ENHANCING SAFETY, QUALITY, AND SENSORY ATTRIBUTES OF FRUIT JUICES THROUGH ULTRA-HIGH-PRESSURE HOMOGENIZATION

by

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(Under the Direction of Rakesh K. Singh and Koushik Adhikari)

ABSTRACT

This study evaluates the potential of Ultra High-Pressure Homogenization (UHPH) to enhance fruit juices' safety, quality, and sensory attributes, presenting a promising alternative to thermal pasteurization. The effects of UHPH on *E. coli* K12 inactivation were investigated across four types of fruit juices —watermelon, cantaloupe, blueberry, and grapefruit—assessing the microbial safety immediately post-treatment. Additionally, the study analyzed the impact of UHPH on key physicochemical properties (pH, titratable acidity, ºBrix, viscosity, turbidity, color, and particle size distribution) and the natural microflora of each juice immediately post-treatment and over a 45-day refrigerated storage period. These effects were compared with those observed under conventional thermal pasteurization and untreated control to evaluate the stability and quality retention of UHPH-treated juices over time. Finally, consumer acceptance of UHPH-treated juices was compared with thermally pasteurized and untreated fresh juices to determine sensory preferences and potential market acceptance.

The results demonstrate that UHPH achieved a 5-log CFU/mL reduction of *E. coli* K12 in all juice types, with higher pressures (250–300 MPa) and higher inlet temperatures (22°C) reducing *E. coli* to undetectable levels. UHPH-treated juices also showed better stability in physicochemical properties, such as pH, acidity, and turbidity, over the 45-day storage period, with minimal loss in freshness and sensory qualities. Treatment combinations involving higher pressures (250–300 MPa), higher inlet temperatures (22°C), and intermediate flow rates (1.125 L/min) were particularly effective in preserving juice quality, maintaining color vibrancy, and reducing sedimentation. Consumer acceptance testing further highlighted a clear preference for UHPH-treated juices over thermally pasteurized ones, especially for appearance, flavor, mouthfeel and overall acceptance, suggesting that UHPH better preserves the fresh-like and natural-like characteristics of juices. These findings support the adoption of UHPH as an alternative processing technique that meets microbial safety standards and enhances physicochemical stability and consumer acceptability in fruit juices.

INDEX WORDS: Watermelon, Cantaloupe, Blueberry, Grapefruit, High pressure homogenization, HPH, UHPH, HTST, Microbial inactivation, System validation, Consumer Acceptance, Physicochemical stability, Microflora, Shelf life, Storage study.

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DEDICATION

This study is wholeheartedly dedicated to my beloved family, who have been a constant source of inspiration, support and encouragement throughout my life.

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CHAPTER 1

INTRODUCTION

Fruits and vegetables are essential for a balanced and healthy lifestyle due to their rich content of nutrients, vitamins, dietary fiber, and bioactive compounds. Their juices offer concentrated sources of vitamins, minerals, and bioactive compounds like polyphenols and carotenoids, which contribute to various health benefits. However, the degree of processing plays a critical role, as minimally processed juices generally provide more health advantages than highly processed ones (Zhang et al., 2024). In today's fast-paced society, there is a growing preference for ready-to-drink juice options as a convenient way to access these nutritional benefits. However, microbial outbreaks in fruit juices pose a significant public health risk due to pathogens like *Salmonella spp.*, *Escherichia coli* O157, and *Listeria monocytogenes*, which can survive in acidic juice environments (Neggazi et al., 2024). From 1995 to 2005, 21 juice-related outbreaks in the U.S. involved these pathogens, primarily in apple and orange juices (Vikraman et al., 2020).

Therefore, ensuring the safety and quality of fruit juices remains a critical concern. The Food and Drug Administration (FDA) mandates a 5-log (CFU/mL) reduction of the pertinent microorganism during juice processing under the Juice HACCP Regulation (21 CFR 120), in response to outbreaks of pathogens in the 1990s (US FDA, 2001) associated with raw juices (Danyluk et al., 2012). While traditional thermal pasteurization effectively eliminates harmful microorganisms, it can lead to undesirable changes in taste, texture, and nutritional composition (Mukhtar et al., 2024; Petruzzi et al., 2017; Roobab et al., 2023).

