



Identify Bioactive Components and Optimize Dehydration Characteristic of Drumstick in GC-MS and Principle Component Analysis by using Heat Pump-assisted Dehumidified Air Drying (HPD)

G. Pandidurai, S. Amutha, S. Kanchana, S. Vellaikumar¹, K. Prabhakaran²

10.18805/ajdfr.DR-1978

ABSTRACT

Background: Drumstick (*Moringa oleifera* Lam.) is a miracle plant because of its therapeutic and nutraceutical properties. 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 which also affect the product quality and safety.

Methods: 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.

Result: HPD dried drumstick powder at 55°C was found maximum drying characteristics and higher retention of bioactive compounds with special reference to high powder recovery (97.22%), excellent flowability and better functional characteristics. 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.

Key words: Bioactive compound, Drumstick, GC-MS, HPD dryer, Nutraceutical, Phytochemicals.

INTRODUCTION

Moringa oleifera is often recognized as the “tree of life” because of its crucial importance (Sekhar *et al.*, 2018). *M. oleifera* is a significant food crop that is gaining popularity as a source of “tropical natural nutrition.” *M. oleifera* is usually thought to be a cure-all for all ailments and disorders (Panacea). (Stadtlander and Becker, 2017). *M. oleifera* has long been used in herbal therapy by Indians and Africans, as it has a strong potential for treating deficiency illnesses. (Lakshmi Priya *et al.*, 2016).

Drumsticks are essential for human health due to their medicinal and therapeutic properties. At present, the demand for moringa has increased annually due to off-season availability, increased utilization by people and improper postharvest practices. 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 (Nithyapriya *et al.*, 2013).

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 (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

Department of Food Science and Nutrition, Community Science College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu, India.

¹Department of Biotechnology, Agricultural College and Research Institute, Madurai-625 104, Tamil Nadu, India.

²Department of Agricultural Statistics, Agricultural College and Research Institute, Madurai-625 104, Tamil Nadu, India.

Corresponding Author: G. Pandidurai, Department of Food Science and Nutrition, Community Science College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu, India. Email: nanalpandi@gmail.com

How to cite this article: Pandidurai, G., Amutha, S., Kanchana, S., Vellaikumar, S. and Prabhakaran, K. (2022). Asian Journal of Dairy and Food Research. DOI: 10.18805/ajdfr.DR-1978.

Submitted: 29-06-2022 **Accepted:** 10-12-2022 **Online:** 16-12-2022

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 HPD dryer saves time and energy (15-20%) along with low temperatures. HPD dried products have higher retention of sensory and nutritional properties (Yohana *et al.*, 2018). Using the HPD drying process, the study was designed with the aim of enhancing drying properties and phytochemicals retention in drumsticks.

MATERIALS AND METHODS

Processing for the preparation of dried drumstick powder

Fresh and mature PKM-2 drumsticks were procured from Horticultural college and Research Institute, Periyakulam and then drumstick pieces were steam blanched for 2-5 min until tender and sulphated at 0.1% for 10 min to preserve the Colour and to 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 $0.90 \times 1.80 \times 1.70$ 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 were 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 air speed.

GC-MS analysis of fresh and dried drumsticks was performed by Kumaravel *et al.* (2010) and Vijayakumari *et al.* (2015). The dehydration characteristics of drumstick powder were analysed, viz., powder recovery, water solubility index (Grabowski *et al.*, 2006), flowability (Seerangurayar *et al.*, 2017), bulk and tap density (Chegini and Ghobadian 2005), Hausner ratio, Carr index (Seerangurayar *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 (Peugh and Enders, 2005). According to the varied drying temperatures, Principal Component Analysis (PCA) was performed on the significant variables.

RESULTS AND DISCUSSION

Identification of bioactive components in drumsticks by GC-MS

Fresh and HPD-dried drumstick powder extracts contained 50 major bioactive compounds, with the maximum quantum found in 15 compounds (Table 1), including 2,6-dihydroxybenzoic acid 3TMS derivative (29.90%), butanal 2-ethyl-3-methyl (23.56%), 3,4-dihydroxymandelic acid 4TMS derivative (8.45%), hexasiloxane and 1,1,3,3,5,5,5,7,7,7,7 (8.02%). These bioactive chemicals have therapeutic significance as hair growth promoters, hydroxylation of liver enzymes during phase I metabolism and inhibiting the formation of uric acid and arachidonic acid inhibitors in the human system, among other things (Bernhard *et al.*, 2014).

