DEVELOPMENT OF SEMI-CONTINUOUS ULTRASOUND ASSISTED INFRARED DRYER FOR FOOD PRODUCTS

By

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SUMMARY AND CONCLUSION

CHAPTER V
SUMMARY AND CONCLUSION

This chapter discusses about the major findings of research work entitled "Development of a semi-continuous ultrasound assisted infrared dryer for food products" such as optimization of process variables for ultrasonic pretreatment of moringa leaves and beetroot slices, development of a semi-continuous treatment chamber for infrared drying, optimization of process parameter for the infrared drying of moringa leaves and beetroot, performance evaluation of the developed dryer, quality evaluation of the dried products, comparison of the developed dryer with the conventional dryers such as heat pump and cabinet dryers and economic analysis of the developed dryer for dried moringa leaves and beetroot.

- **Physico-chemical characteristics of moringa leaves and beetroot.**

The various engineering properties of moringa and beetroot viz. size, shape, bulk density, true density, porosity etc, were computed using standard AOAC procedures. The size of the raw moringa leaves and beetroot was measured using vernier caliper. The mean length, width and height of moringa leaves and beetroot were 25.52$\pm$2.74, 14.95$\pm$2.17 and 0.26$\pm$0.03 and 59.26$\pm$3.25, 57.20$\pm$2.92 and 60$\pm$ 3.88, respectively. The various properties such as roundness, roundness ratio, sphericity and surface area of moringa leaves and beetroot were 0.5, 0.13, 0.51 and 68.44 mm^2 and 0.79, 0.21, 0.84, and 1.10 cm^2, respectively. The loose bulk density of moringa leaves was found to be 0.051 g/cm^3 and tapped density was 0.083 g/cm^3 , respectively. The carr's index was determined as 0.386%. The bulk density of the beetroot was determined as 1.015 $g/cm^3$and true density as 1.132 g/cm^3 with a porosity of 0.103. The moisture content of moringa leaves and beetroot was 79.94% wb and 88.92 % wb, respectively. The colour of the moringa leaves and beetroot were recorded in terms of L*, a*, b*, c* and h° as 35.53, -12.28, 22.63, 25.78 and 118.45 and 24.03, 32.9, 9.13, 34.13 and 15.73, respectively.

Proximate analysis of the moringa leaves and beetroot viz, carbohydrate, protein, fat, ash and fibre were carried out using standard AOAC methods. The result showed that the carbohydrate, protein, fat, ash and energy were 54g/100g, 10.3g/100g, 7.3g/100g, 4.3g/100g and 336g/100g, respectively for moringa leaves. Similarly the proximate analysis values for the beetroot were 7.9 g/100 g, 1.4 g/100 g, 0.35 g/100 g, 1.4 g/100 g and 2.1 g/100 g, respectively.

- **Optimization of ultrasound pretreatment of moringa leaves and beetroot.**

The fresh samples of moringa leaves and beetroot slices having 3 mm thickness were subjected to ultrasound pretreatment using ultrasound bath in a 44 gauge polypropylene bag. The raw material was kept in polypropylene to avoid the leaching out of betalain, which is highly water sensitive. The samples were fed in ultrasound bath for a duration of 5-25 min and 10-30℃ at 3 different levels of temperature and 5 levels of treatment time. The process parameters were optimized based on response surface methodology using central composite design. The different parameters chosen for the optimization of process were moisture content, water activity, % inhibition of antioxidant activity, vitamin C, L*, a* and b* values.

The optimization of process parameters of moringa leaves resulted in a sonication temperature of 22℃ for a duration of 25 min. The quality parameters of optimized sample were observed as moisture content (84.2% wb), water activity (0.981), percentage inhibition in antioxidant activity (74.2%), vitamin C content (287.35 mg/100ml), L* value (36.42), a* value (-11.07) and b* value (22.62), respectively. The derringer's desirability function was 0.893, which is close to 1, which indicated that the model was best fit.

