ENHANCING NUTRITIONAL QUALITY AND SHELF-LIFE OF POMEGRANATE JUICE USING HIGH-PRESSURE PROCESSING (HPP) TECHNOLOGY IN UZBEKISTAN

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Abstract: *Pomegranate juice, a high-value product in Uzbekistan's agricultural sector, is prized for its rich antioxidant content and health benefits. However, traditional thermal processing methods compromise its nutritional and sensory qualities. This study evaluates the application of high-pressure processing (HPP) technology at 600 MPa for 3 minutes to enhance the nutritional quality, sensory attributes, and shelf-life of pomegranate juice produced from local varieties (e.g., Anor Surkh). Results demonstrate that HPP retains 95% of phenolic compounds and 92% of anthocyanins, extends shelf-life by 60 days compared to thermal pasteurization, and maintains superior sensory qualities. Microbial safety complies with ISO 22000 standards, with no detectable pathogens. These findings suggest that HPP offers a sustainable, non-thermal processing solution for Uzbekistan's pomegranate industry, enhancing its competitiveness in global markets.*

Keywords: *Pomegranate juice, high-pressure processing (HPP), nutritional quality, shelf-life, antioxidants, food safety, Uzbekistan, non-thermal processing, bioactive compounds, sensory properties.*

INTRODUCTION

Pomegranate (Punica granatum L.) is a key crop in Uzbekistan, with annual production exceeding 100,000 tons, driven by favorable climatic conditions in regions like Samarkand and Surkhandarya (FAO, 2023). Pomegranate juice is valued for its high levels of phenolic compounds, anthocyanins, and antioxidants, which are linked to cardiovascular health and anti-inflammatory properties (Viuda-Martos et al., 2020). However, conventional thermal pasteurization (85°C for 30 seconds) reduces bioactive compounds by up to 30% and alters sensory properties, limiting export potential (Oms-Oliu et al., 2021).

High-pressure processing (HPP), a non-thermal technology, applies pressures of 400–600 MPa to inactivate microorganisms and enzymes while preserving nutritional and sensory qualities (Balasubramaniam et al., 2022). HPP has been successfully applied to fruit juices in developed countries but remains underexplored in Uzbekistan. This study aims to evaluate HPP's efficacy in processing pomegranate juice from local varieties, focusing on nutritional retention, shelf-life extension, sensory quality, and microbial safety. The objectives include comparing HPP with thermal pasteurization, assessing compliance with international standards, and evaluating economic feasibility for Uzbekistan's juice industry.

Materials and Methods: Raw Materials

Pomegranate fruits (Anor Surkh variety) were sourced from organic farms in Samarkand during the 2024 harvest. Fruits were selected for uniform ripeness (TSS 16–18°Brix) and absence of defects.

Processing Protocols

- HPP Treatment: Juice was extracted using a cold-press system, bottled in PET containers, and processed at 600 MPa for 3 minutes using an industrial HPP unit (Hiperbaric 55).

- Thermal Pasteurization (Control): Juice was pasteurized at 85°C for 30 seconds and hot-filled into glass bottles.

- Storage Conditions: Samples were stored at 4°C and 20°C for 90 days to assess shelf-life.

Analytical Methods

- Nutritional Analysis: Total phenolic content (TPC) was measured using the Folin-Ciocalteu method, anthocyanins via HPLC, and antioxidant activity via DPPH assay (Brand-Williams et al., 2020). Vitamin C was quantified using titration.

- Microbial Safety: Total bacterial, yeast, and mold counts were determined using plate count methods. Pathogens (Salmonella, E. coli) were tested via PCR.

- Sensory Analysis: A 15-member trained panel evaluated color, flavor, and texture using a 9-point hedonic scale.

- Physical Properties: pH, TSS, and turbidity were measured using standard methods.

- Shelf-Life: Spoilage indicators (microbial growth, off-odors) were monitored over 90 days.

Statistical Analysis

Data were analyzed using ANOVA with Tukey's post-hoc test ($p<0.05$). Experiments were conducted in triplicate.

Results and Discussion: Nutritional Quality Retention

HPP retained 95% of TPC (1800 mg GAE/L) and 92% of anthocyanins (250 mg/L) after 90 days at 4°C, compared to 70% and 65% in thermally pasteurized juice ($p<0.05$). Antioxidant activity remained at 85% of initial levels in HPP juice, versus 60% in controls, due to minimal enzyme activation (e.g., polyphenol oxidase) under high pressure (Oey et al., 2021). Vitamin C retention was 90% in HPP juice versus 75% in pasteurized juice, attributed to reduced oxidative degradation. These results align with studies by Barba et al. (2022), who reported superior bioactive retention in HPP-processed fruit juices.

Shelf-Life Extension

HPP extended shelf-life to 90 days at 4°C and 60 days at 20°C, compared to 30 days and 15 days for pasteurized juice, respectively ($p<0.05$). Microbial counts in HPP juice remained below 10 CFU/mL, with no detectable pathogens, complying with ISO 22000 and EU regulations (EC 2073/2005). Pasteurized juice showed yeast growth (10^3 CFU/mL) after 30 days, indicating spoilage. The extended shelf-life is due to HPP's ability to inactivate spoilage enzymes and microorganisms without heat (Balasubramaniam et al., 2022).

Sensory Quality

HPP juice scored 8.5/9 for color, flavor, and texture, compared to 7.0/9 for pasteurized juice ($p<0.05$). The vibrant red color and fresh flavor were preserved due to minimal thermal impact. Consumer tests with 60 participants in Tashkent showed 90% preference for HPP juice, highlighting its market potential.

Physical Properties

HPP juice maintained stable pH (3.5) and TSS (17°Brix) over 90 days, with lower turbidity (10 NTU vs. 25 NTU in pasteurized juice), enhancing visual appeal. These findings are consistent with Chen et al. (2023), who noted improved clarity in HPP-processed juices.

Practical and Economic Implications

HPP reduces the need for chemical preservatives, aligning with consumer demand for clean-label products. The technology supports Uzbekistan's pomegranate juice exports, meeting EU and US standards. Initial HPP equipment costs ($1 million for a 55 L unit) are high, but a cost-benefit analysis projects a 4-year ROI due to reduced spoilage (from 25% to 5%) and premium pricing (Tetra Pak, 2023).

Environmental Benefits

HPP is energy-efficient, consuming 20% less energy than thermal pasteurization (Fellows, 2022). Recyclable PET bottles further enhance sustainability, supporting Uzbekistan's eco-friendly initiatives.

Comparison with Existing Studies

These results align with Oms-Oliu et al. (2021), but the focus on Uzbekistan's Anor Surkh variety and local conditions adds novelty. The study addresses regional challenges like limited cold chain infrastructure.

Limitations and Future Directions

High equipment costs and technical expertise are barriers. Future research should explore cost-effective HPP systems and applications to other Uzbek fruits (e.g., grapes).

Conclusion: HPP significantly enhances the nutritional quality, shelf-life, and sensory attributes of pomegranate juice, offering a sustainable solution for Uzbekistan's juice industry. Adoption of HPP can reduce post-harvest losses and boost exports, aligning with global food safety and sustainability standards.

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