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Possibility of Pulsed Electric Field and Essential Oil Pre-treatment, Microwave-air Dehydration to the Quality of the Dehydrated Sesban (*Sesbania sesban*) Flower

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Abstract

Non-heat ahead-treatment in advance of the main dehydration is essential to preserve the quality and ensure food safety. Pulsed electric field (PEF) utilizes a high-voltage electric field in a very short duration to inhibit microbes and enzymes while maintaining the most sensory and nutritional characteristics. For thermal sensitive components, the dehydration process should be performed at low temperatures. Freeze dehydration, vacuum dehydration required high cost for equipment, energy consumption, low quantity in long dehydration time. Microwave-air dehydration is considered as a promising alternative technical approach. Sesban (*Sesbania sesban*) flower contains numerous phytochemical components promoting health-benefit. However, it's highly perishable after harvesting. Consumers enjoy the dried sesban flower as a healthy drink. This study examined the possibility of PEF ahead-treatment in microbial inhibition and enzymatic inactivation; essential oil and Microwave-air dehydration on retention of total phenolic content (TPC), vitamin C, 2,2 diphenyl-1-picrylhydrazyl of free radical scavenging (DPPH), ferric reducing antioxidant power (FRAP) of the dehydrated sesban flower. Research also monitored the microbial stability of the dehydrated sesban flower during 12 months of preservation. Results showed that PEF at pulse strength 1000 kV/cm, pulse duration 90 µs, pulse number 45 was remarkably inactivated polyphenol oxidase and peroxidase in raw material. Rosemary essential oil soaked for sesban flower before dehydration positively preserved the ascorbic acid, phenolic content and antioxidant capacity. These PEF and essential oil ahead-treatments strongly facilitated for the main Microwave-air dehydration. Among different air temperatures from 20°C to 40°C in microwave-air dehydration, the highest Vitamin C, TPC, DPPH and FRAP of the dried flower were recorded at air temperature from 20°C to 30°C with no significant difference. Meanwhile, airspeed 1.2 m/s showed the highest Vitamin C, TPC, DPPH and FRAP of the dried flower with no significant difference with airspeed 1.4 m/s and 1.6 m/s. There was no significant difference in Vitamin C, TPC, DPPH and FRAP of the dried flower by microwave power from 1.15 to 1.45W/g. Therefore, a combination of microwave and air dehydration at air temperature 25°C, airspeed 1.2 m/s, the microwave energy density of 1.45 W/g was recommended to better preserve vitamin C, TPC, DPPH, FRAP. Microbial stability of the dehydrated flower was also observed during 12 months of storage by 3 month-interval sampling. Coliform, yeast and mold criteria in dried product were stable within acceptable limits.

Keywords: Essential oil, PEF, Microwave-air dehydration, sesban flower

INTRODUCTION

High temperature treatment may cause negative impact to the pigment, aroma, and nutritional composition in food products. Non-heat treatment can resolve heat-borne matters. PEF is one of innovative non-heat treatments popularly implemented in food processing and preservation. The core principle of the PEF is the utilization of high electric field pulses in narrow duration generated to sample located between dual electrodes fulfilling the operating space of the PEF cabinet.[1] It operated on mechanism of electroporation on cell membranes by electric pulses in short duration.[2] It's not only beneficial for microbial inactivation but also ahead-treatment before dehydration.[3] It greatly improved product quality; accelerated dehydration kinetic by reducing the dehydration duration; enhanced rehydration ability.[4-5] There were different applications of PEF for liquid, semi-solid and solid foodstuffs[6]. Many literatures mentioned to the utilization of PEF as ahead-treatment before dehydration of apple, red bell pepper, strawberries, sea cucumber, peach.[7-10]

Ahead-treatment before the main dehydration is vital to obtain high-quality dried products, shorten the dehydration duration, and limit the energy consumption.[11] Supplementation of highly antioxidant ingredient to the raw material before dehydration may stabilize its phytochemical constituents of the subjected material.[12] Aromatic herbs contain essential oils and polyphenolic antioxidants as natural preservatives.[13-16] Essential oil can be utilized as antimicrobial agent against bacteria, yeast, and molds.[17] Essential oil is classified into two groups: volatile and nonvolatile fraction.[18] Cinnamon *(Cinnamomum aromaticum*), clove (*Sycygium aromaticum*) have numerous therapeutic potentials such as antimicrobial, antiviral, anti-inflammatory, cytoprotective.[19-21] Cinnamon contains main bioactive constituents

therefore it's commonly used as a wine preservative.[22] Rosemary (*Rosmarinus officinalis*) oil is applied as a natural antioxidant to enhance food stability.[23-24] It is effective to control Fe-induced oxidation.[25] Basil (*Ocimum-basilicum*) oil contains a great amount of phytochemicals contributing to antioxidant and antifungal activities.[26-27] Basil oil is approved for use by the EC and FDA.[28] Lemongrass (*Cymbopogon citratus*) is used to retard inflammatory diseases and microbial infectious.[29-31] Oregano (*Origanum vulgare*) oil contains a huge amount of phytochemicals exhibiting therapeutic properties against different ailments.[32-37] It could be utilized as an alternative to butylated hydroxytoluene to extend the wholesomeness of meat product.[38]

Aroma, flavor are important indicators in the quality of dehydrated products.[39-40] Moreover, phytochemical constituents are highly sensitive to thermal dehydration. Air dehydration is a conventional method to dehydrate wet porous materials.[41] Microwave-air dehydration is highly appreciated as a promising alternative of dehydration technology by providing short dehydration duration and excellent product quality. Microwave and mild air temperature are incorporated to achieve better dehydration effect.[42-43] Moisture is easily removed out of raw material by the driving force of vapor pressure gradient.[44] Dehydration speed is accelerated by the temperature and moisture content gradients.[45] Microwave dehydration is successfully used in different agricultural products.[46-49] Microwave-air dehydration induced to shorter dehydration duration with higher dehydration rates and high-quality dehydrated product.[50] Microwave-air dehydration was applied for oyster mushroom.[51]

Sesban (*Sesbania sesban*) is a shrub widely distributed on paddy field in Dong Thap province, Vietnam during the flooding season. Its flower has been utilized in stew and omelet as fresh and healthy vegetable due to its numerous bioactive ingredients especially anthocyanins, vitamins, phenols, flavonoids possessing antioxidant properties.[52] It's considered as a potential valuable natural antioxidant source with diversfied applications in pharmacy and food sector.[53] Its flower is highly perishable after harvesting therefore it's necessary to convert the fresh to the dried form for long-term stability while retaining the most valuable constituents. There are many dehydration methods to reduce its moisture content to safe level. However, hot temperature or prolonged exposure results to degradation of bioactive ingredients inside raw sesban flower. The goal of our investigation verified the influence of PEF ahead-treatment in microbial inhibition and enzymatic inactivation; essential oil and Microwave-air dehydration on retention of TPC, vitamin C, DPPH, FRAP of the dehydrated sesban flower. Research also monitored the microbial stability of the dehydrated sesban flower during preservation.

MATERIAL AND METHOD

Material

Sesban flower was obtained from Binh Phuoc province, Vietnam. Sesban flower was primarily washed under portable water to separate dirty matters, then it's ahead-treated under PEF to inactivate enzymes and microorganisms. After that, it was subjected to soaking in essential oils ready for Microwave-air dehydration to the final moisture content around 9±0.5oC. The dried sample was kept in plastic bags for 12 months. Chemical reagents such as DPPH; 6-hydroxy2,5,7,8-tetramethylchromane-2-carboxylic acid; 2,4,6-tripyridyl-s-triazine; N, N-diethyl-p-phylenediamine sulphate; 3-Aminophenol; 2,6-dichlorophenol indophenols; oxalic acid; ethanol; methanol; Folin-Ciocalteu reagent; Na_2CO_3; HCl; $FeCl_3$; $FeS0_4.7H_2O$ were all analytical grade supplied from De Phat Co. Ltd. Essential oils of cinnamon, clove, rosemary, basil, lemongrass, oregano were purchased from Kobi Co. Ltd. 3M-Petrifilm was received from 3M-Vietnam.