Nonthermal pasteurization methods have emerged as promising alternatives to address these challenges and better preserve the inherent qualities of fruits. Techniques such as cold plasma, thermosonication, high-pressure processing and pulsed electric field technology (Ağçam et al., 2019; Fonteles et al., 2024; Ozen et al., 2022), have been implemented to maintain fruit juices' natural flavors, vibrant colors, and essential nutrients while ensuring their safety and longevity. Among these innovative technologies, Ultra High-Pressure Homogenization (UHPH) has gained significant attention for its potential to revolutionize the fruit juice industry and redefine food processing methods (Adhikari, Araghi, et al., 2024; Adhikari, Singh, et al., 2024).

Ultra-high-pressure homogenization (UHPH), also referred to as high-pressure homogenization (HPH), dynamic high-pressure microfluidization (DHPM), ultra-high shear technology (UST), or continuous flow high-pressure throttling (CFHPT), is a non-thermal food processing method. This technology is notable for effectively inactivating microorganisms while preserving nutritional and sensory qualities, making it highly suitable for enhancing the safety, quality, and nutritional value of fruit juices (Chauhan et al., 2023; Lima & Rosenthal, 2023; Salehi, 2020). The technology involves passing the juice through a micrometric gap under high pressure, inducing mechanical forces, such as, cavitation, shear, and turbulence, which effectively reduce particle size and inactivate microorganisms while maintaining bioactive compounds and sensory characteristics (Martínez-Monteagudo et al., 2017). Although this technology is considered a non-thermal system, when a high-pressure fluid exits the micrometering valve and is depressurized to atmospheric pressure, the stored pressure energy is rapidly converted into heat and kinetic energy.

This conversion results in an instantaneous temperature rise and a surge in fluid velocity, creating conditions of intense turbulence, hydrodynamic cavitation, and high shear forces. These extreme physical conditions disrupt microbial cell structures, leading to effective inactivation. The combination of temperature increase, high kinetic energy, and mechanical forces makes this process efficient for microbial control while maintaining the nutritional and sensory qualities of the product.

Figure 1.1 presents a schematic flow diagram of the UHPH system, which includes a 7L feed tank, pressure intensifiers, a homogenization valve, a stabilizer tube, a cooling system, and a steam chamber for sample collection. Figure 1.2 illustrates the MicroMetering Needle Valve (orifice type) used in the experiments. During the process, the fluid is pressurized to the target pressure (up to 300 MPa) and subsequently depressurized to atmospheric pressure. Following depressurization, the fluid passes through a stabilizer tube, which was installed immediately downstream of the valve. The stabilizer tube ensures flow stabilization before the juice enters the cooling system. This arrangement allows the turbulent flow exiting the valve to transition into a uniform and consistent flow profile, enabling effective thermal exchange and temperature reduction during the cooling stage. The stabilizer tube is designed to minimize fluctuations and enhance cooling efficiency by providing sufficient residence time for the juice. Finally, the processed fluid is cooled and bottled, completing the treatment process.

The selection of grapefruit, watermelon, cantaloupe, and blueberry juices for this study is based on their distinct nutritional profiles and potential contributions to a healthier diet. These fruits are rich in health-promoting molecules, including vitamins, carotenoids, flavonoids, and other bioactive compounds. For example, grapefruit is high in vitamin C and flavonoids, which are associated with reduced risks of chronic diseases. Blueberries are known for their high antioxidant content, particularly anthocyanins, which contribute to their health benefits and vibrant color. Watermelon and cantaloupe offer abundant carotenoids and L-citrulline, compounds linked to cardiovascular and metabolic health benefits (Kalt et al., 2020; Manchali et al., 2021; Meghwar et al., 2023; Murthy et al., 2020). Despite these benefits, the short shelf-life and seasonal availability of these fruits present challenges for both producers and consumers.