The optimization of process parameters of beetroot resulted in a desirability of 0.880, with a sonication temperature of 27.128℃ for a duration of 25 min. The various parameters during the optimized treatment condition resulted in a moisture content of 91.92% wb, water activity value of 0.991, percentage inhibition in antioxidant activity as 84.737%, betalain content as 37.836 mg/100 mg, L* value a* value and b* value as 26.293, 31.286 and 9.26, respectively.

- **Development of a semi-continuous infrared dryer**

An infrared dryer was fabricated in the workshop of Kelappaji College of Agricultural Engineering and Food Technology, Tavanur. It consists of a drying chamber having the dimension of 2720 mm length, 765 mm width, 485 mm height and 25 mm thickness. The samples being fed manually, were conveyed inside the chamber using a conveyor belt (PTFE 496 cm × 60 cm) over SS rollers. A blower was employed to provide uniform air circulation inside the drying chamber. A three phase 0.5 hp centrifugal blower having a velocity 1.5 m/s was attached to the drying chamber. Six ceramic infrared heaters of 650 W and 240 V each were installed to produce the far infrared radiations (FIR) throughout the chamber. Control panel consists of a power key, indicators, volt meter, ammeter, switches, variable frequency drive, regulator, temperature controller and a rpm controller.

- **Optimization of process parameters for infrared drying of ultrasound pretreated moringa leaves and beetroot**

Ultrasound pretreated moringa leaves and sliced beetroot thickness were fed into the infrared dryer at three different temperatures *viz.,* 50℃, 60℃ and 70℃ and three levels of air velocity of 0.5, 1, 1.5 m/s with three levels of heater speed 20, 30, 40 rpm. The process parameters were optimized based on the physico-chemical quality of dried beetroot such as drying time, water activity, rehydration ratio, shrinkage, energy consumption, L*, a* and b* values.

The optimization of drying process parameters was done based on Derringer's desirability function. The air temperature (40-60°C), air flow rate (0.5-1.5 m/s) and heater speed (20-40 rpm) was set in range. The values of rehydration ratio and b* value was set at a maximum and the value of drying time, water activity, shrinkage, L* valu, a* value and energy consumption were set to minimize. Based on the maximum desirability (0-1), the optimum condition was chosen.

The methodology of desired function was applied to indicate 60℃ temperature with 0.9 m/s airflow rate at 39 rpm heater speed as the optimum condition for the drying of ultrasound assisted moringa leaves with a derringer's desirability as 0.91. The optimum condition indicated the values of drying time, water activity, rehydration ratio, shrinkage, L*, a*, b* and energy consumption were 13.83 min, 0.381, 5.68, 9.44, 31.66, -6.4, 15.27 and 0.75 kWh, respectively. The error percentage was calculated for confirmation of the result obtained.

Similarly, the methodology of desired function was applied to indicate 69℃ temperature with 1.5 m/s airflow rate at 20 rpm heater speed as the optimum condition for the drying of ultrasound assisted beetroot. The optimum condition indicated the values of drying time, water activity, rehydration ratio, shrinkage, L*, a*, b* and energy consumption were 0.87 h , 0.313, 8.37, 42.69, 30.62, 16.34, 6.79 and 3.52 kWh, respectively. The desirability of the process was 0.821.

- **Quality parameters of dried moringa leaves and beetroot at optimized condition**

Various parameters such as moisture content, effective moisture diffusivity, color, shrinkage, total plate count, biochemical, proximate, and scanning electron microscopy examination were assessed for the dried moringa leaves and beetroot samples under optimized condition. Thin layer model fitting was done to find out the best fit drying model to predict the drying times.

The moisture content of moringa leaves decreased from an initial moisture content of 79.94% wb to 3.8% wb within 13 min, and for beetroot the value decreased from 88.92% to 8.3% wb within 1 h. The value of effective moisture diffusivity of moringa leaves under infrared drying and ultrasound assisted infrared drying were found to be 1.7015×10^{-6} and 2.51602×10^{-6} m^2/s, respectively, where as the effective moisture diffusivity of ultrasound assisted heat pump drying and cabinet drying were 9.10831×10^{-7} and 9.06958×10^{-7} m^2/s, respectively.

