (PCA) results are presented in Fig. 1 and Table 4. PCA was applied to

Table 4. Dehydration characteristics of HPD dried drumstick powder

Particulars	Different drying temperature		
	45°C	55°C	65°C
Powder recovery (%)	96.29±2.26^{e}	97.22±1.08^{d}	92.53±2.23^{d}
Water solubility (%)	67.18±1.88^{d}	71.18±1.64^{e}	69.67±0.32^{c}
Bulk density (g cm^{-3})	0.465±0.03^{a}	0.451±0.08^{a}	0.437±0.02^{a}
Tap density (g cm^{-3})	0.539±0.09^{a}	0.525±0.04^{a}	0.518±0.04^{a}
Dehydration ratio (ml/g)	22.13±0.13^{b}	22.66±0.50^{c}	20.28±0.02^{a}
Rehydration ration (ml/g)	3.48±0.06^{a}	3.61±0.04^{a}	3.78±0.12^{b}
Water absorption capacity (g)	1.988±0.06^{a}	2.053±0.01^{a}	2.196±0.05^{a}
Oil absorption capacity (g)	5.580±0.16^{b}	5.712±0.11^{b}	5.49±0.16^{b}
Hausner's ratio	1.193±0.01^{a}	1.395±0.01^{a}	1.409±0.02^{a}
Carr index (%)	19.416±0.30^{c}	19.44±0.58^{c}	19.51±0.17^{b}
Flowability	Good	Excellent	Excellent
Hygroscopicity (%)	1.389±0.03^{a}	1.41±0.04^{a}	1.502±0.02^{a}

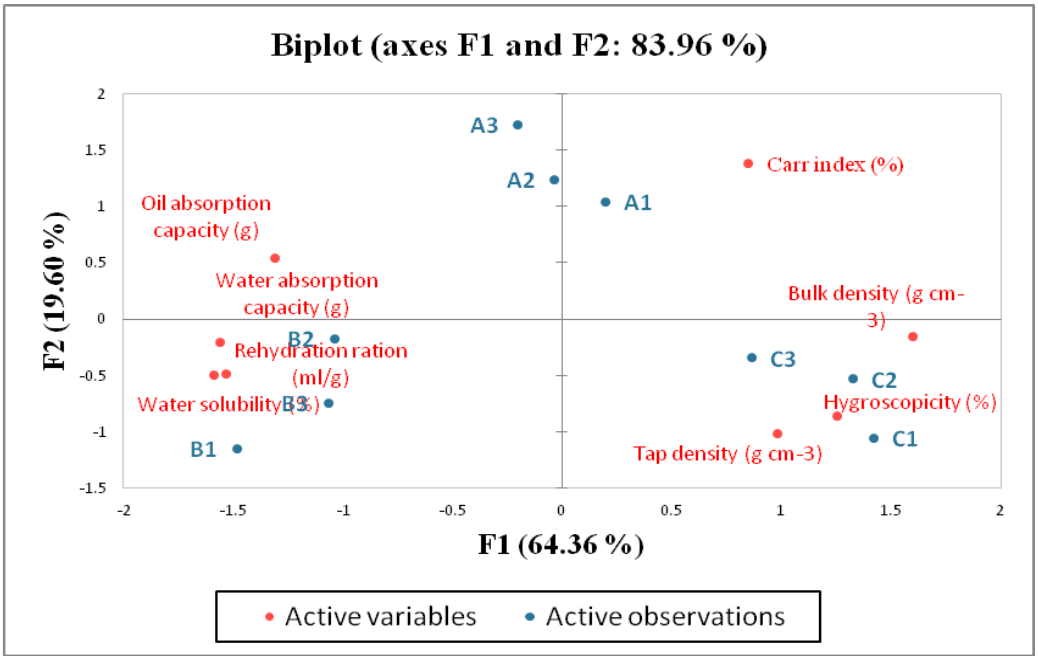


Fig. 1. *Dehydration characteristics variables as a function of both the first (PC1) and the second (PC2) principal components*

describe the relationship between the different dehydration variables and to identify the most important sources of variability, *viz.,* different drying temperatures (45°C (A), 55°C (B) and 65°C (C)). PCA condenses eight variables into two principal components (PC), which explains 83.96 percent of the total variance. PC1 was characterized by high water solubility, rehydration ratio, water absorption capacity, oil absorption capacity, which clustered on the positive axis, and low bulk density, tap density, Carr index and hygroscopicity were negatively correlated. It accounted for 64.36 % of the variance in the model. The negative axis of PC2 was characterized by less water solubility, rehydration ratio, tap density and hygroscopicity. High oil absorption capacity and Carr index lie at the positive axis. PC2 accounts for 19.60 % of the total variance.