Researching method

Experiment #1

Effect of PEF parameters in ahead-treatment in the microbial and enzymatic inactivation. Different PEF parameters such as pulse strength (500, 750, 1000, 1250, 1500 kV/cm), pulse duration (30, 60, 90, 120, 150 µs), pulse number (15, 30, 45, 60, 75) were verified. The focused variables in this examination were relied on percentage inhibition (%) of polyphenol oxidase, peroxidase activity, *Coliform* load (log cfu/g)

Experiment #2

Effect of plant essential oil in ahead-treatment to phenolic and antioxidant stability of flower. Flower was soaked with 5% of aqueous suspension (1:1) in 2 minutes of essential oils from cinnamon, clove, rosemary, basil, lemongrass, oregano. The ahead-treated flower was then dehydrated by Microwave-air drier at air temperature 20°C, velocity 0.6 m/s, microwave power density 1.15 W/g. The focused variables in this examination were relied on vitamin C (mg/100g), TPC (mg GAE/100 g), DPPH (mg TE/100 g), FRAP (mg TE/100 g).

Experiment #3

Effect of air temperature, air velocity and microwave power density in Microwave-air dehydration. Different values of air temperature (20, 25, 30, 35, 40°C), air velocity (0.6, 0.8, 1.0, 1.2, 1.4 m/s) and microwave power density (1.15, 1.30, 1.45, 1.60, 1.75 W/g) in Microwave-air dehydration were deeply examined. The focused variables in this examination were relied on vitamin C (mg/100g), TPC (mg GAE/100 g), DPPH (mg TE/100 g), FRAP (mg TE/100 g).

Experiment #4

Microbial stability of the dehydrated sample during storage. In 3 month-interval, the dehydrated samples kept in plastic bags at ambient temperature were also taken to monitor *coliform* (log cfu/g), yeast (log cfu/g) and mold (log cfu/g) load during 12 months of storage.

The dried sesban flowers were grounded by grinder. The grounded powders (50 g) were soaked in methanol (450 mL) for 30 min at ambient condition with periodical agitation. The filtrates were filtered using Whatman No. 2 filter paper with vacuum pump. Each filtrate was concentrated to by vacuum rotary evaporator (RV 3V, IKA, Germany) at 45°C to obtain the end sesban extract.

Physicochemical evaluation

Polyphenol oxidase activity (U) was determined by oxidoreduction potential method via measuring the initial rate of quinone formation, expressed as an acceleration in the absorbance units at 420 nm. An accumulation in absorbance of 0.001/min was considered as one unit of enzyme activity.[54] M_0 is initial polyphenol oxidase activity (raw material), and Mi is polyphenol oxidase activity after treatment.

Percentage inhibition (%) of polyphenol oxidase = $(M_0 - M_i / M_0) \times 100\%$

Peroxidase activity (U) was determined by spectrophotometric method utilizing N, N-diethyl-p-phylenediamine sulphate and 3-Aminophenol as a chromogenic reagent.[55] The procedure was established on the enzymatic utilization of H_2O_2 to produce deep-blue substance at wavelength 660 nm. The intensity in absorbance was scaled to the peroxidase activity. N_0 is initial peroxidase activity (raw material), and Ni is peroxidase activity after treatment.

Percentage inhibition (%) of peroxidase = $(N_0 - N_i / N_0) \times 100\%$

Vitamin C content (mg/100g) was quantified by volumetric method utilizing a 2,6-dichlorophenol-indophenol manual titration protocol described by AOAC.[56] Take 1 ml of the testing pure liquid into a 20 mL of flask. Supplement 2 mL of 5% oxalic acid and titrate the reagent (V_1, ml). The final point was the occurrence of pink pigment. The quantity of chemical titrated was equal to the quantity of vitamin C. Pattern was weighed (M, g) and filled with 4% oxalic acid to volume (20 ml), separated by centrifugator. Take 1ml of this supernatant with 2 mL of 5% oxalic acid and then titrate one more time the reagent (V_2, ml).

$$\text{Vitamin C content (mg/100 g)} = \frac{0.5*V_2*20*100}{V_1*M}$$

TPC (mg GAE/ 100g) was examined by Folin-Ciocalteu reagent protocol57. Extract was disolved with 90% ethanol (v/v) in a 10 mL tube and centrifuged at 4,000 g within 2.5 min. A 1.4 mL of the extract was combined with 2.0 mL Folin-Ciocalteu reagent 10% (w/v). After 10 min of reaction, 4.0 mL of Na_2CO_3 (5% w/v) was added. Reaction lasted for one hour without light, the absorbance was recorded at 760 nm by spectrophotometer (Shimazu, UV-1800) and compared with a pure linear of gallic acid (0-300 mg/L). R^2 of the calibration curve was noticed at 0.87.

DPPH (mg TE/100 g) was estimated using UV-VIS spectrophotometric method with mobile phase methanol and water mixed online in the ratio of 80:20 (v/v), injected at a current speed of 1.0 mL/min. Aliquots of the samples 0.5 mL were

supplemented with 3.5 mL of the 0.05 mM DPPH solution in the dark place, and the mixture was thoroughly vibrated and then incubated for 20 min at 37°C. DPPH peaks were quantified at wavelength 517 nm.[58] R^2 of the calibration curve was noticed at 0.79.

FRAP (mg TE/100 g) was defined as capacity in reducing of Fe^{+3} to Fe^{+2} by an antioxidant utilizing the protocol described by Benzie and Strain.[59] FRAP reagent was formulated by diluting acetate buffer (100 mM, pH 3.5), 5 mM 2,4,6-tripyridyl-s-triazine in 25 mM HCl, and 15 mM $FeCl_3$ at 8:1:1 (v/v/v). All standards and samples were mixed at 500 mg/L in water or methanol. The 100 L reagent, the 20 µL standard ($FeS0_4.7H_20$) or sample and 10 µL water were pipetted to the well and gently mixed. The absorbance were read at 600 nm immediately and 60 min after using a microplate reader. A standard calibration curve of Fe ($^{3+}$) sulphate penta hydrate ($FeS0_4.7H_20$) was plotted at concentrations between 500 and 2000 mM as the reference standard. R^2 of the calibration curve was noticed at 0.83.

Coliform (log cfu/g), yeast (log cfu/g), mold (log cfu/g) were enumerated by 3M-Petrifilm protocols.

Statistical summary

All tests were arranged in three replications. The values were expressed as average ± standard deviation. Statistical summary was executed by the Statgraphics Centurion version XVI.

RESULT AND DISCUSSION

Possibility of PEF as ahead-treatment to the microbial and enzymatic inactivation

Polyphenol oxidase is commonly available in fruits and vegetables located in various organelles, like chloroplast thylakoids, peroxisomes, and mitochondria.[60] Polyphenol oxidase is responsible for enzymatic browning contributing to lower organoleptic property and economical value of foodstuffs.[61-64] Polyphenol oxidase caused polymerization of quinones to form brown and black pigments.[65] By the way, reaction of polyphenol oxidase led to lower total phenolic content.[66-67] In the presence of peroxidase, phenolics were oxidized at the existing of H_2O_2, inducing to flavour degradation.[68] With hydrogen donor, peroxidase converted hydrogen peroxide into H_2O and O_2.[69] The inactivation of peroxidase and polyphenol oxidase was very

Table 1. Impact of pulse strength (kV/cm) of PEF ahead-treatment to enzymatic and microbial inactivation in flower

Pulse strength (kv/cm)	500	750	1000	1250	1500
% inhibition of peroxidase activity	46.25±0.07^b	53.49±0.04^{ab}	59.34±0.05^a	60.07±0.03^a	60.15±0.02^a
% inhibition of polyphenol oxidase activity	38.12±0.03^b	45.86±0.01^{ab}	52.07±0.04^a	52.21±0.02^a	52.32±0.03^a
Coliform load (log cfu/g)	4.36±0.02^a	4.01±0.01^{ab}	3.74±0.02^b	3.71±0.00^b	3.68±0.03^b

Values are the average of triplicate; numbers in row accompanied by the alike symbols are not varied significantly (α = P=0.05).