Similarly, the value of effective moisture diffusivity of beetroot under infrared drying and ultrasound assisted infrared drying were found to be 1.2071×10^{-6} and 1.4845×10^{-6} m^2/s, respectively, where as the effective moisture diffusivity of ultrasound assisted heat pump drying and cabinet drying were 4.9787×10^{-7} and 5.7427×10^{-7} m^2/s, respectively. It indicated that the highest moisture diffusivity was observed for ultrasound assisted infrared dried samples.

The value of activation energy and diffusion constant for moringa leaves and beetroot were found to be 0.615 and 18.61 kJ/kg and 2.69×10^{-5} and 1.03×10^{-3} m^2/s, respectively. It was similar to that of the previous researchers findings. Drying efficiency of the developed infrared dryer for ultrasound assisted moringa leaves and beetroot slices were observed to be 56.74% and 30.38%, respectively. Infrared radiation penetrates into the product and the moisture from inside moves towards the surface and from the surface it easily evaporates. The cavitation effect produced during ultrasound helps in creating more porous structure and easier removal of water from the surface.

The moisture ratio versus time plot for US-IR moringa leaves and beetroot from MATLAB 2021a indicated the best fit model for US-IR moringa leaves was Page model, with R^2 value of 1 and for US-IR beetroot, logarithmic model was selected as the best fit model with R^2 value of 0.9951. The equations for the models are given below.

Page model : MR = exp (-0.2356 $t^{-0.8777}$)

The page model exhibit higher R^2 value (1), reduced RMSE (0.001232) and reduced χ^2 value (0.00000126476) for ultrasound assisted infrared drying of moringa leaves.

Logarithmic model : MR = 0.9863 exp (-2.032 t)+0.01794

The logarithmic model exhibit higher R^2 value (0.9952), reduced RMSE (0.02033) and reduced χ^2 value (0.000991) for ultrasound assisted infrared drying of moringa leaves.

To confirm the suitability of the selected model, obtained moisture ratio values were plotted against predicted values. It was observed that the actual values were close to the predicted value with R^2 values of 1 and 0.9951, respectively for the Page and Logarithmic model.

- **Performance evaluation of the developed infrared dryer**

The performance evaluation of the developed dryer was done based on the capacity, thermal efficiency, specific energy consumption. The capacity of the developed dryer was 6 kg per batch with a thermal efficiency of 30.38% for beetroot and 56.74% for moringa leaves. Specific energy consumption of ultrasound assisted infrared dried moringa leaves and beetroot slices were observed to be 0.79 and 3.51 kWh/kg, respectively.

- **Comparative evaluation of the developed dryer with conventional dryers such as heat pump and cabinet dryers**

The quality parameters viz. moisture content, water activity, rehydration ratio, colour, shrinkage, proximate analysis, microstructural analysis and microbial load of the dried samples under different drying conditions were compared at the optimized drying conditions.

The moisture content of dried moringa leaves under IR, US-IR, US-HP and US-C were 4.5%, 3.8%, 6.07% and 6.49% (%wb), respectively. The water activity of the dried moringa leaves under IR, US-IR, US-HP and US-C were 0.392, 0.381, 0.421 and 0.375, respectively. The percentage inhibition of antioxidant activity of dried moringa leaves under IR, US-IR, US-HP and US-C were 51.8, 52.3, 47.95 and 25.24, respectively. The shrinkage percentage of IR, US-IR, US-HP and US-C dried moringa leaves were 10.3, 9.94, 18.76 and 28.3, respectively.