The moringa fruit HPD dried at 55°C (B) had 97.22 % powder recovery, where increasing the temperature (65°C) led to a lower process yield. The water solubility index of the drumstick powder increased (67.18 to 71.18 %) with increasing drying temperature. The bulk density and tap density of the HPD-dried moringa powder varied from 0.437- 0.465 and 0.518- 0.539 g cm^{-3} respectively. During the drying process, a higher drying temperature (55°C (B) and 65°C (C) will reduce the density of the powder to rapidly remove moisture.

The effects of functional characteristics such as water absorption capacity (WAC) and oil absorption capacity (OAC) in dried drumstick powder were analysed. The WAC was 1.988 g at 45°C (A), 2.053 g at 55°C (B) and 2.196 g at 65°C(C). The oil absorption capacity ranged between 5.49 g and 5.712 g at different temperatures. The water absorption was higher at 65°C, and the oil absorption was higher at 55°C, which may be due to the protein concentration. The values of WAC (23.2%) and OAC (18.5%) compared favourably with the results of spinach (Amaranthus hybridus) by Adeyeye and Omolayo (2011).Water absorption capacity is an important dehydration characteristic that correlates the function of hydrophilic molecules such as proteins, carbohydrates and dietary fibre. However, the oil absorption capacity of flours facilitates the improvement of flavour and mouth feel during food preparation (Abe - Inge *et al.,* 2018).

Hauser's ratio of HPD dried powder was found in the range of 1.193 - 1.409, and the carr index was in the range of 19.41- 19.51 %. Hauser's ratio and carr index measure the flow properties of dried powders. This clearly shows that the drumstick powder dried between 55°C (B) and 65°C (C) has excellent flowability characteristics and good flowability at 45°C. The hygroscopicity of HPD-dried moringa powder was 1.389 (45°C), 1.41 (55°C) and 1.502 (65°C). The lowest hygroscopicity values were recorded at low temperatures.

The dehydration ratio of drumstick powder dried by an HPD dryer ranged between 20.28 and 22.66 ml/g at different drying temperatures. The dehydration ratio was observed to be higher at 55°C (B) because of the incomplete removal of moisture and lower at 65°C due to the complete removal of moisture (heat air treatment). Similarly, the rehydration ratio ranged between 3.48 and 3.78 ml/g. The rehydration ratio was observed to be lower at 45°C (A) due to incomplete reabsorption.

Similar trends were reported by Potisate *et al.* (2015) in HPD dried moringa and express the excellent flowability, hygroscopicity (1.25-2.30) and rehydration ratio

(3.821-4.220).

Tummanichanont *et al.* (2017) also opined that the HPD dried *Andrographis paniculata* spinach shows the results of hygroscopicity (1.42 - 1.95), dehydration ratio (18.5 – 24.01) and rehydration ratio (3.12 – 3.69). So, the loss of water and heat leads to tension in the product's cell structure, leading to hygroscopicity of the powder and dehydration will decrease the dimensions of HPD dried moringa powder.

Conclusion

The optimized drying temperature of 55°C for both fresh and dried drumstick powder showed better physicochemical properties such as β – carotene (174.49 mg), total antioxidant (266.02 mg), flavonoids (6.207 mg/RE), phenol (229.54 mg/GAE) and vitamin C (253.16 mg). The HPD dried drumstick powder had high powder recovery (97.22 %) and excellent flowability. The drumstick extract contained 50 major bioactive compounds and found that 15 numbers of compounds retained in both fresh and dried drumstick powder. These bioactive compounds have various nutraceutical and therapeutic properties. From this research finding, HPD drying was considered one of the best drying techniques to conserve nutritional quality attributes with higher efficiency and economically feasible for all the food processing sectors. The products will be affordable for both consumer and producer prospects. The drumstick incorporated food products will be highly suitable for commercialization and alleviate nutritional deficiency problems, especially in vulnerable groups in the community.

