THERMAL AND NON-THERMAL EXTRACTION AND PASTEURIZATION OF RED DRAGON FRUIT JUICE

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CHAPTER V

SUMMARY & CONCLUSION

The first objective examined the impact of Pulsed electric field (PEF) and Ultrasound (US) pretreatments on the process of extracting juice from red dragon fruit. The PEF pretreatment led to a 51.1% increase in juice yield, a 3.41% rise in betacyanin content, a 6.78% enhancement in total phenolic content (TPC), and a 9.25% boost in antioxidant activity. The US pretreatment achieved even greater results, with a 72.83% increase in juice yield, a 10.08% rise in betacyanin content, a 19.13% increase in TPC, and a 12.33% improvement in antioxidant activity. Both pretreatments significantly enhanced the juice's quality and nutritional properties, with US pretreatment showing superior effectiveness. Scanning electron microscopy (SEM) analysis conformed the results by indicating increased roughness and shrinking on US pretreated fruit surfaces. Furthermore, significant differences in the *a color value were noted, suggesting noticeable visual changes in the treated juices. These results highlight the potential of PEF and US pretreatments as powerful techniques to improve the extraction, quality, and nutritional value of dragon fruit juice.

The second objective assessed the impact of PEF pasteurization on bioactive compounds and enzyme inactivation in red dragon fruit juice extracted using an ultrasound-assisted method. The results showed a notable increase in betacyanin levels with higher pulse width and electric field strength. Similarly, the TPC increased with stronger electric fields, while total flavonoid content (TFC) rose with all experimental variables. Polyphenoloxidase (PPO) activity declined in proportion to both electric field strength and pulse width. Additionally, all variables contributed to a significant reduction in peroxidase (POD) activity. The optimal conditions for PEF treatment were determined to be a 40 kV/cm electric field strength, a 21 µs pulse width, and 600 pulses. Under these conditions, the juice exhibited a betacyanin content of 21.42 ± 0.15 Betacyanin equivalents (BCE)/100 mL, a TPC of 68.46 ± 0.56 mg Gallic acid equivalents (GAE)/100 mL, a TFC of 23.54 ± 0.16 Quercetin equivalents (QE)/100 mL, and residual enzyme activities of 14.6 ± 0.09% for PPO and 7.2 ± 0.03% for POD. The study revealed that PEF pasteurization is a promising technology to pasteurize red dragon fruit juice for enhancing bioactive compounds and reducing enzymatic spoilage.

The third study examined the critical influence of retort pasteurization parameters, particularly temperature and time, on the nutritional and enzymatic properties of red dragon fruit juice. Optimal pasteurization conditions (90°C for 5 minutes) were identified to maximize TPC while minimizing residual PPO and POD activities. These conditions effectively preserved the juice's nutritional quality, as evidenced by the retention of significant levels of betacyanin, TPC, and TFC, along with negligible enzymatic activity. Additionally, microbiological analysis confirmed the juice's safety, with no detectable microbial colonies observed. These findings provide valuable insights into the optimization of thermal processing to enhance the safety, quality, and shelf life of functional fruit beverages.

The fourth study comprehensively characterized red dragon fruit juice processed using PEF (40 kV/cm, 21 μs pulse width, 600 pulses) and retort pasteurization (90 °C for 5 minutes), evaluating their effects on bioactive compounds, vitamin C, reducing sugars, physicochemical properties, and FTIR analysis. The findings highlight that PEF pasteurization effectively preserved betacyanins, with a 2.59% increase compared to untreated juice, whereas retort pasteurization resulted in an 8% reduction. Although retort pasteurization retained a slightly higher percentage of total phenols (90.82%) than PEF (88.23%), PEF treatment better preserved antioxidant properties, with a minimal reduction (1.2%) in DPPH radical scavenging activity, while retort pasteurization caused a 4.8% decline. Notably, flavonoid content increased in both treatments, with retort pasteurization leading to a higher enhancement (42.37%) compared to PEF (26%). However, vitamin C degradation was more pronounced in retort-treated juice, confirming the adverse impact of thermal processing. FTIR analysis further validated the structural integrity of processed juice samples, while also confirming betacyanin degradation in retort-pasteurized juice. Sensory evaluation indicated no significant difference in consumer acceptance between the two treatments, suggesting that both methods produce a marketable product. From an economic perspective, both pulsed electric field (PEF) and retort pasteurization methods are commercially viable, as they demonstrate comparable benefit-cost ratios. Despite the higher production cost, PEF technology offers advantages in preserving key bioactive compounds and antioxidant properties, making it a promising alternative for high-quality juice production. The study underscores the commercial potential of both PEF and retort pasteurization in the red dragon fruit juice industry, with a trade-off between cost-effectiveness and superior nutritional retention.