Antibacterial and antioxidant capabilities, as well as hypocholesterolemic and alpha-reductase inhibitor properties, are found in hexadecanoic acid-methyl ester

(6.03%) (Mazumder *et al.*, 2020). Ethanone 1-(3-ethyloxiranyl) - (5.10%) possesses powerful antibacterial and antioxidant capabilities that aid in the destruction of food-borne pathogens and disease prevention (Jusuf *et al.*, 2020). The chemical cyclohexasiloxane dodecamethyl (4.86%) is used in skincare, cosmetics, breast implantation and as an antibacterial agent (Pinto *et al.*, 2017). The bioactive component squalene (4.58%) has antimicrobial, hypoglycemic, hypolipidemic, cancer-preventive and immunostimulant activities (Chandrasekaran *et al.*, 2011). In humans, tetratetracontane (4.02%) demonstrated antioxidant and anti-inflammatory characteristics as well as therapeutic efficacy (Melappa *et al.*, 2014). Because it contains antibacterial and antifungal properties, bis (2-ethylhexyl) phthalate (3.63%) aids in the prevention of foodborne illness (Abubakar *et al.*, 2018). Cancer-preventive, anti-inflammatory, antihistaminic and antieczemic activities are found in heneicosane (3.54%) and (E)-9-octadecenoic acid ethyl ester (2.95%). (Sivakumar *et al.*, 2011; Bukhari *et al.*, 2017). 1-Dodecanol (2.56%) and eicosane (2.18%) are anticancer chemicals in 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%) is a flavouring ingredient in moringa fruit (Muñoz *et al.*, 2021).

The results demonstrated that the above-mentioned bioactive compounds were not significantly affected by drying temperature due to HPD drying techniques that used a low temperature for a short time.

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

The principal component analysis (PCA) results are shown in Fig 1. Optimization drying temperatures (45°C (A), 55°C (B) and 65°C (C) were used to explain the relationship between the different dehydration factors and to determine the most relevant causes of variability (Table 2). PCA condenses eight variables into two principal components (PC), which explains 83.96 percent of the total variance. PC1 accounted for 64.36% of the variance in the model and PC2 accounts for 19.60% of the total variance. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy for the PCA is 0.530. To further investigate the contributors to the principal components, the factor loadings in PC1 and PC2 were compared (Table 3 and 4). The eigen values for the F1, F2 and F3 (Factor) were 4.337, 2.034 and 0.797. In factor loading F1, water solubility (0.983), rehydration ration (0.903) and water absorption capacity (0.865) were positively correlated and bulk density (-0.870), carr index (-0.688) and hygroscopicity (-0.729) were negatively correlated. Similarly in F2 and F3, oil absorption capacity (0.919) and tap density (0.695) had positive correlation whereas other variances had negative correlation. These results suggested that the reasonable score range of the principal components could be used for excellent sample selection according to the correlations between the original three variables and these two principal components.

Table 1: 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.

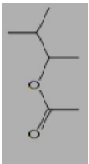
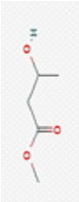
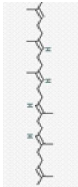
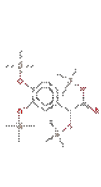
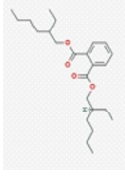
RT	Name of the compound	Molecular formula	MW (g/mol)	Peak area %	Structure	Biological activity	Citation
4.984	1-Dodecanol	$C_{12}H_{26}O$	186	2.56		Flavouring agent	(Muñoz <i>et al.</i> , 2021)
5.486	Butanal, 2-ethyl-3-methyl-	$C_7H_{14}O$	116.20	23.56		Flavouring agent	(Muñoz <i>et al.</i> , 2021)
5.990	Ethanone, 1-(3-ethyloxiranyl)-	$C_6H_{10}O_2$	114.14	5.10		Antioxidant, antimicrobial	(Jusuf <i>et al.</i> , 2020)
7.602	Hexadecanoic acid, methyl ester (lauric palmitic)	$C_{17}H_{34}O_2$	270.45	6.03		Antibacterial activity, Antioxidant, Antiandrogenic flavor, Flavouring agent	(Mazumder <i>et al.</i> , 2020)
11.675	Butanoic acid, 3-hydroxy-3-methyl-, methyl es	$C_6H_{12}O_3$	132.11	2.04		Flavouring agent	(Muñoz <i>et al.</i> , 2021)
15.113	Cyclohexasiloxane, dodecamethyl-	$C_{12}H_{36}O_6Si_6$	444.92	4.86		Skin care, cosmetics products, breast implantation, Antimicrobial	(Pinto <i>et al.</i> , 2017)
16.532	Eicosane	$C_{20}H_{42}$	282.54	2.18		Antitumour activity against the human gastric SGC-7901 cell line antifungal.activity	(Adnan <i>et al.</i> , 2019)
20.226	Heneicosane	$C_{21}H_{44}$	296.57	3.54		Antimicrobial	(Sivakumar <i>et al.</i> , 2011)
23.281	Hexasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11-dodecamethyl	$C_{12}H_{38}O_6Si_6$	430	8.02		Antioxidative, Anti-allergic, Anti-hyperuricemic, Activities.	(Nalawade <i>et al.</i> , 2015)
25.933	2,6-Dihydroxybenzoic acid, 3TMS derivative	$C_{16}H_{30}O_4Si_3$	370	29.90		Antioxidant and Anti-inflammatory Antimicrobial	(Lu <i>et al.</i> , 2012)
29.542	Tetratetracontane	$C_{44}H_{90}$	619.20	4.02		Antibacterial Activities, Antioxidant and cytoprotective activities	(Melappa <i>et al.</i> , 2014)