ACKNOWLEDGEMENTS

The authors wish to express their profound gratitude to the Farmer Producers Organization (FPO) in Madurai District for Drumstick collection and processing.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Abbas, R. K., Elsharbasy, F. S. & Fadlelmula, A. A. (2018). Nutritional Values of *Moringa oleifera*, Total Protein. Amino Acid, Vitamins, Minerals, Carbohydrates, Total Fat and Crude Fiber, under the Semi-Arid Conditions of Sudan*. J. Microb. Biochem. Technol.*, 10, 56-58. DOI: 10.4172/1948-5948.1000396
2. Abe-inge, V., Agbenorhevl, J. K., Kpodo, F. M. & Adziny, O. A. (2018). Effect of different drying techniques on quality characteristics of African palmyra palm (Borossusaethiopum) fruit flour. *Food. Res*, 2(4), 331-339. DOI:10.26656/fr.2017.2(4).050
3. Abubakar, K., A. Yunus, M. Abubakar, J. Ugwah-Oguejiofor, and A. Muhammad. (2018). Antioxidant and antikindling effect of Tapinanthus globiferus growing on Ficus glumosa in pentylenetetrazole induced kindled rats. *African Journal of Biotechnology* 17 (4):73-80. doi:org/10.5897/AJB2017.16048
4. Adeyey, I. A. & Omolayo, F. O. (2011). Chemical composition and functional properties of leaf protein concentrates of *Amaranthus hybridus* and *Telfairia occidentalis*. *Agriculture And Biology Journal of North America,* 2151(7517), 500-511.
5. Adnan, M., N.U. Chy, A. Mostafa Kamal, M.O.K. Azad, A. Paul, S.B. Uddin, J.W. Barlow, M.O. Faruque, C.H. Park, and D.H. Cho. (2019). Investigation of the biological activities and characterization of bioactive constituents of Ophiorrhiza rugosa var. prostrata (D. Don) & Mondal leaves through in vivo, in vitro, and in silico approaches. *Molecules* 24 (7),1367. doi.org/10.3390/molecules240 71367
6. Aktaş, M., Taşeri, L., Şevik, S., Gülcü, M., UysalSeçkin, G., &Dolgun, E. C. (2019). Heat pump drying of grape pomace: Performance and product quality analysis. *Drying Technology*, *37*(14), 1766-1779. https://doi.org/10.1080/07373937.2018.1536983
7. Aliyu, A., Chukwuna, U. D., Omoregie, E. H. & Folashade, K. O. (2016). Qualitative phytochemical analysis of the leaf of Moringa oleifera lam. from three climatic zones of Nigeria. *Journal of Chemical and Pharmaceutical Research*, *8*(8), 93-101.
8. Altameme, H.J., I.H. Hameed, and L.F. Hamza. (2017). Anethum graveolens: Physicochemical properties, medicinal uses, antimicrobial effects, antioxidant effect, anti-inflammatory and analgesic effects: A review. *International Journal of Pharmaceutical Quality Assurance* 8 (03):88-91.
9. Andzouana, M. & Mombouli, J. B. (2012). Assessment of the chemical and phytochemical constituents of the leaves of a wild vegetable-Ochthocharis dicellandroides (Gilg). *Pakistan Journal of Nutrition*, *11*(1), 94-99. http://pjbs.org/pjnonline/fin2202.pdf.
10. AOAC. (1990). Official Methods of Analysis. Association of Official Analytical Chemists, Washington D.C.
11. AOAC. (1995). Official Methods of Analysis, 16th Edition. Cuniff, P. (Ed.), AOAC International, Washington, p. 7 (Chapter 12; Tecn. 960.52).
12. Arun Prabhu, R., Anand Prem Rajan & Sarita Santhalia. (2011). Comparative analysis of preservation techniques on *Moringa oleifera*. *Asian Journal of Food and Agro-Industry*, 4 (02), 65-80.
13. Bamishaiye E. I., Olayemi F. F., Awagu E. F. & Bamishaiye O. M. (2011). Proximate and phytochemical composition of Moringa oleifera leaves at three stages of maturation. *Adv. J. Food Sci. Technol*, 3(4), 233- 237.
14. Bernhard HJJ, Haya JA, Alaa MZA, Basmah MHA, Paul G. (2014). Hydroxybenzoic acid isomers and the cardiovascular system. *Nutrition Journal*, 13, 1-10.doi; 10.1186/1475-2891-13-63
15. Boudieb, Kaissa, Sabrina Ait Slimane-Ait Kaki & Hayet Amellal-Chibane. (2019). Effect of Maturation Degree on the Fixed Oil Chemical Composition, Phenolic Compounds, Mineral Nutrients and Antioxidant Properties of Pistacia lentiscus L. Fruits. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca,* 47(3), 836-847. https://doi.org/10.15835/nbha47311534