Table 2. Impact of pulse time (µs) of PEF ahead-treatment to enzymatic and microbial inactivation in flower

Pulse time (µs)	30	60	90	120	150
% inhibition of peroxidase activity	59.34±0.05^b	64.57±0.02^{ab}	72.15±0.01^a	72.23±0.02^a	72.29±0.03^a
% inhibition of polyphenol oxidase activity	52.07±0.04^b	59.16±0.03^{ab}	65.84±0.02^a	66.01±0.00^a	66.12±0.01^a
Coliform load (log cfu/g)	3.74±0.02^a	3.09±0.00^{ab}	2.75±0.03^b	2.71±0.01^b	2.68±0.02^b

Values are the average of triplicate; numbers in row accompanied by the alike symbols are not varied significantly (α = P=0.05).

necessary to retain quality attributes of samples during processing. Thermal treatment was utilized to inactivate the enzyme activity, but it led to negative damage on sensory and proximate compositions.[70] Non-heat treatment was highly prefered to overcome damage of colour, flavour and heat-sensitive components in food.[71]

The impact of pulse strength (500, 750, 1000, 1250, 1500 kV/cm) on polyphenol oxidase (PPO), peroxidise (POD) activity and *coliform* load on the flower was illustrated in Table 1. There were trends of increasing % inhibition of peroxidase activity (46.25±0.07 to 60.15±0.02 %) and % inhibition of polyphenol oxidase activity (38.12±0.03 to 52.32±0.03 %) by increasing pulse strength from 500 to 1500 kv/cm. Meanwhile there was a declining trend of *Coliform* load (from 4.36±0.02 to 3.68±0.03 log cfu/g) by increasing pulse strength from 500 to 1500 kv/cm. There was no significant difference of % inhibition of peroxidase activity, % inhibition of polyphenol oxidase activity and *Coliform* load by pulse strength 1000, 1250 and 1500 kv/cm treatment. Therefore, pulse strength 1000 kv/cm was selected for further experiments.

The influence of pulse duration (30, 60, 90, 120, 150 µs) on polyphenol oxidase (PPO), peroxidise (POD) activity and *coliform* load on the flower was presented in Table 2. There were trends of increasing % inhibition of peroxidase activity (59.34±0.05 to 72.29±0.03 %) and % inhibition of polyphenol oxidase activity (52.07±0.04 to 66.12±0.01 %) by increasing pulse time from 30 to 150 µs. Meanwhile there was a declining trend of *Coliform* load (from 3.74±0.02 to 2.68±0.02 log cfu/g) by increasing pulse time from 30 to 150 µs. There was no significant difference of% inhibition of peroxidase activity, % inhibition of polyphenol oxidase activity and *Coliform* load by pulse time 90, 120 and 150 µs treatment. Therefore, pulse time 90 µs was selected for further experiments.

The effect of pulse number (15, 30, 45, 60, 75) on polyphenol oxidase (PPO), peroxidise (POD) activity and *coliform* load on the flower was recorded in Table 3. There were trends of increasing% inhibition of peroxidase activity (72.15±0.01 to 92.73±0.02 %) and % inhibition of polyphenol oxidase activity (65.84±0.02 to 85.07±0.00 %) by increasing pulse number from 15 to 75. Meanwhile there was a declining trend of *Coliform* load (from 2.75±0.03 to 1.95±0.01 log cfu/g) by increasing pulse number from 15 to 75. There was no significant difference of % inhibition of peroxidase activity, % inhibition of polyphenol oxidase activity and *Coliform* load by pulse number 45, 60, and 75. Therefore, pulse number 45 was selected for further experiments.

It's thoroughly realized that under pulse strength 1000 kV/cm, pulse duration 90 µs, pulse number 45 could effectively inactivated 84.96±0.00 % of polyphenol oxidase, 92.34±0.02 % of peroxidase activity and 2.03±0.01 log cfu/g of *coliform* load. Increasing electric field density (EFD) and treatment duration resulted to more enzyme inactivation.[72-73] Bipolar mode was superior to monopolar mode inducing to greater inactivation of polyphenol oxidase, while monopolar pulse was more beneficial to peroxidase inactivation.[72] Peroxidase and polyphenol oxidase inactivation was strongly correlated to the damage of a-spiral of secondary structure.[74] A 70 % maximum inactivation of polyphenol oxidase activity was noticed after 5 ms applying width pulses at 0.02 ms in bipolar regime at 24.30 kV/cm.[75] 97 % of polyphenol oxidase and peroxidase in plant-based product was inactivated under PEF processing.[76]. PPO activity in apple extract was completely inhibited at 40 kV/cm, width pulses >

Table 3. Effect of pulse number of PEF ahead-treatment to enzymatic and microbial inactivation in flower

Pulse number	15	30	45	60	75
% inhibition of peroxidase activity	72.15±0.01^{b}	80.37±0.03^{ab}	92.34±0.02^{a}	92.60±0.03^{a}	92.73±0.02^{a}
% inhibition of polyphenol oxidase activity	65.84±0.02b	73.52±0.01^{ab}	84.96±0.00^{a}	85.02±0.01^{a}	85.07±0.00^{a}
Coliform load (log cfu/g)	2.75±0.03^{a}	2.29±0.02^{ab}	2.03±0.01^{b}	1.99±0.02^{b}	1.95±0.01^{b}

Values are the average of triplicate; numbers in row accompanied by the alike symbols are not varied significantly (α = P=0.05).

Table 4. Effect of herbal essential oil ahead-treatment prior to Microwave-air dehydration to phenolic content and antioxidant capacity in flower

Essential oil	Cinnamon	Clove	Rosemary	Basil	Lemongrass	Oregano
Vitamin C (mg/100g)	25.45±0.12^{d}	29.66±0.08^{cd}	51.35±0.11^{a}	42.14±0.07^{b}	37.50±0.12^{bc}	34.11±0.09^{c}
TPC (mg GAE/100g)	86.32±1.28^{d}	91.07±2.35^{cd}	136.19±1.64^{a}	115.24±0.95^{b}	108.42±1.16^{bc}	100.67±1.29^{c}
DPPH (mg TE/100g)	147.31±1.54^{d}	152.43±1.37^{cd}	196.07±1.29^{a}	175.20±1.33^{b}	167.14±1.21^{bc}	159.78±1.09^{c}
FRAP (mg TE/100g)	764.15±2.40^{d}	807.53±2.19^{cd}	1327.19±1.58^{a}	968.15±2.04^{b}	916.42±1.83^{bc}	871.24±1.61^{c}

Values are the average of triplicate; numbers in row accompanied by the alike symbols are not varied significantly (α = P=0.05).

Table 5. Impact of air temperature in microwave-air dehydration to phenolic content and antioxidant capacity in dried flower

Air temperature (°C)	20	25	30	35	40
Vitamin C (mg/100 g)	37.32±0.07^{a}	37.15±0.04^{a}	32.67±0.03^{ab}	29.60±0.05^{b}	17.18±0.02^{c}
TPC (mg GAE/100 g)	107.16±0.73^{a}	105.83±0.91^{a}	96.42±0.69^{ab}	92.27±0.57^{b}	73.46±0.45^{c}
DPPH (mg TE/100 g)	130.75±0.89^{a}	128.96±1.01^{a}	101.30±1.18^{ab}	94.05±0.98^{b}	79.12±0.83^{c}
FRAP (mg TE/100 g)	1038.51±1.15^{a}	1029.17±1.03^{a}	947.25±1.24^{ab}	906.73±1.08^{b}	724.08±0.95^{c}

~~Values are the average of triplicate; numbers in row accompanied by the alike symbols are not varied significantly (α = P=0.05).~~

10077. PPO activity in apple was reduced by 3.15 % at 24.6 k/ cm in 6 ms.[78] 71 % of PPO activity in apple extract was inactivated by preheating at 50°C and PEF in 100 µs at 40 kV/cm.[79] 70 % polyphenol oxidase activity in apple extract was inactivated by PEF at 38.5 kV/cm and 300 pulse/s by preheating at 50°C.[80] 48 % polyphenol oxidase activity in apple juice was destabilized by preheating to 40°C and PEF at 30 kV/cm.[81] 90 % of peroxidase and polyphenol oxidase in carrot and apple mash was inactivated by PEF at 80°C.[82] PEF as ahead-treatment could minimize the dehydration duration 25 % and improved the rehydration property of freeze-dried apple.[9] PEF stabilized the appearance and improved porosity 86 % of freeze-dehydrated apple.[7] Rehydration capacity of the dehydrated red bell pepper and strawberries increased by up to 50 % under PEF in advance of dehydration.[10] Dehydration duration was shorter and rehydration ratio became higher on sea cucumber ahead-treated by PEF.[8] PEF was demonstrated to inactivate on microorganisms in apple juice.[83-85] PEF at 35 kV/ cm and 90 µs sterilized *S. cerevisiae* 5.30 log and *E. coli* 5.15 log.[86] Antimicrobial by PEF could be due to cell membrane perforation. This phenomenon induced to increasing of cell membrane rupture and permeability, irreversible holes resulting to the overflow of macromolecules through the pores.[86] Membrane permeability became higher by accelerating the EFD. The elevated membrane instability led to destruction of microbial cells. Spores were more stable to vegetative cells under PEF.[87] The EFD of 10.82 kV/cm and 120 pulses resulted to reduction of total plate counts of 1.18×10^{4} cfu/g to < 10 cfu/g of mesophilic aerobic bacteria in date palm. The EFD of 8.84 kV/cm and 90 pulses caused a elimination of total plate counts of 3.27×10^{3} cfu/g of yeasts and fungi to < 10 cfu/g. When 10.82 kV/cm of EFD and 60 of pulses number were used, non-detectable levels of yeasts and molds were noticed1. PEF (2.9 kV/ cm, 100 Hz, 5000 pulses, pulse duration 10 µs) was applied to inactivate *S. cerevisiae*.[88]. Yeast/fungus and mesophilic bacterial activity was thoroughly inhibited in apple extract treated by PEF during 3-month storage.[77]