This study aims to address these challenges by developing and optimizing UHPH parameters, including pressure, inlet temperature, and flow rate, to maximize the retention of physicochemical quality and fresh-like sensory attributes while ensuring microbial safety and extended shelf-life of these juices. Specifically, this research investigates the inactivation mechanism of non-pathogenic bacteria through inactivation modeling. Additionally, it assesses juice quality by comparing UHPH-treated samples with fresh, untreated, and thermally treated samples over 45 days of refrigerated storage, analyzing microbial growth and physicochemical properties. Lastly, an acceptance study evaluates consumer preference for UHPH-treated juices against untreated and thermally treated juices. The findings of this study aim to assist the fruit juice industry in producing high-quality juices that retain nutritional value and cater to health-conscious consumers who prefer clean-label, minimally processed products, while also contributing to the scale-up of high-pressure applications for industrial juice processing.

The central hypothesis of this dissertation is that Ultra-High-Pressure Homogenization (UHPH) can enhance the stability and shelf-life of grapefruit, watermelon, cantaloupe, and blueberry juices while maintaining their natural sensory attributes. This hypothesis is based on existing literature and preliminary findings, which suggest that (a) pressure level, flow rate, and inlet temperature are key factors affecting microbial inactivation, (b) UHPH can extend shelf-life and maintain juice quality during refrigerated storage, and (c) UHPH retains the fresh-like sensory attributes of juices. This work seeks to understand the effect of pressure, inlet temperature, flow rate on safety, physicochemical stability during refrigerated storage, and consumer acceptance of these juices compared to thermal treatment. The specific objectives of this research were as follows:

- **Objective 1:** Develop and optimize processing parameters through variations in pressure level, inlet temperature, and flow rate in UHPH for the inactivation of *E. coli* K12 in grapefruit, watermelon, cantaloupe, and blueberry juices.
- **Objective 2:** Evaluate the effects of different UHPH treatments on the quality of selected juices over 45 days of refrigerated storage, comparing microbial growth and physicochemical parameters with those of untreated and thermally treated juices.
- **Objective 3:** Assess consumer acceptance of UHPH-treated juices compared to untreated and thermally treated juices.

This dissertation is structured as follows: Chapter 2 comprehensively reviews the literature relevant to UHPH and its application in fruit juice processing. Chapters 3 through 5 present the experimental work to achieve the objectives above. Chapter 6 concludes the research, offering recommendations for future studies and industrial applications of UHPH in the fruit juice industry.

The findings from this research are expected to significantly advance food processing technologies, by demonstrating UHPH's effectiveness in preserving the physicochemical and sensory qualities of fruit juices while ensuring safety. This study provides a foundation for the broader adoption of UHPH in producing high-quality fruit juices.