Table 1: Continue.....

Table 1: Continue....

30.651	Squalene	$C_{30}H_{50}$	410.73	4.58		Antibacterial, Antioxidant, Antitumor, Anti-inflammatory,	(Chandrasekaran <i>et al.</i> , 2011)
32.598	3,4-Dihydroxymandelic acid, 4TMS derivative	$C_{20}H_{40}O_5Si_4$	472	8.45		Antitumor, analgesic, Antimicrobial, Therapeutic activities.	(Al Tamimi <i>et al.</i> , 2017)
35.754	(E)-9-Octadecenoic acid ethyl ester	$C_{18}H_{32}O_2$	310.5	2.95		Cancer preventive, Anti-inflammatory, Hepatoprotective, Antibacterial and antifungal activity	(Bukhari <i>et al.</i> , 2017)
43.682	Bis(2-ethylhexyl) phthalate	$C_{24}H_{38}O_4$	394.6	3.63			(Abubakar <i>et al.</i> , 2018)

The moringa pod 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 (*Amaranthushybridus*) 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. From the above, it is clearly found 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.

The 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.

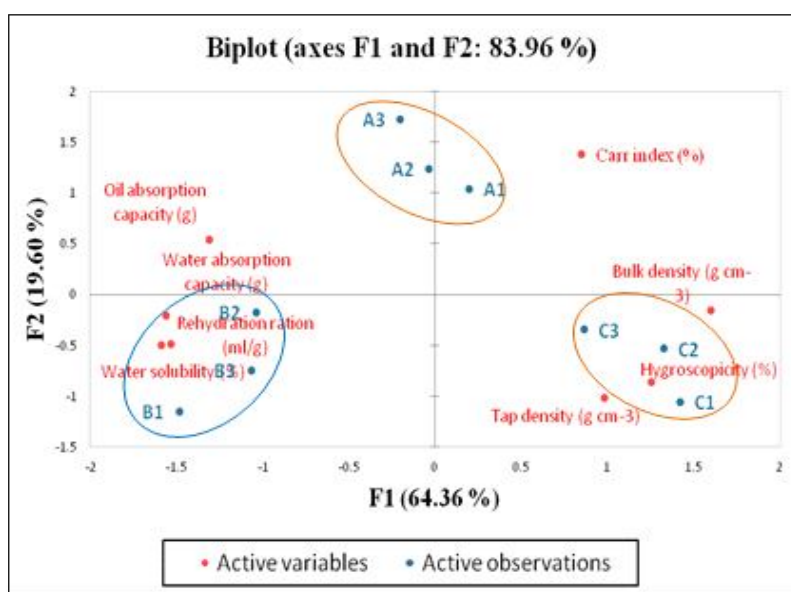


Fig 1: Dehydration characteristics variables as a function of both the first (PC1) and the second (PC2) principal components.

Table 2: 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

Table 3: Correlation matrix of PCA optimization of dehydration characteristics.