16. Bukhari, D.A.M., M.J. Siddiqui, S.H. Shamsudin, M.M. Rahman, and S.Z.M. So'ad. (2017). A-glucosidase inhibitory activity of selected Malaysian plants. *Journal of Pharmacy & Bioallied Sciences* 9 (3), 164. doi: 10.4103/ jpbs.JPBS_35_17.
17. Cai Y.Z. & Corke. H. (2000). Production and properties of spray-dried Amaranthus betacyanin pigments. *Journal of Food Science*, 65(6), 1248 -1252. https://doi.org/10.1111/ j.1365-2621.2000.tb10273.x.
18. Chandrasekaran, M., A. Senthilkumar, and V. Venkatesalu. (2011). Antibacterial and antifungal efficacy of fatty acid methyl esters from the leaves of Sesuvium portulacastrum L." *European review for medical and pharmacological sciences* 15 (7),775-780.
19. Chegini, G., & Ghobadian, B. (2005). Effect of spray-drying conditions on physical properties of orange juice powder. *Drying Technology*, 23(3), 657-668.
20. Chen, J., Li, F., Li, Z., McClements, D. J. & Xiao, H. (2017). Encapsulation of carotenoids in emulsion-based delivery systems: Enhancement of β-carotene water-dispersibility and chemical stability. *Food Hydrocolloids*, *69*, 49-55. https://doi.org/10.1016/j.foodhyd.20 17.01.024
21. Grabowski J., Truong, V.D. & Daubert, C. (2006). Spray-drying of amylase hydrolyzed sweet potato puree and physicochemical properties of powder. *J. Food Sci*, 71, E209 - E217. https://doi.org/10.1111/j.1750-3841.2006.00 036.x
22. Jusuf, N.K., I.B. Putra, & N.K. Dewi. (2020). Antibacterial activity of passion fruit purple variant (Passiflora edulis Sims var. edulis) seeds extract against Propionibacterium acnes. *Clinical, cosmetic and investigational dermatology* 13:99. https://doi.org/10.1111/ijd.15178
23. Kinki, A., Mezgebe, A., &Lema, T. (2020). Antioxidant and Sensory Properties of Herbal Teas Formulated from Dried Moringa (MoringaStenopetala) and Stevia (Stevia RebaudianaBertoni) Leaves. 10.7176/FSQM/102-01
24. Klungboonkrong, V., Phoungchandang, S., &Lamsal, B. (2018). Drying of Orthosiphonaristatus leaves: Mathematical modeling, drying characteristics, and quality aspects. *Chemical Engineering Communications,* 205(9), 1239-1251. https://doi.org/10.1080/00986445.2018.1443080
25. Kumaravel S, Praveen Kumar, P. & Vasuki, P. (2010). GC –MS Study on Microbial degradation of Lindane, *Int. J. of Appl.Chem*, 6 (3), 363- 366,
26. Lakshmipriya Gopalakrishnan, Kruthi Doriya & Devarai Santhosh Kumar. (2016). *Moringa Oleifera*: A review on nutritive importance and its medicinal application. *Food Science and Human Wellness,* 5(2), 49-56. https://doi.org/10.1016/ j.fshw.2016.04.001
27. Lim Y. Y., T. T. Lim & J. J. Tee. (2007). Antioxidant properties of several tropical fruits: A comparative study. *Food Chemistry,* 103, 1003-1008. https://doi.org/10.1016/ j.foodchem.2006.08.038
28. Liu, F. F., Ang, C. Y., & Springer, D. (2000). Optimization of extraction conditions for active components in Hypericum perforatum using response surface methodology. *Journal of agricultural and food chemistr*y, 48(8), 3364-3371. https://doi.org/10.1021/jf991086m
29. Lu, J.-J., J.-L. Bao, X.-P. Chen, M. Huang, and Y.-T. Wang. (2012. Alkaloids isolated from natural herbs as the anticancer agents." *Evidence-based complementary and alternative medicine* 2012. https://doi.org/10.1155/20 12/485042