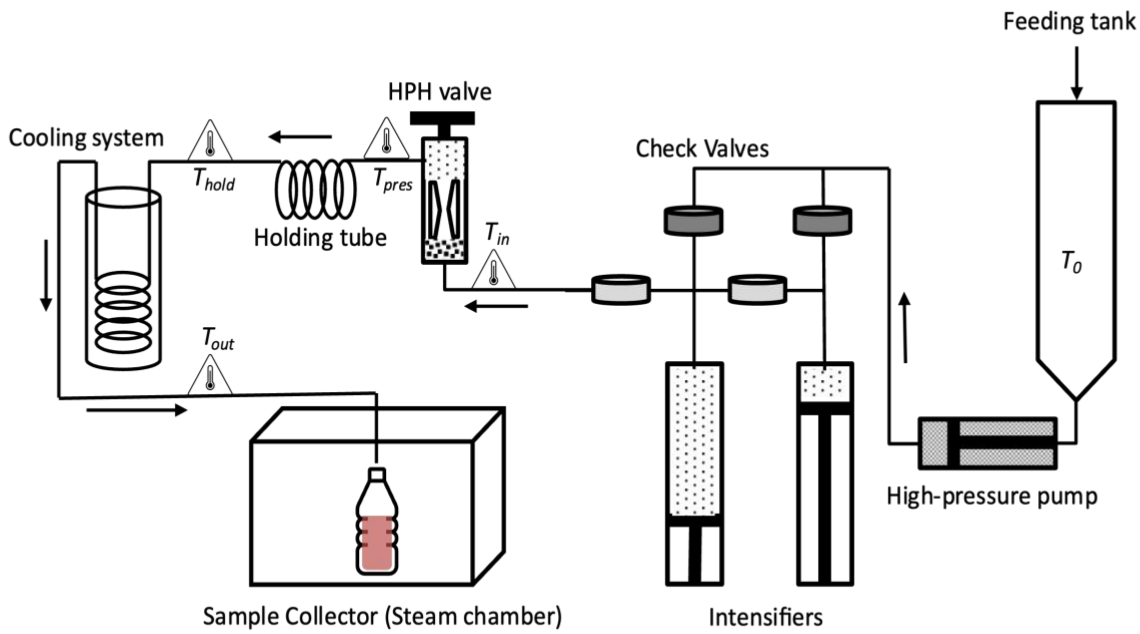

Figure 1.1 Schematic representation of UHPH system used in experiments. T_0 is the temperature of untreated product, T_{in} is product inlet temperature (increased due to hydrostatic compression), T_{pres} is product temperature after homogenization pressure discharge, T_{hold} is product temperature after stabilizing tube, T_{out} is product temperature after cooling system

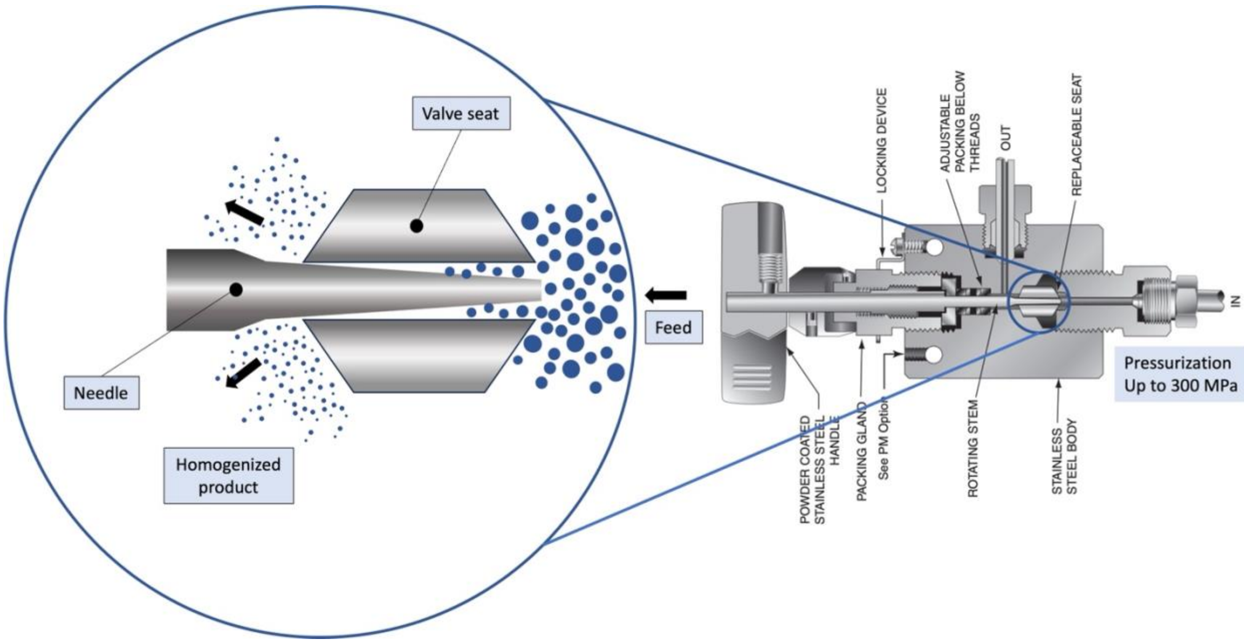

Figure 1.2 MicroMetering Needle Valve cross-section view and components. Instead of having fixed opening, regulates the fluid flow under high pressure though an adjustable and extremely narrow orifice.