Table 6. Impact of air speed in microwave-air dehydration to phenolic content and antioxidant capacity in dried flower

Air speed (m/s)	0.6	0.8	1.2	1.4	1.6
Vitamin C (mg/100g)	19.43±0.03^{c}	30.07±0.01^{b}	34.25±0.02^{ab}	36.89±0.03^{a}	37.15±0.04^{a}
TPC (mg GAE/100g)	75.06±0.49^{c}	90.54±0.25^{b}	97.60±0.57^{ab}	104.71±0.64^{a}	105.83±0.91^{a}
DPPH (mg TE/100g)	81.23±0.39^{c}	102.45±0.71^{b}	113.27±0.84^{ab}	126.77±0.72^{a}	128.96±1.01^{a}
FRAP (mg TE/100g)	809.72±0.86^{c}	938.64±0.75^{b}	997.35±0.63^{ab}	1026.52±0.71^{a}	1029.17±1.03^{a}

Values are the average of triplicate; numbers in row accompanied by the alike symbols are not varied significantly (α = P=0.05).

Table 7. Impact of microwave energy in microwave-air dehydration to phenolic content and antioxidant capacity in dried flower

Microwave power density (W/g)	1.15	1.30	1.45	1.60	1.75
Vitamin C (mg/100g)	34.25±0.02^{a}	33.89±0.00^{a}	31.05±0.03^{ab}	26.34±0.02^{b}	14.75±0.01^{c}
Total phenolic (mg GAE/100g)	97.60±0.57^{a}	96.97±0.63^{a}	91.23±0.48^{ab}	84.76±0.59^{b}	70.61±0.58^{c}
DPPH (mg TE/100g)	113.27±0.84^{a}	112.79±0.56^{a}	106.50±0.42^{ab}	99.72±0.51^{b}	81.53±0.60^{c}
FRAP (mg TE/100g)	997.35±0.63^{a}	995.24±0.69^{a}	961.15±0.81^{ab}	919.34±0.73^{b}	806.17±0.37^{c}

Values are the average of triplicate; numbers in row accompanied by the alike symbols are not varied significantly (α = P=0.05).

Impact of herbal essential oil ahead-treatment prior to Microwave-air dehydration

There were many changes of raw material after dehydration like shrinkage, porosity, biopolymer structure, and biochemical activity. Purpose of pre-dehydration treatment focused on either quality enhancement of the dried product or accelerated dehydration kinetics.[89] Inorganic compounds (Sulfur dioxide, calcium, sodium, Na_2CO_3), organic compounds, biopolymers, surface active agents were literatured in pre-dehydration treatment.[90-94] Influence of essential oils from cinnamon, clove, rosemary, basil, lemongrass, oregano in ahead-treatment prior to Microwave-air dehydration was presented in table 4. It's clearly noted that among different herbal essential oils, rosemary strongly preserved vitamin C (51.35±0.11 mg/100g), total phenolic content (136.19±1.64 mg GAE/100g), DPPH free radical scavenging (196.07±1.29 mg TE/100g), FRAP ferric reducing antioxidant power (1327.19±1.58 mg TE/100g) in the dried samples. In the European Union, rosemary has been approved as a safe natural antioxidant with low toxicity suitable for food preservation. Dried black chokeberry fruit preliminarily soaked in a suspension of cinnamon or cloves maintained the highest phenolic content during freeze-dehydration.[12] Inclusion of 1% rosemary in the active film of biodegradable serum protein could retard *L. monocytogenes* effectively.[95] Oregano oil supplemented in the diet (200 mg/kg of diet) improved antioxidant capacity and limited oxidative rancidity in turkey.[96] The impact of lemongrass cinnamon, oregano and clove oils on proliferation and FB1 production of *F. proliferatum* in irradiated maize grain was evaluated. Cinnamon and oregano oils was greatly beneficial in retarding proliferation and FB1 formation by *F. proliferatum* in corn.[97] Cinnamon, clove and rosemary oils were useful on retarding lipid oxidation.[98] Clove oil revealed the highest inhibition rate against DPPH radical.[99] Basil oil contained major components such as linalool, methyl chavicol, methyl cinnamate, and eugenol.[100-102]

Effect of air temperature, air velocity and microwave power density in Microwave-air dehydration

Ascorbic acid and polyphenol are the most thermo-labile bioactive constituents in herb and plant. The decomposed reactions of these bioactive substances are catalyzed by high

Table 8. Microbial load in the dried sample during storage

Storage (months)	0	3	6	9	12
Coliform (log cfu/g)	0.15±0.01[b]	0.17±0.02[b]	0.24±0.03[ab]	0.31±0.00[ab]	0.38±0.01[a]
Yeast (log cfu/g)	Not detected	Not detected	Not detected	Not detected	Not detected
Mold (log cfu/g)	Not detected	Not detected	Not detected	Not detected	Not detected

Values are the average of triplicate; numbers in row accompanied by the alike symbols are not varied significantly (α = P=0.05).

temperature, ascorbate oxidase, polyphenol oxidase escaped from damaged cell membranes in dehydration. They should be preserved at utmost level in dehydrated products.

Influence of air temperature (20, 25, 30, 35, 40°C) to phenolic content and antioxidant capacity of dried flower during microwave-air dehydration was elaborated in table 5. By accelerating air temperature (20-40°C), there was declining trends of vitamin C (37.32±0.07 down to 17.18±0.02 mg/100 g), TPC (107.16±0.73 down to 73.46±0.45 mg GAE/100 g), DPPH (130.75±0.89 down to 79.12±0.83 mg TE/100 g), and FRAP (1038.51±1.15 down to 724.08±0.95 mg TE/100 g). The descending trend of phenolic substances and antioxidant capacities in sesban flower during dehydration by increasing air temperature could be explained by thermal-sensitive degradation. There was no significant difference of vitamin C, TPC, DPPH, FRAP by air temperature 20°C, 25°C and 30°C. We decided to choose air temperature 25°C to preserve the most phenolic substances and antioxidant capacities in sesban flower.

Impact of air velocity (0.6, 0.8, 1.0, 1.2, 1.4 m/s) to phenolic content and antioxidant capacity of dried flower during microwave-air dehydration was shown in table 6. By accelerating air speed (0.6-1.6 m/s), there was ascending trends of vitamin C (19.43±0.03 up to 37.15±0.04 mg/100 g), TPC (75.06±0.49 up to 105.83±0.91 mg GAE/100 g), DPPH (81.23±0.39 up to 128.96±1.01 mg TE/100 g), and FRAP (809.72±0.86 up to 1029.17±1.03 mg TE/100 g). The ascending trend of phenolic substances and antioxidant capacities in sesban flower during dehydration by increasing air speed could be explained by quick moisture evaporation rate under high air speed which minimized oxidation. There was no significant difference of vitamin C, TPC, DPPH, FRAP by air speed 1.2, 1.4 and 1.6 m/s. We decided to choose air speed 1.2 m/s to preserve the most phenolic substances and antioxidant capacities in sesban flower.

Effectiveness of microwave power density (1.15, 1.30, 1.45, 1.60, 1.75 W/g) to phenolic content and antioxidant capacity of dried flower during microwave-air dehydration was recorded in table 7. By accelerating microwave power density (1.15-1.75 W/g), there was declining trends of vitamin C (34.25±0.02 down to 14.75±0.01 mg/100 g), TPC (97.60±0.57 down to 70.61±0.58 mg GAE/100 g), DPPH (113.27±0.84 down to 81.53±0.60 mg TE/100 g), and FRAP (997.35±0.63 down to 806.17±0.37 mg TE/100 g). The decreasing trend of phenolic substances and antioxidant capacities in sesban flower during dehydration by increasing microwave power density could be explained by degradation of thermal-sensitive components under high energy of microwave. There was no significant difference of vitamin C, TPC, DPPH, FRAP by microwave power density 1.15, 1.30 and 1.45 W/g. We decided to choose microwave power density 1.45 W/g to preserve the most phenolic substances and antioxidant capacities in sesban flower.