The fifth study focused on the storage study of control, PEF and retort pasteurized juice. The retort pasteurization at 90 °C for 5 minutes effectively preserved the quality of juice, maintaining high levels of betacyanins, total phenolics, and flavonoids. Although there was a slight reduction in betacyanin content and a significant reduction in total phenolics due to heat-induced oxidation, flavonoid content increased. The juice retained 91.9% of betacyanins, 90.82% of TPC, and 95.19% of its DPPH radical scavenging activity immediately after pasteurization. After 2 months of refrigerated storage, 81.9% of the initial betacyanin content, 98.61% of TPC, and 80.19% of DPPH activity were retained. Importantly, retort pasteurization also inhibited microbial growth, with no mesophilic bacterial growth up to 20 days, no psychrophilic growth during entire storage period and minimal yeast and mold growth by the end of the storage period. However, additional control measures are recommended to prevent yeast and mold growth during storage. The storage study of red dragon fruit juice obtained by ultrasound-assisted extraction and PEF pasteurization retained 91.5% of its initial betacyanin content and maintained 82.26% of initial DPPH radical scavenging activity after two months. TPC and TFC levels increased during storage, with the highest TPC (68.38 ± 0.32 mg GAE/100 ml) observed at 30 days and the highest TFC (22.23 ± 0.07 mg QE/100 ml) at 10 days of storage. The TSS showed no significant difference between control and PEF-treated juice but decreased over time. The juice's pH significantly dropped after two months in both control and treated samples. PEF pasteurization reduced PPO activity by 86.3% and POD activity by 81.4%, though enzyme activity fluctuated during storage due to incomplete inactivation. About 5-log reduction in total plate count was achieved with PEF pasteurization. The total plate count in both control and treated samples increased for up to 30 days, then gradually decreased, likely due to the natural antimicrobial properties of the juice. No psychrophilic growth was detected throughout storage. PEF-treated juice showed lower yeast and mould counts compared to the control after two months, but yeast and mould growth during storage indicated that PEF pasteurization was less effective at controlling them compared to bacteria. Adding natural antimicrobial agents and increasing pulse number or treatment time may help reduce microbial growth during storage.

In conclusion, this research comprehensively evaluated the effects of PEF, US, and retort technology on the extraction, preservation, and storage stability of red dragon fruit juice. The findings underscore the effectiveness of these advanced processing techniques in enhancing juice yield, bioactive compound retention, enzymatic stability, and microbial safety, thereby addressing key challenges in fruit juice processing. Among the pretreatments, ultrasound-assisted extraction proved superior in maximizing juice yield and preserving bioactive compounds, as confirmed by structural modifications observed through SEM analysis. In terms of pasteurization, PEF treatment successfully inactivated enzymatic activity while preserving key bioactives, positioning it as a promising non-thermal alternative to conventional heat-based methods. PEF processing further demonstrated its ability to enhance nutritional retention, particularly in terms of betacyanin and antioxidant capacity, although it involved higher production costs. Retort pasteurization, while leading to minor losses in bioactive compounds due to thermal degradation, ensured microbial stability and extended shelf life, making it a cost-effective solution for large-scale juice production. Storage studies revealed that both HIPEF and retort pasteurization effectively maintained the juice's bioactive composition over time. However, microbial stability varied, with retort pasteurization offering superior control over yeast and mold growth, whereas PEF-treated juice required additional antimicrobial measures to enhance shelf life. These findings highlight a trade-off between cost efficiency and superior nutritional preservation, offering valuable insights for optimizing processing methods in the functional beverage industry. Overall, this study establishes a strong foundation for the application of innovative extraction and preservation technologies in red dragon fruit juice processing. By demonstrating the efficacy of non-thermal and thermal treatments in enhancing both nutritional quality and shelf life, this research contributes to the development of high-quality, commercially viable functional beverages.

Future Research directions

- **Refinement of Processing Parameters**

  Further refinement of processing conditions to maximize bioactive compound retention while minimizing processing costs.

- **Integration of Natural Preservatives**

  Exploration of natural antimicrobial agents (e.g., essential oils, plant extracts) to enhance microbial stability and extend shelf life without compromising quality.

- **Synergistic Processing Approaches**

  Investigation of combined techniques (e.g., ultrasound + PEF, HIPEF + mild thermal processing) to achieve optimal extraction efficiency and preservation.

- **Long-Term Storage Studies**

  Assessment of physicochemical, microbiological, and sensory stability over extended storage periods under different environmental conditions.

- **Nutritional and Functional Analysis**

  Detailed evaluation of bioactive compound degradation pathways and their impact on health benefits during processing and storage.

- **Consumer Acceptability and Market Viability**

  Sensory evaluation studies with diverse consumer groups to assess preferences and optimize formulations for commercial success.

- **Economic and Environmental Sustainability**

  Life cycle assessment (LCA) and cost-benefit analysis of PEF, HIPEF, and retort pasteurization to determine their feasibility for large-scale adoption.

- **Application to Other Fruit Juices**

  Extension of these processing techniques to other tropical fruit juices to explore their broader applicability in the beverage industry.

- **Mechanistic Studies on Enzyme Inactivation**

  In-depth exploration of enzyme kinetics and inactivation mechanisms under different processing conditions to improve enzymatic control.

- **Industrial Scale-Up and Automation**
  Development of pilot-scale and industrial-scale implementations to bridge the gap between laboratory research and commercial production.

These future research directions will help further enhance the efficiency, sustainability, and commercial viability of advanced processing methods for red dragon fruit juice.