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CHAPTER 2

LITERATURE REVIEW

ULTRA HIGH-PRESSURE HOMOGENIZATION OF FRUIT JUICES: A REVIEW[1]

[1]Rahimi Araghi, L., Adhikari, K., Singh, R.K. To be submitted to *Trends in Food Science & Technology*.

Abstract

Ultra-High-Pressure Homogenization (UHPH) is an advanced non-thermal food processing technology that has attracted significant attention for its ability to produce high-quality, safe, and shelf-stable fruit juices without the negative effects of conventional thermal treatments. UHPH aligns with growing consumer demand for minimally processed, fresh-like juices that retain natural sensory and nutritional qualities, such as flavor, color, and bioactive compounds. This process works by combining high pressure, shear, cavitation, and a controlled temperature increase, effectively inactivating microorganisms, deactivating enzymes, and enhancing stability in juice products.

This review provides a comprehensive analysis of recent advancements in UHPH applications for fruit juice processing, emphasizing its impact on physicochemical properties, microbial safety, shelf life, sensory and consumer acceptance. Findings from the last decade highlight that UHPH preserves essential juice attributes, maintains stability against sedimentation and color change, and significantly extends shelf life, offering a promising alternative to thermal pasteurization. Although high equipment costs remain a challenge, UHPH holds immense potential for the fruit juice industry, enabling the production of minimally processed, additive-free juices that meet the preferences of health-conscious consumers. This review also offers theoretical insights to optimize UHPH technology for enhanced product quality, safety, and industrial scalability.

Introduction

The increasing consumer demand for high-quality, minimally processed, affordable, and nutritious fruit and vegetable products has driven the food industry to explore innovative processing technologies beyond conventional thermal methods. Traditional thermal pasteurization, although effective in microbial inactivation and ensuring food safety, often leads to the degradation of sensory and nutritional qualities in heat-sensitive products such as fruit juices. For example, thermal treatments can cause a reduction of up to 50% of vitamin C content due to its heat sensitivity and oxidative degradation, as well as the polymerization of polyphenols, which may reduce their bioavailability (Kubo et al., 2021). These drawbacks have highlighted the need for non-thermal processing technologies that can better preserve the flavor, color, and nutritional integrity of fruit and vegetable juices. Ultra-High-Pressure Homogenization (UHPH), an extension of High-Pressure Homogenization (HPH) operating at pressures typically above 200 MPa, has emerged as a promising non-thermal alternative to traditional heat treatments. UHPH utilizes intense mechanical forces—such as shear, turbulence, and cavitation—generated in specially designed homogenizing valves to inactivate microorganisms and stabilize liquid food products with controllable heat generation (Sevenich & Mathys, 2018). Recent technological advancements, including the development of pressure-resistant materials (e.g., stainless steel, ceramics), the design of new homogenization valves, and enhanced pressure intensifiers, have enabled UHPH systems to reach pressures as high as 400 MPa in laboratory settings (Dumay et al., 2013).

This review examines UHPH technology, including its principles, process parameters, and recent studies on its application in fruit and vegetable juice processing. It provides a comprehensive analysis of the impact of UHPH on physicochemical properties, microbial safety, enzyme inactivation, and shelf life, with particular attention to its ability to retain bioactive compounds and nutritional quality. Additionally, this review discusses the potential applications, current challenges, and future directions for UHPH in the fruit and vegetable juice industry, positioning it as a viable and consumer-aligned alternative to thermal pasteurization.