It's easily noticed that air temperature 25°C, air velociy 1.2 m/s, microwave power density 1.45 W/g resulted to the highest retention of vitamin C (31.05±0.03 mg/100g), total phenolic content (91.23±0.48 mg GAE/100g), DPPH free radical scavenging (106.50±0.42 mg TE/100g), FRAP ferric reducing antioxidant power (961.15±0.81 mg TE/100g) in the dried samples. At low temperature, air velocity and microwave power, the extended exposure of materials in dehydrating condition induced the degradation of bioactive constituents like ascorbic acid, phenolic limiting the health-promoting advantage and antioxidant activity. With the support of microwave, moisture in core of sample migrated

to the surface and escaped greatly to environment even at low temperature of air dehydration. High dehydration rate could prevent overheating and quality decomposition. Microwave could maintain phenolics by inactivating the polyphenol oxidase, lipoxygenase and peroxidase enzymes escaped from the damaged tissue.[103] Different literatures mentioned to the protective advantages of phenolic substances in oat flour tarhana, sour cherry, jujube fruit dehydration with the presence of microwave.[104-106] Dehydration temperature and microwave power significantly affected to total phenolic content in the dehydrated pomelo.[50] Microwave- air dehydration at 200 W - 60°C on pear slice resulted to higher protection of phytochemical constituents.[107]. Basil, lovage, mint, oregano, parsley and rocket leaves were dried by Microwave-air dryer at 40°C, air velocity 0.8 m/s, and power 300 W having high retention of chlorophyll.[108] Air temperature and velocity were important parameters in Microwave-air dehydration to remove moisture leading to homogeneous and faster dehydration.[109] Microwave energy 100 W, temperature 60°C, air speed 0.86 m/s resulted to high ascorbic acid, total phenolic retention in thermal-sensitive food matrix.[110]

Storage of the dehydrated sample

Microbial stability in the dried sample was observed during 12 months of storage (Table 8). Yeast and mold were not detected in the dried sample. Meanwhile, *coliform* slightly increased during preservation but within acceptable limit. According to the FAO, the lowest water activity for bacteria, yeast, mold was 0.91, 0.88, 0.80 respectively. In the present study, the moisture content in the dried sesban flower was 9±0.5%. This was a very low limit and not suitable for *coliform*, yeast and mold to growth and proliferation.

CONCLUSION

Ahead-treatment prior to dehydration had two goals: decrease the dehydration duration and enhance properties of the dried product. PEF was an essential ahead-treatment for flower before the official dehydration step to inactivate enzyme, disinfect microbial load at low temperature. It provided short treatment duration, minimal heating damage, and environmental friendly impact. Essential oil of rosemary primarily treated prior to dehydration was useful to protect ascorbic acid, phenolic content and antioxidant capacity of sesban flower. The present research proved that microwave-air dehydration had beneficial advantages to preserve vitamin C, TPC, DPPH, FRAP in the dehydrated flower. The dried flower had microbial load within acceptable limits during 12 months of storage. PEF would be a near-future alternative to conventional thermal processing like blanching. PEF could be successfully utilized in ahead-treatment step before the microwave-air dehydration to protect thermal-sensitive phytochemical constituents. Microwave-air dehydration retained maximal thermo-labile bioactive constituents by avoiding hot temperature or long exposure in mono treatment. Dried sesban flower would be used as an functional food drink contributing to human health.

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DATA AVAILABILITY

All datasets generated or analyzed during this study are included in the manuscript.

ETHICS STATEMENT

Not applicable.

REFERENCES

1. Mohammed MEA, Amer-Eissa AH, Aleid SM. Application of Pulsed electric field for microorganisms inactivation in date palm fruits. *J Food Nutr Res.* 2016;4(10):646-652. doi: 10.12691/jfnr-4-10-3
2. Wu X, Wang C, Guo Y. Effects of the high-PEF ahead-treatment on the mechanical properties of fruits and vegetables. *Journal of Food Engineering.* 2020;274(2):109837. doi: 10.1016/j.jfoodeng.2019.109837
3. Ghosh S, Gillis A, Levkov K, Vitkin E, Golberg A. Saving energy on meat air convection dehydration with Pulsed electric field coupled to mechanical press water removal. *Innov Food Sci Emerg Technol.* 2020;66(4):102509. doi: 10.1016/j.ifset.2020.102509
4. Rybak K, Samborska K, Jedlinska A, et al.. The impact of pulsed electric field pretreatment of bell pepper on

the selected properties of spray dried juice. *Innov Food Sci Emerg Technol.* 2020;65(3):102446. doi: 10.1016/j.ifset.2020.102446

5. Yamada T, Yamakage K, Takahashi K, et al. Influence of dehydration rate on hot air dehydration processing of fresh foods using Pulsed electric field. *IEEJ Transactions on Electrical and Electronic Engineering.* 2020;15(7):1123-1125. doi: 10.1002/tee.23158
6. Qamar AS, Anum I, Ubaid UR, Sadia A, Rizwan S. Pulsed electric field technology in food preservation: a review. *Journal of Nutritional Health and Food Engineering.* 2017;6(5):168-172. http://medcraveonline.com/JNHFE/JNHFE-06-00219.pdf
7. Parniakov O, Bals O, Lebovka N, Vorobiev E. Pulsed electric field assisted vacuum freeze-dehydration of apple tissue. *Innov Food Sci Emerg Technol.* 2016;35(2):52-57. doi: 10.1016/j.ifset.2016.04.002
8. Bai Y, Luan Z. The effect of high-pulsed electric field pretreatment on vacuum freeze drying of sea cucumber. *International Journal of Applied Electromagnetics and Mechanics.* 2018;57(2):247-256. doi: 10.3233/JAE-180009
9. Lammerskitten A, Mykhailyk V, Wiktor A, et al. Impact of Pulsed electric fields on physical properties of freeze-dried apple tissue. *Innov Food Sci Emerg Technol.* 2019;57(3):102211. doi: 10.1016/j.ifset.2019.102211
10. Fauster T, Giancaterino M, Pittia P, Jaeger H. Effect of pulsed electric field pretreatment on shrinkage, rehydration capacity and texture of freeze-dried plant materials. *LWT.* 2020;121(1):108937. doi: 10.1016/j.lwt.2019.108937
11. Deng LZ, Mujumdar AS, Zhang Q, et al. Chemical and physical ahead-treatments of fruits and vegetables: Effects on dehydration characteristics and quality attributes - A comprehensive review. *Crit Rev Food Sci Nutr.* 2019;59(9):1408-32. doi: 10.1080/10408398.2017.1409192
12. Sidor A, Drozdzynska A, Brzozowska A, Gramza-Michalowska A. The effect of plant additives on the stability of polyphenols in dried black chokeberry (Aronia melanocarpa) fruit. *Foods.* 2021;10(1):44. doi: 10.3390/foods10010044
13. Seddigi ZS, Kandhro GA, Shah F, Danish E, Soylak M. Assessment of metal contents in spices and herbs from Saudi Arabia. *Toxicol Ind Health.* 2016;32(2):260-269. doi: 10.1177/0748233713500822
14. Arantes S, Picarra A, Candeias F, Caldeira AT, Martins MR, Teixeira D. Antioxidant activity and cholinesterase inhibition studies of four flavouring herbs from Alentejo. *Nat Prod Res.* 2017;31(18):2183-2187. doi: 10.1080/14786419.2017.1278598
15. Farshchi HK, Azizi M, Jaafari MR, Nemati SH, Fotovat A. Green synthesis of iron nanoparticles by rosemary extract and cytotoxicity effect evaluation on cancer cell lines. *Biocatalysis Agricultural Biotechnology.* 2018;16(3):54-62. doi: 10.1016/j.bcab.2018.07.017
16. Ferriccioni N, Mateuccic R, Zangrando A, Santana S, Campos CA. Effect of decontamination treatment on the quality of dehydrated thyme, coriander, and mustard. *Food Sci Technol Int.* 2019;25(7): 579-587. doi: 10.1177/1082013219850667
17. Grant T, Ingegerd S, Federico GG. A review of dehydration methods for improving the quality of dried herbs. *Crit Rev Food Sci Nutr.* 2021;61(11):1763-1786. doi: 10.1080/10408398.2020.1765309
18. Orphanides A, Goulas V, Gekas V. Dehydration technologies: Vehicle to high-quality herbs. *Food Engineering Reviews.* 2016;8(2):164-80. doi: 10.1007/s12393-015-9128-9
19. Cortes-Rojas DF, Souza CR, Oliveira WP. Clove (*Syzygium aromaticum*): A precious spice. *Asian Pac J Trop Biomed.* 2014;4(2):90-96. doi: 10.1016/S2221-1691(14)60215-X
20. Zhang C, Fan L, Fan S, et al. *Cinnamomum cassia* Presl: A review of its traditional uses, phytochemistry, pharmacology and toxicology. *Molecules*. 2019;24(19):3473. doi: 10.3390/molecules24193473
21. Kaur K, Kaushal S. Phytochemistry and pharmacological aspects of Syzygium aromaticum: A review. *Journal of Pharmacognosy and Phytochemistry.* 2019;8(1):398-406. https://www.phytojournal.com/archives/?year=2019&vol=8&issue=1&ArticleId=6762&si=false
22. Mitropoulou G, Nikolaou A, Santarmaki V, Sgouros G, Kourkoutas Y. Citrus medica and *Cinnamomum zeylanicum* essential oils as potential biopreservatives against spoilage in low alcohol wine products. *Foods.* 2020;9(5):577. doi: 10.3390/foods9050577
23. Habtemariam S. The therapeutic potential of rosemary (*Rosmarinus officinalis)* diterpenes for alzheimer's disease. *Evidence-Based Complementary and Alternative Medicine.* 2016;2016:2680409. doi: 10.1155/2016/2680409
24. Andrade JM, Faustino C, Garcia C, Ladeiras D, Reis CP, Rijo P. *Rosmarinus officinalis* L.: An update review of its phytochemistry and biological activity. *Future Science OA.* 2018a;4(4):FSO283. doi: 10.4155/fsoa-2017-0124
25. Zhou FB, Jongberg S, Zhao MM, Sun WZ, Skibsted LH. Antioxidant efficiency and mechanisms of green tea, rosemary or mate extracts in porcine Longissimus dorsi subjected to iron-induced oxidative stress. *Food Chemistry.* 2019;298(4):125030. doi: 10.1016/j.foodchem.2019.125030
26. Nawaz H, Hanif MA, Ayub MA, et al. Raman spectroscopy for the evaluation of the effects of different concentrations of Copper on the chemical composition and biological activity of basil essential oil. *Spectrochim Acta Part A Mol Biomol Spectrosc.* 2017;185(3):130-138. doi: 10.1016/j.saa.2017.05.049
27. Shiwakoti S, Saleh O, Poudyal S, Barka A, Qian Y, Zheljazkov VD. Yield, composition and antioxidant capacity of the essential oil of sweet basil and holy basil as influenced by distillation methods. *Chem Biodivers.* 2017;14(4):e1600417. doi: 10.1002/cbdv.201600417
28. Li QX, Chang CL. Basil (*Ocimum basilicum* L.) oils. In: Preedy V.R., editor. Essential Oils in Food Preservation, Flavor and Safety. Elsevier Inc.; London, UK; 2016;231-238. doi: 10.1016/B978-0-12-416641-7.00025-0
29. Abe S, Maruyama N, Hayama K, et al. Suppression of tumor necrosis factor-alpha-induced neutrophil adherence responses by essential oils. *Mediator Inflamm.* 2003;12(6):323-328. doi: 10.1080/09629350310001633342
30. Alitonou GA, Avlessi F, Sohounhloue DK, Agnaniet H, Bessiere JM, Menut C. Investigations on the

