CONCLUSION AND FUTURE SCOPE OF WORK

CHAPTER 7

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7.1. Conclusion

Passion fruits are rich in several bioactive compounds but due to lack of awareness and proper knowledge, these fruits have not been fully exploited to maximise the benefits of the bioactive compounds present and are therefore, categorized as underutilized fruits. The present work studied the novel technologies and approaches which can be utilized for value-addition of passion fruit and improve the quality of final products. In India, currently, the end use of passion fruit cultivation is juice processing only and passion fruit juice processing industries create a large amount of waste (approximately 60%) comprising of peels and seeds. Further, raw passion fruit juice is less accepted by customers due to rapid microbial growth (perishable in nature), astringency and sour taste. Most of the work in the current study was based upon emerging technological interventions and strategic planning to develop shelf-stable ready-to-serve sensory optimized Pickering emulsion-based healthier passion fruit beverage. The work included the use of ultrasonication, high-pressure homogenization technologies as well an emulsion-based approach to achieve the goals. The research work has successfully demonstrated the use of ultrasonication and microwave-assisted extraction to extract the carotenoids from the passion fruit peel along with appropriate oil as solvent, which was later used as a dispersed phase in the emulsion. The study also emphasized the development of passion fruit peel-derived carotenoids enriched starch-based emulsion and thermally stable starch nanoparticles. The present study also utilized novel technologies/ approaches for the optimized extraction of oils and dietary fibre from passion fruit seeds. A comparative study between thermal and high-pressure homogenization and the effect of passion fruit peel fibre and passion fruit peel oil-based emulsion on quality characteristics of sensory-optimized blended beverage was also carried out. The effect of high-pressure homogenization and emulsion addition on microbial inactivation, quality, and shelf life was also investigated.

The experimental works have been detailed in Chapters 3-6. The major conclusions drawn from the current thesis work are stated chapter-wise here.

7.2. Chapter 3

This chapter first dealt with the selection of appropriate solvents and novel technologies for the optimized extraction of carotenoids from passion fruit peel (PFP). The work presents the strategy to extract more than 90% of the carotenoids present in PFP.The quality evaluation and kinetics study revealed the industrial feasibility of the technological approaches applied. The major conclusions of this chapter are mentioned below:

1. Results implied that oil can be used for the green extraction of carotenoids from PFP and in this study olive oil (OO) was observed to be a better solvent than sunflower oil.
2. At optimized conditions with OO as a solvent, the carotenoids yield on ultrasonic-assisted extraction (UAE) (91.4 %) was higher than microwave-assisted extraction (MAE) (86.9 %) and conventional extraction (CE) (85.5 %). Also, in terms of energy density, UAE was more efficient than MAE.
3. UAE-treated passion fruit peel-derived carotenoids enriched olive oil (CEOO) was acceptable for different quality parameters. Ultrasonication resulted in a good extraction of bioactive compounds and there was quality improvement of treated oil as the oil was enriched with carotenoids by more than three times and phenolic content by fifteen times.
4. Pseudo second order kinetics and phenomenological kinetic modelling can be used for the mathematical understanding of the process and efficient prediction of the extraction process.
5. The effective diffusion coefficient and mass transfer coefficient for UAE extraction were much higher than CE but the reverse was for Biot number. For the same parameter conditions, the mass transfer coefficient was much higher than effective diffusion for both UAE and CE
6. The thermodynamics results showed that CE and UAE processes for recovery of carotenoids from passion fruit peel using oil as solvent were endothermic, irreversible, and spontaneous but UAE was more feasible as compared to CE at the same temperature.
7. The kinetics information, mainly rate constant, effective diffusivity, and mass transfer coefficient obtained from the green extraction process of ultrasonication allowed the prediction of operation conditions for industrial implementation.

7.3. Chapter 4

This chapter includes the development of thermally stable starch nanoparticles and CEOO-based emulsion. Results confirmed that ultrasonication and high-pressure homogenization (HPH) have the potential to fabricate starch nanoparticles and starch-based emulsion. The following conclusions from the results were made.

1. Ultrasound (US) treatment for 90 min (optimized time) significantly reduced particle size of native starch granules exhibiting bi-modal distribution (1.2-1.5 µm and 5-7 µm and 230-510 nm range). HPH treatment of US treated starch, further decreased the size to 38-96 nm with uni-modal distribution. Both treatments have the potential to be used for the development of starch nanoparticles.
2. Using the treatments, carotenoids-enriched starch nanoparticles with better physicochemical and functional properties can be developed.
3. Among the used models, First order reaction model based on random nucleation with one nucleus on the individual particle was best suited to explain the thermal degradation of starch nanoparticles; and starch nanoparticles after treatments became more thermally stable.
4. Reactive -OH groups on the surface of the starch nanoparticles increased after the treatments.
5. The optimized conditions of the developed nanoemulsion indicated that starch nanoparticles could be used for the development of Pickering nanoemulsion. CEOO based Pickering nanoemulsion was rich in carotenoids and total phenolic content and exhibited high antioxidant activity, which had a protective effect on its stability. The developed nanoemulsion was found to be stable to heat and freeze-thaw treatments. The nanoemulsion showed better oxidative stability as well as physical stability during storage at 6 ℃ and 25 ℃.
6. The developed carotenoids enriched starch nanoparticles can be used as thermostable and biologically active functional molecules. Further, the combination of physical treatments of starch particles could be applied in the food processing industries as effective natural chemical-free emulsifying agents.