Variables	Water solubility (%)	Bulk density (g cm ⁻³)	Tap density (g cm ⁻³)	Rehydration ration (ml/g)	Water absorption capacity (g)	Oil absorption capacity (g)	Carr index (%)	Hygrosc- -opicity (%)
Water solubility (%)	1							
Bulk density (g cm ⁻³)	-0.893	1						
Tap density (g cm ⁻³)	-0.401	0.652	1					
Rehydration ration (ml/g)	0.960	-0.820	-0.406	1				
Water absorption capacity (g)	0.851	-0.810	-0.280	0.775	1			
Oil absorption capacity (g)	0.573	-0.718	-0.463	0.449	0.843	1		
Carr index (%)	-0.676	0.369	-0.089	-0.677	-0.526	-0.114	1	
Hygroscopicity (%)	-0.515	0.655	0.645	-0.590	-0.637	-0.648	-0.045	1

Table 4: Principal component analysis, Eigen values and factor loadings.

Variances	Different factors				
	F1	F2	F3	F4	F5
Eigen value	4.337	2.034	0.797	0.539	0.208
Variability (%)	54.214	25.423	9.961	6.742	2.606
Cumulative %	54.214	79.637	89.598	96.339	98.945
Factor loadings					
Water solubility (%)	0.983	0.070	-0.034	-0.100	-0.046
Bulk density (g cm ⁻³)	-0.870	-0.383	-0.052	0.101	0.271
Tap density (g cm ⁻³)	-0.205	-0.650	0.695	0.193	-0.118
Rehydration ration (ml/g)	0.903	-0.181	-0.198	0.306	-0.107
Water absorption capacity (g)	0.865	0.285	0.275	0.234	0.117
Oil absorption capacity (g)	0.054	0.919	0.507	0.116	0.171
Carr index (%)	-0.688	0.631	0.189	-0.187	-0.222
Hygroscopicity (%)	-0.729	0.321	-0.255	0.534	-0.122

*F- Factors.

CONCLUSION

The effects of drying temperature were studied for both fresh and dried drumstick powder. The optimized drying temperature of 55°C shows better dehydration properties such high powder recovery (97.22%), excellent flowability and functional characteristics. The drumstick extract contains 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 as one of the best drying technique to conserve nutritional quality attributes with higher efficiency and economically feasible for all the food processing sector. HPD dried drumstick powder can be used to develop novel functional food products such as vegetable soup, energy bars, energy drinks, extruded products and incorporated food products may be utilized in nutritional intervention programmes.

Conflict of interest: None.

REFERENCES

- Abe-inge, V., Agbenorhevi, J.K., Kpodo, F.M. and Adziny, O.A. (2018). Effect of different drying techniques on quality characteristics of African palmyra palm (*Borossus aethiopum*) fruit flour. *Food. Res.* 2(4): 331-339.DOI:10.26656/fr.2017.2 (4).050.
- Abubakar, K., Yunus, A., Abubakar, M., Ugwah-Oguejiofor, J. and Muhammad, A. (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.
- Adeyey, I.A. and 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.
- Adnan, M., Chy, N.U., Mostafa Kamal, A., Azad, M.O.K., Paul, A., Uddin, S.B., Barlow, J.W., Faruque, M.O., Park, C.H. and Cho, D.H. (2019). Investigation of the biological activities and characterization of bioactive constituents of *Ophiorrhiza rugosa* var. prostrata (D. Don) and Mondal leaves through *in vivo*, *in vitro* and *in silico* approaches. *Molecules* 24 (7): 1367.doi.org/10.3390/molecules24071367.
- Al Tamimi, M., AlSalamah, A., AlKhulaifi, M., and AlAjlan, H. (2017). Comparison of phenotypic and PCR methods for detection of carbapenemases production by Enterobacteriaceae. *Saudi Journal of Biological Sciences*. 24(1): 155-161.
- Bernhard, H.J.J., Haya, J.A., Alaa, M.Z.A., Basmah, M.H.A. and Paul, G. (2014). Hydroxybenzoic acid isomers and the cardiovascular system. *Nutrition Journal*. 13: 1-10.doi;10.1186/1475-2891-13-63.
- Bukhari, D.A.M., Siddiqui, M.J., Shamsudin, S.H., Rahman, M.M. and So'ad, S.Z.M. (2017). Á-glucosidase inhibitory activity of selected Malaysian plants. *Journal of Pharmacy and Bioallied Sciences*. 9(3): 164.doi: 10.4103/jpbs.JPBS_35_17.
- Cai, Y.Z. and 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.
- Chandrasekaran, M., Senthikumar, A. and Venkatesalu, V. (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.
- Chegin, G. and Ghobadian, B. (2005). Effect of spray-drying conditions on physical properties of orange juice powder. *Drying Technology*. 23(3): 657-668.
- Grabowski J., Truong, V.D. and Daubert, C. (2006). Spray- drying of amylase hydrolyzed sweet potato puree and physico chemical properties of powder. *J. Food Sci.* 71: E209 - E217. https://doi.org/10.1111/j.1750-3841.2006.00036.x