Principles and mechanisms of UHPH technology

UHPH is a process in which fluid is pressurized to a predetermined level and then passed through a homogenization valve. During the pressure release, various effects occur, such as shear, collision, cavitation, and temperature rise, which help destroy microorganisms and enhance food quality. UHPH typically involves one or two stages to restrict fluid flow, depending on the intended application and the desired characteristics of the final product. High-pressure homogenizers are generally equipped with high-pressure valves (HP valves or first-stage valves), low-pressure valves (LP valves or second-stage valves), pressure pumps, and heat exchangers (Dumay et al., 2013). Depending on the processing objective (e.g., emulsification, homogenization, sterilization), the fluid is pre-cooled or pre-heated to the required inlet temperature using a heat exchanger. Once pressurized by the pressure pump, the fluid's pressure decreases after passing through the first homogenizer valve. Due to this pressure drop, some of the kinetic energy of the fluid—defined as the energy associated with the mass and velocity of the moving liquid—is converted into heat, leading to a rise in temperature. The second homogenizer valve further reduces the fluid pressure to approximately atmospheric pressure, breaking up any agglomerates that may have formed during the initial discharge through the first valve (Levy et al., 2021).

Key Principles of UHPH

The main principles governing UHPH are explained below:

1. Shear Force: UHPH applies extremely high pressure through a small valve, generating intense shear forces. Formula: $\sigma = \frac{F}{A}$, where σ is shear stress (Pa), F is shear force (N), and A is the area of the valve orifice (m^2).

2. Cavitation: Rapid pressure changes cause cavitation, resulting in the formation and violent collapse of tiny bubbles. This enhances disruption of particles and cells. Formula: $C_v = \frac{P - P_v}{\frac{1}{2}\rho v^2}$, where P is pressure, P_v is the vapor pressure, ρ is fluid density, and v is velocity.

3. Temperature Rise: The potential energy stored in pressurized fluid converts into heat energy upon depressurization, leading to a temperature increase. Formula: $T_{out} = T_{in} + (P_{in} - P_{out})/\rho C_P$, where T_{in} is the inlet temperature, ρ is fluid density, and C_p is the specific heat capacity.

4. Particle Size Reduction: High shear forces result in finer and more uniform particle sizes, enhancing product stability and texture. Formula: $D_{32} = K\left(\frac{\eta_d}{\sigma}\right)^n \left(\frac{1}{\epsilon}\right)^m$, where η_d is dispersed phase viscosity, σ is surface tension, and $\epsilon$is energy dissipation rate.

5. Flow Rate (Reynolds Number): Flow rate through the homogenizing valve influences turbulence and mixing. Higher flow rates increase turbulence, enhancing cavitation and shear forces. Formula: $R_e = \frac{\rho v D}{\mu}$, where ρ is fluid density, v is velocity, D is diameter, and μ is dynamic viscosity.

6. Turbulence: Turbulent flow promotes uniform mixing, enhances microbial inactivation, and supports particle and droplet size reduction. Calculated key principles of UHPH parameters are summarized in Tables C. 29 (a-c).

The combined effects of compression heating and homogenization can lead to a rise in fluid temperature. To prevent overheating of the final product, heat exchangers are commonly employed for immediate cooling after homogenization, thus minimizing damage to heat-sensitive components. Alternatively, stabilizing tubes can be used to stabilize the fluid flow before reaching the cooling system, optimizing the thermal effects as needed (Sidhu & Singh, 2016). The design and geometry of the homogenizer valve are central to the functioning of high-pressure homogenization equipment and are key factors that influence the process performance and final product characteristics. The common valve geometries include orifice valves, piston valves, and microjet valves (Levy et al., 2021; Martínez-Monteagudo et al., 2017; Sevenich & Mathys, 2018). Orifice valves reduce the valve diameter to increase fluid velocity, which leads to violent impacts inside the valve. Although the orifice valve maintains a constant product flow under the set pressure, intense collisions and friction may reduce the valve's lifespan (Martínez-Monteagudo et al., 2017). The piston valve, an enhancement of the orifice valve, includes a collision valve and a collision ring structure to reduce wear, thereby extending its service life. High-Pressure Microjet (HPJ) technology is a specialized form of high-pressure homogenization that uses microjet valves. These valves restrict liquid flow through nozzles made of special materials (such as diamond, sapphire, or ruby), forcing the fluid to form a jet at pressures reaching up to 600 MPa (Levy et al., 2021; Tran et al., 2018). Different valve geometries influence the homogenization and sterilization performance of the equipment (Levy et al., 2021; Martínez-Monteagudo et al., 2017). Pang and Ngaile (2021) demonstrated, through computational fluid dynamics simulations, that serrated valve heads generate a higher strain rate in the gap compared to smooth valve heads, which results in higher shear stress and improved emulsion homogenization efficiency (Pang & Ngaile, 2021). Valve geometry also impacts the extent of temperature rise during homogenization, which is irreversible (Osorio-Arias et al., 2020).