30. Mahmood, K. T., Mugal, T. & Haq, I. U. (2010). *Moringa oleifera*: a natural gift-A review. *Journal of Pharmaceutical Sciences and Research*, 2(11), 775.
31. Marcel, A., Hubert, M., Bienvenu, M. J. & Pascal, O. (2016). Physicochemical characteristics and biochemical potential of *Moringa oleifera* Lam.(Moringaceae). *Der Pharmacia Lettre*, 8(18), 43-47. https://doi.org/10.1111/ jfpp.13915
32. Mazumder, K., A. Nabila, A. Aktar & A. Farahnaky. (2020). Bioactive variability and in vitro and in vivo antioxidant activity of unprocessed and processed flour of Nine cultivars of Australian lupin species: A comprehensive substantiation. *Antioxidants* 9 (4), 282. doi.org/10.3390/ antiox9040282.
33. Meda, A., Lamien, C.E., Romito, M., Millogo, J. & O. G. Nacoulma, (2005). Determination of the total phenolic, flavonoid and proline contents in Burkina Fasan honey, as well as their radical scavenging activity. *Food Chemistry*, 91(3), 571–577. https://doi.org/10.1016/j.foodchem.2004.1 0.006
34. Melappa, G., R. Channabasava, C. Chandrappa & T. Sadananda. (2014). In vitro antidiabetic activity of three fractions of methanol extracts of Loranthus micranthus, identification of phytoconstituents by GC-MS and possible mechanism identified by GEMDOCK method. *Asian Journal of Biomedical and Pharmaceutical Sciences* 4 (34),34. doi: 10.15272/ajbps.v4i34.520
35. Muñoz-Tebar, N., González-Navarro, E. J., López-Díaz, T. M., Santos, J. A., Elguea-Culebras, G. O. D., García-Martínez, M. M., ... & Berruga, M. I. (2021). Biological activity of extracts from aromatic plants as control agents against spoilage molds isolated from sheep cheese. *Foods*, *10*(7), 1576. https://doi.org/10.3390/ foods10071576
36. Nalawade, T.M., K. Bhat, & S.H. Sogi. (2015). "Bactericidal activity of propylene glycol, glycerine, polyethylene glycol 400, and polyethylene glycol 1000 against selected microorganisms." *Journal of International Society of Preventive & Community Dentistry* 5 (2):114. https:// dx.doi.org/10.4103%2F2231-0762.155736
37. Nithyapriya, S., R. Vishwanathan, Z. John Kennedy & R. Kasthuri. (2013). Preservation of ready to eat drumstick products by canning and retort packaging. *International Journal of Processing and Post Harvest Technology*, 4(2), 122-13.
38. Nweze, N. O. & Nwafor, F. I. (2014). Phytochemical, proximate and mineral composition of leaf extracts of *Moringa oleifera* Lam. from Nsukka, South-Eastern Nigeria.
39. Okwu D. E. & Okwu M. E. (2004). Chemical composition of *Spondias mombin* Linn plant parts. *J. Sustain. Agric. Environ*, 6, 140-147.
40. Pinto, M.E., S.G. Araujo, M.I. Morais, N.P. Sá, C.M. Lima, C.A. Rosa, E.P. Siqueira, S. Johann & L.A. Lima. (2017). Antifungal and antioxidant activity of fatty acid methyl esters from vegetable oils. *Anais da Academia Brasileira de Ciências* 89:1671-1681. https://doi.org/10.1590/0001-3765201720160908
41. Potisate, Y., Phoungchandang, S. & Kerr, W. L. (2014). The effects of predrying treatments and different drying methods on phytochemical compound retention and dry-