essential oil of Cymbopogon giganteus from Benin for its potential use as an anti-inflammatory agent. *International Journal of Aromatherapy.* 2006;16(1):37-41. doi: 10.1016/j.ijat.2006.01.001

31. Tiwari M, Dwivedi UN, Kakkar P. Suppression of oxidative stress and pro-inflammatory mediators by *Cymbopogon citrates* DC. Stapf extract in lipopolysaccharide stimulated murine alveolar macrophages. *Food Chem Toxicol.* 2010;48(10):2913-2919. doi: 10.1016/j.fct.2010.07.027
32. Bayramoglu B, Sahin S, Sumnu G. Solvent-free microwave extraction of essential oil from oregano. *Journal of Food Engineering.* 2008;88(4):535-540. doi: 10.1016/j.jfoodeng.2008.03.015
33. Mechergui K, Coelho JA, Serra MC, Lamine SB, Boukhchina S, Khouja ML. Essential oils of *Origanum vulgare* L. subsp. *glandulosum* (Desf.) Ietswaart from Tunisia: Chemical composition and antioxidant activity. *J Sci Food Agric.* 2010;90(10):1745-1749. doi: 10.1002/jsfa.4011
34. Tan C, Wei H, Sun H, et al. Effects of dietary supplementation of oregano essential oil to sows on oxidative stress status, lactation feed intake of sows, and piglet performance. *Biomed Res Int.* 2015;2015:525218. doi: 10.1155/2015/525218
35. Han X, Parker TL. Anti-inflammatory, tissue remodeling, immunomodulatory, and anticancer activities of oregano (*Origanum vulgare*) essential oil in a human skin disease model. *Biochimie Open.* 2017;4(2):73-77. doi: 10.1016/j.biopen.2017.02.005
36. Leyva-Lopez N, Gutierrez-Grijalva EP, Vazquez-Olivo G, Heredia JB. Essential oils of oregano: Biological activity beyond their antimicrobial properties. *Molecules.* 2017;22(6):989. doi: 10.3390/molecules22060989
37. de Rostro-Alanis MJ, Baez-Gonzalez J, Torres-Alvarez C, Parra-Saldivar R, Rodriguez-Rodriguez J, Castillo S. Chemical composition and biological activities of oregano essential oil and its fractions obtained by vacuum distillation. *Molecules.* 2019;24(10):1904. doi: 10.3390/molecules24101904
38. Cantu-Valdez JA, Gutierrrez-Soto G, Hernandez-Martinez CA, et al. Mexican oregano essential oils as alternatives to butylated hydroxytoluene to improve the shelf life of ground beef. *Food Sci Nutr.* 2020;8(8):4555-4564. doi: 10.1002/fsn3.1767
39. Duan HY, Barringer SA. Changes in furan and other volatile compounds in sliced carrot during air-dehydration. *Journal of Food Processing and Preservation.* 2012;36(1):46-54. doi: 10.1111/j.1745-4549.2011.00550.x
40. Grauwet T, Kebede BT, Delgado RM, et al. Evaluating the potential of high pressure high temperature and thermal processing on volatile compounds, nutritional and structural properties of orange and yellow carrots. *Eur Food Res Technol.* 2015;240(1):183-198. doi: 10.1007/s00217-014-2319-4
41. Edna GS, Ricardo SG, Josivanda PG, et al. Air and microwave assisted dehydration of wet porous materials with prolate spheroidal shape: a finite-volume approach. *Agriculture.* 2020;10(11):507. doi: 10.3390/agriculture10110507
42. Hemis M, Choudhary R, Becerra-Mora N, Kohli P, Raghavan V. Modelling of microwave assisted air dehydration and microstructural study of oil seeds. *Int J Agric Biolog Engin.* 2016;9(6):167-177. doi: 10.3965/j.ijabe.20160906.2442
43. Talens C, Arboleya JC, Castro-Giraldez M, Fito PJ. Effect of microwave power coupled with hot air dehydration on process efficiency and physico-chemical properties of a new dietary fibre ingredient obtained from orange peel. *LWT Food Sci Technol.* 2017;77(2):110-118. doi: 10.1016/j.lwt.2016.11.036
44. Wanxiu X, Jianfeng Y, Jinghong T, et al. Aroma and quality of carrot dried using a Microwave-air dehydration system as affect by temperature gradient. *Int J Food Prop.* 2020;23(1):63-79. doi: 10.1080/10942912.2019.1709497
45. Constant T, Moyne C, Perre P. Dehydration with internal heat generation: theoretical aspects and application to microwave heating. *AIChE Journal.* 1996;42(2): 359-368. doi: 10.1002/aic.690420206
46. Maskan M. Microwave/air and microwave finish dehydration of banana. *Journal of Food Engineering.* 2000;44(2):71-78. doi: 10.1016/S0260-8774(99)00167-3
47. Torringa E, Esveled E, Scheewe I, Bartels P, Berg R. Osmotic dehydration as a pre-treatment before combined microwave-air dehydration of mushrooms. *Journal of Food Engineering.* 2001;49(2):185-191. doi: 10.1016/S0260-8774(00)00212-0
48. Srikiatden J, Roberts JS. Measuring moisture diffusivity of potato and carrot (core and cortex) during air hot air and isothermal dehydration. *Journal of Food Engineering*. 2006;74(1):143-152. doi: 10.1016/j.jfoodeng.2005.02.026
49. Bingo LG, Pan Z, Roberts JS, Devres YO, Balaban MO. Mathematical modeling of microwave-assisted air heating and dehydration of grapes. *International Journal Agricultural Biology and Engineering.* 2008;1(2):46-54. https://ijabe.org/index.php/ijabe/article/view/71
50. Gulcin Y, Gokcen I. Influence of microwave and Microwave-air dehydration on the dehydration kinetics and quality characteristics of pomelo. *Journal of Food Processing and Preservation.* 2019;43(6): e13812. doi: 10.1111/jfpp.13812
51. Bhattacharya M, Srivastav PP, Mishra HN. Thin-layer modeling of air and Microwave-air dehydration of oyster mushroom (Pleurotus ostreatus). *Journal of Food Science and Technology.* 2013;52(4):2013-2022. doi: 10.1007/s13197-013-1209-2
52. Kathiresh M, Suganya D, Saravanakumar M. Bioactive compounds in *Sesbania sesban* flower and its antioxidant and antimicrobial activity. *Journal of Pharmacy Research.* 2012;5(1):390-393.
53. Kathiresh M, Suganya D, Saravanakumar M. Antioxidant effect of *Sesbania sesban* flower extract. *International Journal of Pharmaceutical Sciences.* 2011;3(2):1307-1312.
54. Mustafa R, Alwazeer D. Determination of polyphenol oxidase activity using the oxidoreduction potential method. *J Biotechnol.* 2010;150:297. doi: 10.1016/j.jbiotec.2010.09.250
55. Chamaraja NA, Shivakumar A, Kumar CSC, Kumar