The rehydration ratio of dried moringa leaves under different conditions such as IR, US-IR, US-HP and US-C were calculated as 5.2, 5.68, 4.32 and 4.28, respectively. The vitamin C content for moringa leaves under various drying operations were 251.8, 253.71, 231.32 and 193.87 mg/100 ml, respectively for IR, US-IR, US-HP and US-C drying. L* value of US-IR as 31.64, US-HP as 36.48 and US-C as 34.5.The a* value of US-IR, US-HP and US-C were observed as -6.4, -5.8 and -5.2 respectively. The b* indicated a value of 15.2, 13.2 and 14.18 respectively for US-IR, US-HP and US-C samples.

The carbohydrate content of IR, US-IR, US-HP and US-C were calculated as 34.9, 35.7, 33.6 and 31.7 g/100g, respectively. The protein content of dried moringa leaves under infrared drying was calculated as 2.96 g/100g and for ultrasound assisted infrared drying was 3.93 g/100g. The higher value of fat content was for the US-C sample (1.8 g/100g) followed by the US-IR sample (1.7 g/100g). The values of fat content for US-HP and IR were 1.6 g/100g. The percentage of crude fat content was higher in dried leaves (about 5%) than its fresh leaves.

Fibre content enhances bowel movement and promotes digestion. The enhanced fibre content was indicated in US-IR dried moringa leaves as 5.6 g/100g and followed by 5.2 g/100g for IR dried moringa leaves. The fibre content of US-HP and US-C dried moringa leaves were found to be 4.6 and 4.2 g/100g, respectively. The elevated ash content was observed for the IR dried sample as 0.18 g/100g. The ash content of ultrasound pretreated infrared dried, heat pump and cabinet dried samples were not significantly varying and were 0.16, 0.14 and 0.15 g/100g, respectively. The total energy obtained during the consumption of dried moringa leaves were 692.582, 725.911, 668.701 and 632.867 kJ/kg, respectively for IR, US-IR, US-HP and US-C drying conditions.

The total plate count was evaluated for dried moringa leaves under different drying conditions such as IR, US-IR, US-HP and US-C as 13.9×10^3, 12.6×10^3, 24.6×10^3 and 27.9×10^3 CFU/g, respectively. SEM image of ultrasound assisted heat pump dried sample under 5 µm and 3000 X resolution indicated a needle like structure, the long duration drying resulted in more diffusion of moisture across the interior and exterior surface of the sample. It resulted in more shrinkage of the sample. The SEM image of ultrasound assisted infrared dried samples and infrared dried samples under 5 µm and 3000 X resolution depicts that the surface was smooth, indicating rapid removal of moisture from the surface. It resulted in less shrinkage and more rehydration ratio.

The moisture content of dried beetroot under IR, US-IR, US-HP and US-C were 8.5%, 8.3%, 8.01% and 9.86% (%wb), respectively.The water activity of the dried beetroot under IR, US-IR, US-HP and US-C were 0.385, 0.321, 0.496 and 0.547, respectively. The percentage inhibition of antioxidant activity of dried beetroot under IR, US-IR, US-HP and US-C were 93.8, 96.8, 90.88 and 89.73, respectively. The shrinkage percentage of IR, US-IR, US-HP and US-C dried beetroot were 48.9, 43.2, 53.8 and 58.6, respectively. The rehydration ratio of dried beetroot slices under different conditions such as IR, US-IR, US-HP and US-C were calculated as 7.92, 8.37, 7.53 and 7.2, respectively.

Betalain content of IR dried sample was found to be 29.3 mg/100g and that of US-IR was 31.2 mg/100g. US-HP and US-C samples of beetroot exhibit a betalain content of 23.6 and 13.18 g/100g respectively. The colour value, L* value of US-IR as 29.6, US-HP as 22.4 and US-C as 16. The a* value of US-IR, US-HP and US-C were found to be 16.32, 7.93 and 5.85, respectively. The b* value of US-IR, US-HP and US-C were found to be 6.7, 3.25, 1.825, respectively.The change in b* value was associated with change of red pigment of betalains converted into yellow betaxanthin due to thermal treatment and thermochemical reaction

The carbohydrate content of IR, US-IR, US-HP and US-C beetroot samples are calculated as 25.5, 36.1, 35.5 and 32.5 g/100g, respectively. The protein content of dried beetroot under infrared drying was calculated as 1.74 g/100g and for ultrasound assisted infrared drying was 1.95 g/100g. The elevation in the protein content is due to the release of intracellular protein by cavitation reaction. The ultrasound assisted heat pump and cabinet drying indicated 1.91 and 1.8 g/100g, respectively. The reduction in protein content is due to the denaturation of protein under elevated temperature for a long duration of time.