ing characteristics of Moringa leaves (Moringa oleifera Lam.). *Drying Technology*, 32(16), 1970-1985. https://doi.org/10.1080/07373937.2014.926912
42. Potisate, Y., Kerr, W. L. & Phoungchandang, S. (2015). Changes during storage of dried *M oringa oleifera* leaves prepared by heat pump-assisted dehumidified air drying. *International Journal of Food Science & Technology*, 50 (5), 1224-1233. https://doi.org/10.1111/ijfs.12744
43. Quettier-Deleu C., Gressier, B., Vasseur, J., Dine, T., Brunet, C. & Luyckx M. (2000). Phenolic compounds and antioxidant activities of buckwheat (*Fagopyrum sculentum* Moench) hulls and flour. *Journal of Ethnopharmacology*, 72, 35-42. https://doi.org/10.1016/S0378-8741(00)00196-3
44. Ranganna S. (1995). Manual of analysis of fruits and vegetables products. Tata McGraw Hill publishing Co, Ltd., New Delhi. P. 1-2, 7- 13.
45. Ranganna, S. (1986). Handbook of analysis and quality control for fruits and vegetable
46. Rosario, R. D. & Flores, D. M. (1981). Functional properties of flour types of mung bean flours. *J. Sci. Food. Agric*, 32, 172-180. https://doi.org/10.1002/jsfa.2740320213
47. Seerangurayar, T., Manickavasagan, A., Al-Ismaili, A. M., & Al-Mulla, Y. A. (2017), Effect of carrier agents on flowability and microstructural properties of foam-mat freeze dried date powder. *Journal of Food Engineering,* 215, 33-43. https://doi.org/10.1016/j.jfoodeng.2017.07.016
48. Sekhar, C., Venkatesan, N., Murugananthi, D. & Vidhyavathi, A. (2018). Status of Value Addition and Export of Moringa Produce in Tamil Nadu A Case Study. Economic Botany, 34(3), 276-283.
49. Shailendra Patni, Krishan Kumar Bijarnia, Harsh Enaniya, Kailash Sharma, Bhanwar Lal & Raaz K Maheshwari. (2016). Drumstick tree: A miracle forwell-beingand sociopecuniary diverse therapeutic applicability. *International Journal of Chemistry and Pharmaceutical Sciences,* 4 (2),108 - 114.
50. Sivakumar, R., A. Jebanesan, M. Govindarajan & P. Rajasekar. (2011). Larvicidal and repellent activity of tetradecanoic acid against Aedes aegypti (Linn.) and Culex quinquefasciatus (Say.)(Diptera: Culicidae). *Asian Pacific journal of tropical medicine* 4 (9), 706-710. https://doi.org/10.1016/S1995-7645(11)60178-8
51. Stadtlander, T. & Becker, K. (2017). Proximate composition, amino and fatty acid profiles and element compositions of four different Moringa species. *Journal of Agricultural Science*, 9(7), 46-57. https://doi.org/10.5539/jas.v9n7p46
52. Trirattanapikul, W. & Phoungchandang, S. (2012). Microwave blanching and drying characteristics of *Centella Asiatica* (L.) urban leaves using tray and heat pumpassisted dehumidified drying. *Journal of Food Science and Technology*, Doi 10.1007/s 13197-012-0876-8. https://doi.org/10.1007/s13197-012-0876-8
53. Tunckal, C. & Doymaz, İ. (2020). Performance analysis and mathematical modelling of banana slices in a heat pump drying system. *Renewable Energy*, *150*, 918-923. https://doi.org/10.1016/j.renene.2020.01.040
54. Tummanichanont, C., Phoungchandang, S. & Srzednicki, G. (2017). Effects of pretreatment and drying methods on drying characteristics and quality attributes of Andrographis paniculata. *Journal of Food Processing and Preservation*, 41(6), e13310. https://doi.org/10.1111/jfpp.13310
55. Vijayakumari, B., P. C. Vengaiah & P. Kiranmayi. (2015)."Qualitative phytochemical screening, GC–MS analysis and antibacterial activity of palmyra fruit pulp (*Borassus flabellifer* L.)." *International Journal of Pharma and Bio Sciences,* 6(2), 430-435.
56. Wang, G. X., Han, J., Feng, T. T., Li, F. Y. & Zhu, B. (2009). Bioassay-guided isolation and identification of active compounds from Fructus Arctii against Dactylogyrus intermedius (Monogenea) in goldfish (*Carassius auratus*). *Parasitology research*, *106*(1), 247-255. https://doi.org/10.1007/s00436-009-1659-7
57. Xu, B., Feng, M., Chitrakar, B., Wei, B., Wang, B., Zhou, C. & Duan, X. (2022). Selection of drying techniques for Pingyin rose on the basis of physicochemical properties and volatile compounds retention. *Food Chemistry*, 132539. https://doi.org/10.1016/j.foodchem.2022.132539
58. Yohana, E., Yulianto, M. E., Bahar, S., Muhammad, A. A. & Indrayani, N. L. (2018). A study of tea leaves drying using dehumidification process and regeneration of liquid desiccant in a closed-cycle dehumidification-humidification. In *MATEC Web of Conferences* (Vol. 159, p. 02025). EDP Sciences. https://doi.org/10.1051/matecconf/201815902025
59. Zhao, Y., Bi, J., Yi, J., Jin, X., Wu, X. & Zhou, M. (2019).Evaluation of sensory, textural, and nutritional attributes of shiitake mushrooms (Lentinulaedodes) as prepared by five types of drying methods. *Journal of Food Process Engineering*, 42(4), e13029. https://doi.org/10.1111/jfpe.13029.