7.4. Chapter 5

This chapter was divided into two sections. The first section dealt with the optimized extraction of oil from the passion fruit seeds using different techniques and the second section emphasized on the extraction of dietary fire (DF) from defatted passion fruit seed cake using different approaches. The key conclusions are as follows:

1. Results indicated that combined ultrasound and Soxhlet extraction (UAES) were more effective in extracting passion fruit seed oil (PFSO) than Soxhlet (in terms of time consumption) and UAE (in terms of extraction yield).
2. Model parameters reflected that the washing step was faster than the diffusion step for all extraction processes, which also implied that UAES had higher extraction efficiency capacity than individual method and was able to enhance the washing process greatly.
3. The pseudo-first-order model and instantaneous washing followed by diffusion model had small R^2 value, relatively high MRPD (%) and MSE values as compared to phenomenological model for the adopted extraction technique.
4. Comparison of the quality parameters of oil extracted by UAES and Soxhlet revealed that UAES is a viable alternative to only Soxhlet extraction with better quality, and phenomenological model with UAES could be recommended for modelling the extraction kinetics for a better-quality extracted product.
5. Using the optimized conditions, the extraction yield of DF by ultrasonic-alkaline method (61.35 %) was higher than only alkaline extraction (52.8 %) and ultrasound extraction (50.4 %).
6. Ultrasonication treatment enhanced the functional quality of DF by increasing the water-holding, oil-holding, and swelling capacities while decreasing the cation exchange capacity. Ultrasonication also improved considerably the glucose adsorption capacity, α-amylase activity, emulsion capacity, and cytotoxicity. The observed increase in toxicity value was within the acceptable limit.
7. Results indicated that DFs from defatted passion fruit seeds could be used as a functional food ingredient. Moreover, because of the right protein-to-pectin ratio, alkali-free ultrasound extracted DF could be utilized as a natural emulsifier, hypoglycaemic agent, and food ingredient.

7.5. Chapter 6

This chapter was divided into three sections. The first section described the effect of thermosonication treatment on passion fruit juice and its predictive modelling for shelf life and quality changes during storage. The second and third sections dealt with the use of extracted fibre and oil in the development of emulsion for incorporation in the sensory-optimized blended beverages for the improvement of quality. The following points can be concluded from the study:

1. Themosonication treatment can be efficiently predicted and optimized by ANN/GA.
2. Thermosonication increased the phenolic and β-carotene content, and maintained the TSS, pH, TTA, ascorbic acid content, and DPPH scavenging activity after treatment as well as during storage.
3. Thermosonication of passion fruit juice can be a way forward to enhance the overall quality of the juice and leverage its economic worth over traditional processing techniques. However, thermosonication alone was not sufficient for prolonging shelf life.
4. Fuzzy logic sensory optimization technique graded the order of the quality attributes of blended beverage as judged by the sensory panellists: Taste > Overall acceptability = Color > Consistency = Flavour > Mouthfeel. The blended beverage combination of sugar-added passion fruit juice and guava juice in the ratio of 60:40 showed the best sensory result.
5. Nanoemulsion developed using optimized conditions indicated that the dietary fibre extracted from passion fruit seed had good emulsification properties and can be suggested for use as a novel green emulsifier.
6. Blended beverages showed higher TSS, total sugar, and ascorbic acid content than passion fruit juice but lower total phenolics and carotenoids content. The improvement of the ratio of sugar to acid ratio enhanced the overall sensory quality.
7. Heat treatment, HPH treatment, and addition of emulsion enhanced the shelf life of blended beverages. Heat treatment, on the other hand, caused significant degradation of bioactive compounds.
8. Optimized blended beverage added with seed fibre and seed oil-based emulsion (BNESPFJT) showed better quality soon after treatment and during the storage period with higher bio-accessibility of carotenoids, longer shelf life, and improved functional properties.

9. Addition of Pickering nanoemulsion incorporated with materials having natural antimicrobial properties and use of high-pressure homogenization therefore, can be useful as a novel preservation technique.

7.6. Future scope of work

The findings of the research work and insights gained from the study provided with the following areas of research for further consideration**.**

1. More strategies with other novel techniques and approaches can be worked out to have a product that further enhances shelf life while retaining organoleptic properties.
2. More in-depth studies regarding the use of natural antimicrobial materials, and different stabilizers in emulsion for the shelf-life enhancement of food products are required.
3. *In-vivo* study of passion fruit juice is suggested.
4. Development of passion fruit by-products and dietary fibre-based functional products such as bakery products, meat, dairy, and other food products.
5. Pilot plant studies are to be conducted and consumer analysis needs to be carried out that will help in the industrial scaling up of the process as discussed in this thesis.
6. In depth studies are necessary for commercial utilization of passion fruit seeds for the production of dietary fibre and oil.
7. Studies related to the valorisation of passion fruit peel can be carried out.