The higher value of fat content was for the US-IR sample (1.92 g/100g) followed by the US-HP sample (1.9 g/100g). The values of fat content for US-C and IR are 1.8 and 1.02 g/100g, respectively. The enhanced fibre content was indicated in US-IR dried beetroot as 6.8 g/100g and followed by 6.2 g/100g for IR dried beetroot slices. The fibre content of US-HP and US-C dried moringa leaves were found to be 3.8 and 4.2 g/100g, respectively. The elevated ash content was observed for the US-IR dried sample as 0.14 g/100g. The ash content of ultrasound pretreated heat pump and cabinet dried samples were not significantly varying and were 0.11 and 0.1 g/100g, respectively, whereas the sample dried without pretreatment resulted in 0.1 g/100 g ash content.The total energy obtained during the consumption of dried beetroot samples were 493.362, 707.819, 693.377 and 640.67 kJ/kg, respectively for IR, US-IR, US-HP and US-C drying conditions.

The drying removes moisture content to a level at which microbial spoilage and deterioration reactions are minimized. The higher moisture retention in cabinet dried samples resulted in higher TPC. The total plate count was counted for dried beetroot slices under different conditions such as IR, US-IR, US-HP and US-C as

8×10^3, 8×10^3, 18×10^3 and 22×10^3 CFU/g, respectively. SEM image of ultrasound assisted heat pump dried sample under 100 µm and 250 X resolution, inferred that the pore size of the infrared dried sample varied between 12.82 - 67.54 µm. The ultrasound pretreatment enhanced the pore size to 29.12 - 79.2 µm. The pore size of the ultrasound assisted heat pump was 14.42 - 38.64 µm. From the above observation it was clear that more pore space was associated with ultrasound assisted infrared samples, which was the main reason for more rehydration ratio of the sample.

- **Economic analysis of infrared dried moringa leaves and beetroot**

The cost of the developed dryer is 20,00,000/-. The economic analysis indicated a benefit cost ratio 1.03:1 with a payback period of 1.38 years for moringa leaves, and a benefit cost ratio of 1.53:1 with a payback period of 1.28 years for beetroot samples.

CONCLUSIONS

- Ultrasound pretreatment resulted in a cavitation reaction, which helps in extraction of bound moisture and intracellular nutrients.
- Ultrasound pretreatment helps in enhanced moisture diffusion and reduction in process time during drying.
- Infrared drying resulted in reduced drying time, shrinkage, energy consumption and enhanced rehydration ratio and colour of the dried sample.
- Infrared drying resulted in high heat transfer rate, less energy consumption, rapid heating, and improved quality of the dried produce.
- Infrared drying resulted in an economically feasible method of drying compared to other conventional drying technologies.
- Biochemical, microbiological and microstructure analysis results showed that the dried product was a stable one with high shelf life.
- Infrared dryer resulted in reduced energy consumption compared to heat pump and cabinet dryer with a reduced drying time.

- Infrared drying is a green technology.

SCOPE OF FUTURE WORK

- Continuous ultrasound treatment chamber can be designed and developed.
- Continuous infrared dryer can be designed and developed.
- Explore the possibility of ultrasound frequency and power in the optimization of process parameters for pretreatment.
- In addition to ultrasound baths, ultrasound probes can also be used and its results can be compared.
- Shelf-life studies of the dried produce can be conducted with different packaging materials and packaging technologies.
- Further pretreatment can be employed to reduce bleaching of the sample after drying.