- Jusuf, N.K., Putra, I.B. and Dewi, N.K. (2020). Antibacterial activity of passion fruit purple variant (*Passiflora edulis* Sims var. *edulis*) seeds extract against *Propioni bacterium* acnes. Clinical, Cosmetic and Investigational Dermatology. 13: 99. <https://doi.org/10.1111/ijd.15178>.
- Kinki, A., Mezgebe, A. and Lema, T. (2020). Antioxidant and sensory properties of herbal teas formulated from dried moringa (*Moringa stenopetala*) and Stevia (*Stevia rebaudiana* Bertoni) Leaves. 10.7176/FSQM/102-01.
- Klungboonkrong, V., Phoungchandang, S. and Lamsal, B. (2018). Drying of *Orthosiphon aristatus* leaves: Mathematical modeling, drying characteristics and quality aspects. Chemical Engineering Communications. 205(9): 1239-1251. <https://doi.org/10.1080/00986445.2018.1443080>
- Kumaravel, S., Praveen Kumar, P. and Vasuki, P. (2010). GC-MS study on microbial degradation of lindane. Int. J. of Appl. Chem. 6(3): 363- 366.
- Lakshmipriya, Krishnan, G., Doriya, K. and Kumar, D.S. (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>.
- Lu, L., Xing, D., and Ren, N. (2012). Pyrosequencing reveals highly diverse microbial communities in microbial electrolysis cells involved in enhanced H₂ production from waste activated sludge. Water Research. 46(7): 2425-2434.
- Mazumder, K., Nabila, A., Aktar, A. and Farahnaky, A. (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.
- Melappa, G., Channabasava, R., Chandrappa, C. and Sadananda, T. (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.
- Muñoz-Tobar, N., González-Navarro, E.J., López-Díaz, T.M., Santos, J.A., Elguea-Culebras, G.O. D., García-Martínez, M.M. and 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>.
- Nalawade, R.A., Nalawade, A.M., Kamble, G.S., and Anuse, M.A. (2015). Rapid, synergistic extractive spectrophotometric determination of copper (II) by using sensitive chromogenic reagent N 3 , N 3 2 -bis [(E)-(4-fluorophenyl) methylidene] thiocarbonohydrazide. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 146: 297-306.
- Nithyapriya, S., Vishwanathan, R., John Kennedy, Z. and Kasthuri, R. (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.
- Peugh, J.L., and Enders, C.K. (2005). Using the SPSS mixed procedure to fit cross-sectional and longitudinal multilevel models. Educational and psychological measurement. 65(5): 717-741.
- Pinto, M.E., Araujo, S.G., Morais, M.I., Sá, N.P., Lima, C.M., Rosa, C.A., Siqueira, E.P., Johann, S. and Lima, L.A. (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>.
- Potisate, Y., Phoungchandang, S. and Kerr, W.L. (2015). The effects of predrying treatments and different drying methods on phytochemical compound retention and drying characteristics of Moringa leaves (*Moringa oleifera* Lam.). Drying Technology. 32(16): 1970-1985. <https://doi.org/10.1080/07373937.2014.926912>.
- Ranganna, S. (1986). Handbook of Analysis and Quality Control for Fruits and Vegetable Products. 2nd Edition, Tata McGraw-Hill Education, New York.
- Rosario, R.D. and 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>.
- Seerangurayar, T., Manickavasagan, A., Al-Ismaili, A.M. and 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>.
- Sekhar, C., Venkatesan, N., Muruganathi, D. and Vidhyavathi, A. (2018). Status of value addition and export of moringa produce in Tamil Nadu: A case study. Economic Botany. 34(3): 276-283.
- Sivakumar, R., Jebanesan, A., Govindarajan, M. and Rajasekar, P. (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](https://doi.org/10.1016/S1995-7645(11)60178-8).
- Stadtlander, T. and 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>.
- Tummanichanont, C., Phoungchandang, S. and Szrednicki, 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>.
- Vijayakumari, B., Vengaiah, P. C. and Kiranmayi, P. (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.
- Yohana, E., Yulianto, M.E., Bahar, S., Muhammad, A.A. and Indrayani, N.L. (2018). A study of tea leaves drying using dehumidification process and regeneration of liquid desiccant in a closed-cycled dehumidification-humidification. EDP Sciences. (Vol.159, p.02025). <https://doi.org/10.1051/mateconf/201815902025>.