CBP, Swamy NK. Spectrophotometric determination of peroxidase using N, N-diethyl-p-phylenediamine sulphate and 3-Aminophenol as a chromogenic reagent: Application of the method to seeds of some fruits. *Chemical Data Collections.* 2017;11(12):84-95. doi: 10.1016/j.cdc.2017.08.005

56. AOAC. Official method of analysis. 18th ed. Washington DC: Association of Official Analytical Chemists; 2005.
57. Singleton VL, Rossi JAJR. Colorimetry of total phenolics with phosphomolybdic phosphotungstic acid reagents. *Am J Enol Vitic.* 1965;16:144-158.
58. Andriana Y, Xuan TD, Quy TN, Minh TN, Van TM, Viet TD. Antihyperuricemia, antioxidant, and antibacterial activities of Tridax procumbens L. *Foods.* 2019;8:21. doi: 10.3390/foods8010021
59. Benzie IFF, Strain JJ. The ferric reducing ability of plasma (FRAP) as a measure of antioxidant power: The FRAP assay. *Anal Biochem.* 1996;239(1):70-76. doi: 10.1006/abio.1996.0292
60. Yoruk R, Marshall MR. Physicochemical properties and function of plant polyphenol oxidase: A review. *J Food Biochem.* 2003;27(5):361-422. doi: 10.1111/j.1745-4514.2003.tb00289.x
61. Zhang Q, Liu Y, He C, Zhu S. Postharvest exogenous application of abscisic acid reduces internal browning in pineapple. *J Agric Food Chem.* 2015;63(22):5313-5320. doi: 10.1021/jf506279x
62. Sun Y, Zhang W, Zeng T, Nie Q, Zhang F, Zhu L. Hydrogen sulfide inhibits enzymatic browning of fresh-cut lotus root slices by regulating phenolic metabolism. *Food Chemistry.* 2015;177(15):376-381. doi: 10.1016/j.foodchem.2015.01.065
63. Yi JH, Dong XL, Zhu ZB. Effect of polyphenol oxidase (PPO) enzymatic inducing factors on non-enzymatic browning of apple polyphenols. *Modern Food Science and Technology.* 2015;31(2):119-127. doi: 10.13982/j.mfst.1673-9078.2015.2.021
64. Sikora M, Swieca M. Effect of ascorbic acid postharvest treatment on enzymatic browning, phenolics and antioxidant capacity of stored mung bean sprouts. *Food Chemistry.* 2018;239(15):1160-1166. doi: 10.1016/j.foodchem.2017.07.067
65. Mayer AM. Polyphenol oxidases in plants and fungi: Going places? A review. *Phytochemistry.* 2006;67(21):2318-2331. doi: 10.1016/j.phytochem.2006.08.006
66. Sullivan ML. Beyond brown: Polyphenol oxidases as enzymes of plant specialized metabolism. *Front Plant Sci.* 2015;5(1):783. doi: 10.3389/fpls.2014.00783
67. Swieca M, Seczyk L, Gawlik-Dziki U. Elicitation and precursor feeding as tools for the improvement of the phenolic content and antioxidant activity of lentil sprouts. *Food Chem.* 2014;161(3):288-295. doi: 10.1016/j.foodchem.2014.04.012
68. Hendrickx M, Ludikhuyze L, Van den Broeck I, Weemaes C. Effects of high pressure on enzymes related to food quality. *Trends Food Sci Technol.* 1998;9(5):197-203. doi: 10.1016/S0924-2244(98)00039-9
69. Lopes AM, Toralles RP, Rombaldi CV. Thermal inactivation of polyphenoloxidase and peroxidase in Jubileu clingstone peach and yeast isolated from its spoiled puree. *Food Science Technology, Campinas.* 2014;34(1):150-156. doi: 10.1590/S0101-20612014000100022
70. Barsotti L, Dumay E, Mu TH, Diaz MDF, Cheftel JC. Effect of high voltage electric pulses on protein-based food costituents and structutres. *Trends Food Science Technology.* 2001;12(3):136-144. doi: 10.1016/S0924-2244(01)00065-6
71. Lasekan O, Ng S, Azeez S, Shittu R, Teoh L, Gholivand S. Effect of Pulsed electric field processing on flavor and color of liquid foods. *Journal of Food Processing and Preservation.* 2017;41(3):e12940. doi: 10.1111/jfpp.12940
72. Elez-Martinez P, Aguilo-Aguayo I, Martin-Belloso O. Inactivation of orange juice peroxidase by high intensity Pulsed electric fields as influenced by process parameters. *J Sci Food Agric.* 2006;86(1):71-81. doi: 10.1002/jsfa.2306
73. Aguilo-Aguayo I, Soliva-Fortuny R, Martin-Belloso O. Color and viscosity of watermelon juice treated by high-intensity Pulsed electric field or heat. *Innov Food Sci Emerg Technol.* 2010;11(2):299-305. doi: 10.1016/j.ifset.2009.12.004
74. Zhong K, Wu J, Whang Z, et al. Inactivation kinetics and secondary structural change of PEF-treated POD and PPO. *Food Chem.* 2007;100(1):115-123. doi: 10.1016/j.foodchem.2005.09.035
75. Giner J, Ortega M, Mesegue M, Martin-Belloso O. Inactivation of peach polyphenoloxidase by exposure to Pulsed electric fields. *Journal of Food Science.* 2002;67(4):1467-1472. doi: 10.1111/j.1365-2621.2002.tb10307.x
76. Netsanet ST, Roman B, Cornelis V. Quality-related enzymes in plant-based products: effects of novel food processing technologies part 2: Pulsed electric field processing. *Crit Rev Food Sci Nutr.* 2015;55(1):1-15. doi: 10.1080/10408398.2012.701253
77. Ertugay MF, Mehmet Baslar M, Ortakci F. Effect of Pulsed electric field treatment on polyphenol oxidase, total phenolic compounds, and microbial growth of apple juice. *Turkish Journal of Agriculture and Forestry.* 2013;37(6):772-780. doi: 10.3906/tar-1211-17
78. Giner J, Gimeno V, Martin O, Barbosa-Canovas GV, Martin O. Effects of Pulsed electric field processing on apple and pear polyphenoloxidases. *Food Science Technology International.* 2001;7(4):339-345. doi: 10.1106/MJ46-8J9U-1H11-T0ML
79. Riener J, Noci F, Cronin DA, Morgan DJ, Lyng JG. Combined effect of temperature and Pulsed electric fields on apple juice peroxidase and polyphenoloxidase inactivation. *Food Chem.* 2008;109(2):402-407. doi: 10.1016/j.foodchem.2007.12.059
80. Sanchez-Vega R, Mujica-Paz H, Marquez-Melendez R, Ngadi MO, Ortega-Rivas E. Enzyme inactivation on apple juice treated by ultrapasteurization and Pulsed electric field technology. *Journal of Food Processing and Preservation.* 2009;33(4):486-499. doi: 10.1111/j.1745-4549.2008.00270.x
81. Schilling S, Schmid S, Jager H, et al. Comparative study of Pulsed electric field and thermal processing of apple juice with particular consideration of juice quality and enzyme deactivation. *J Agric Food Chem.* 2008;56(12):4545-4554. doi: 10.1021/jf0732713

82. Cinzia M, Kamon R, Thomas F, et al. Influence of Pulsed Electric Field and Ohmic Heating Pretreatments on Enzyme and Antioxidant Activity of Fruit and Vegetable Juices. *Foods.* 2019;8(7):247; doi: 10.3390/foods8070247
83. Evrendilek GA, Jin ZT, Ruhlman KT, Qiu X, Zhang QH, Richter ER. Microbial safety and shelf-life of apple juice and cider processed by bench and pilot scale Pulsed electric field systems. *Innov Food Sci Emerg Technol.* 2000;1(1):77-86. doi: 10.1016/S1466-8564(99)00004-1
84. Charles-Rodriguez AV, Nevarez-Moorillon GV, Zhang QH, Ortega-Rivas E. Comparison of thermal processing and Pulsed electric field treatment in pasteurization of apple juice. *Food Bioproducts Processing.* 2007;85(2):93-97. doi: 10.1205/fbp06045
85. Torkamani AE. Impact of Pulsed electric field and thermal processing on apple juice shelf life. *Iran J Microbiol.* 2011;3(3):152-155.
86. Xiaoyun T, Jian C, Luning L, Liyi Z, Meng Z, Aidong S. Influence of Pulsed electric field on *Escherichia coli* and *Saccharomyces cerevisiae*. *International Journal of Food Properties*. 2015;18(7):1416-1427. doi: 10.1080/10942912.2014.917098
87. Katsuki S, Majima T, Nagata K, et al. Inactivation of Bacillus strearothermophilus by Pulsed electric field. *IEEE Transactions on Plasma Science.* 2000;28(1):155-160. doi: 10.1109/27.842890
88. Efrat E, Irina D, Ester H, Gad AP, Roman P, Rivka C. Eradication of *Saccharomyces cerevisiae* by Pulsed electric field treatments. *Microorganisms.* 2020;8(11):1684. doi: 10.3390/microorganisms8111684
89. Lewicki PP. Effect of pre-dehydration treatment, dehydration and rehydration on plant tissue properties: A review. *International Journal of Food Properties.* 1998;1(1):1-22. doi: 10.1080/10942919809524561
90. Jayaraman KS, Das Gupta DK, Rao NB. Effect of ahead-treatment with salt and sucrose on the quality and stability of dehydrated cauliflower. *International Journal of Food Science and Technology.* 1990;25(1):47-60. doi: 10.1111/j.1365-2621.1990.tb01058.x
91. Mudahar GS, Buhr JR, Jen JJ. Infiltrated biopolymers effect on quality of dehydrated carrot. *Journal of Food Science.* 1991;57(2):526-529. doi: 10.1111/j.1365-2621.1992.tb05533.x
92. Picchioni GA, Watada AE, Roy S, Whitaker BD, Wergin WP. Membrane lipid metabolism, cell permeability and ultrastructural changes in lightly processed carrot. *Journal of Food Science.*1994;59(3):597-601. doi: 10.1111/j.1365-2621.1994.tb05571.x
93. Kostaropoulos AE, Saravacos GD. Microwave pretreatment for sundried raisins. *Journal of Food Science.* 1995;60(2):344-347. doi: 10.1111/j.1365-2621.1995.tb05669.x
94. Sitkiewicz I, Lenart A, Lewicki PP. Mechanical properties of osmoconvection dried apples. *Polish Journal of Food and Nutrition Sciences.* 1996;5(4):105-112.
95. Andrade M, Ribeiro-Santos R, Bonito MCC, Saraiva M, Sanchez-Silva A. Characterization of rosemary and thyme extracts for incorporation into a whey protein based film. *LWT Food Science Technology.* 2018b;92(2):497-508. doi: 10.1016/j.lwt.2018.02.041
96. Papageorgiou G, Botsoglou N, Govaris A, Giannenas I, Iliadis S, Botsoglou E. Effect of dietary oregano oil and alpha-tocopheryl acetate supplementation on iron-induced lipid oxidation of turkey breast, thigh, liver and heart tissues. *Journal of Animal Physiology and Animal Nutrition.* 2003;87(9):324-335. doi: 10.1046/j.1439-0396.2003.00441.x
97. Velluti A, Sanchis V, Ramos A, Marin S. Inhibitory effect of cinnamon, clove, lemongrass, oregano and palmarose essential oils on growth and fumonisin B1 production by *Fusarium proliferatum* in maize grain. *Int J Food Microbiol.* 2004;89(2):145-154. doi: 10.1016/S0168-1605(03)00116-8
98. Mehmet MO, Derya A. Antioxidant effect of essential oils of rosemary, clove and cinnamon on hazelnut and poppy oils. *Food Chem.* 2011;129(1):171-174. doi: 10.1016/j.foodchem.2011.01.055
99. El-baky HHA, Farag RS, Saleh M. A Characterization of antioxidant and antimicrobial compounds of cinnamon and ginger essential oils. *African Journal of Biochemical Research.* 2010;4(6):167-174.
100. Pandey AK, Kumar P, Singh P, Tripathi NN, Bajpai V. Essential oils: sources of antimicrobials and food preservatives. *Front Microbiol.* 2017;7(1):2161. doi: 10.3389/fmicb.2016.02161
101. Antora RA, Salleh RM. Antihyperglycemic effect of Ocimum plants: A short review. *Asian Pacific Journal of Tropical Biomedicine.* 2017;7(8):755-759. doi: 10.1016/j.apjtb.2017.07.010
102. Ahmed AF, Attia FAK, Liu Z, Li C, Wei J, Kang W. Antioxidant activity and total phenolic content of essential oils and extracts of sweet basil (*Ocimum basilicum* L.) plants. *Food Science and Human Wellness.* 2019;8(3):299-305. doi: 10.1016/j.fshw.2019.07.004
103. McSweeney M, Seetharaman K. State of polyphenols in the dehydration process of fruits and vegetables. *Crit Rev Food Sci Nutr.* 2015;55(5):660-669. doi: 10.1080/10408398.2012.670673
104. Degirmencioglu N, Gurbuz O, Herken EN, Yildiz AY. The impact of dehydration techniques on phenolic compound, total phenolic content and antioxidant capacity of oat flour tarhana. *Food Chem.* 2016;194(1):587-594. doi: 10.1016/j.foodchem.2015.08.065
105. Wang R, Ding S, Zhao D, Wang Z, Wu J, Hu X. Effect of dehydration methods on antioxidant activities, phenolic contents, cyclic nucleotides, and volatiles of jujube fruits. *Food Sci Biotechnol.* 2016;25(1):137-143. doi: 10.1007/s10068-016-0021-y
106. Horuz E, Bozkurt H, Karatas H, Maskan M. Effects of hybrid (microwave-convectional) and convectional dehydration on dehydration kinetics, total phenolics, antioxidant capacity, vitamin C, color and rehydration capacity of sour cherries. *Food Chem.* 2017;230(3):295-305. doi: 10.1016/j.foodchem.2017.03.046
107. Gulcin Y. The effect of novel Microwave-air dehydration on the functional properties of dried-pears (Pyrus communis). *Current Microwave Chemistry.* 2021;8(1):22-26. doi: 10.2174/22133356079992012

31212208
108. Sledz M, Witrowa-Rajchert D. Influence of Microwave-air dehydration of chlorophyll content and colour of herbs. *Acta Agrophysica.* 2012;19(4):865-887.
109. Ahrne LM, Pereira NR, Staack N, Floberg P. Microwave air dehydration of plant foods at constant and variable microwave power. *Dehydration Technology.* 2007;25(7):1149-1153. doi: 10.1080/07373930701438436
110. Nghia DP, Martens W, Karim A, Joardder M. Nutritional quality of heat-sensitive food materials in intermittent microwave convective drying. *Food Nutr Res*. 2018;62(1):1292. doi: 10.29219/fnr.v62.1292