Studies have shown that even at the same pressure, different valve designs can affect microbial inactivation. Piston valves are more effective than orifice valves in inactivating microorganisms (Donsì et al., 2013). This difference may be due to varying flow characteristics—such as cavitation, wall impacts, and fluid jet collisions—caused by the distinct valve designs. Thus, in the food industry, specific technical outcomes can be achieved by modifying valve designs and adjusting the initial fluid temperature and pressure. Existing research indicates that UHPH is a green, energy-efficient, and environmentally sustainable processing technology. For instance, Bot et al. (2017) compared the efficiency of high-pressure homogenization and ultrasound in processing tomato juice. Their findings revealed that, at the experimental scale, the energy consumption of high-pressure homogenization at 150 MPa was more than four times lower than that of ultrasound equipment, highlighting UHPH's potential for energy savings and reduced environmental impact (Bot et al., 2017). Valsasina et al. (2017) conducted a life cycle impact assessment (LCA) to compare the environmental impact of Ultra-High-Pressure Homogenization (UHPH) and Ultra-High Temperature Homogenization (UHTH) on milk processing. Their findings indicated that, at the pilot scale (360 L/h), UHPH had a 31% lower carbon footprint than UHTH, highlighting its environmental advantages. Consequently, UHPH is increasingly recognized as a viable alternative to thermal processing for heat-sensitive liquid foods, such as fruit and vegetable juices (Valsasina et al., 2017).

Impact of UHPH on microbiological inactivation of fruit juices

The inactivation of microorganisms is a critical step in the industrial production of food. UHPH can effectively kill microorganisms through a combination of high pressure, shear, collision, cavitation, and temperature effects. However, the efficacy of microbial inactivation is influenced by various factors, including pressure levels, flow rates, the number of cycles, inlet and outlet temperatures, juice composition, and the type of microorganisms. Research has shown that UHPH treatment can reduce microbial counts in fruit and vegetable juices to undetectable levels, allowing them to be stored at 4°C for 1–2 months while maintaining their sensory quality (Maresca et al., 2011; Suárez-Jacobo et al., 2010). Table 2.1 summarizes the effects of UHPH technology on various microorganisms in fruit juices. Different conditions, such as temperature, pH, and pressure, significantly impact microbial inactivation. Higher temperatures and pressures generally lead to more effective microbial reduction.

The inactivation effect varies depending on the homogenization conditions used in fruit and vegetable juices. At lower pressures (<100 MPa), the effect on most microorganisms in food is negligible. However, under higher pressures (>200 MPa), significant microbial inactivation can be achieved (Calligaris et al., 2012; Kumar et al., 2009). At lower pressures, the gap in the piston-type homogenizer valve allows cells to pass through without damaging the cell wall. As the pressure increases, the gap narrows, exponentially increasing shear stress and cavitation effects on the cells, ultimately damaging the cell wall (Sevenich & Mathys, 2018). Additionally, increasing the number of homogenization cycles under the same pressure enhances mechanical destruction of microbial cell integrity, further improving microbial inactivation (Guan et al., 2016; Zhang et al., 2021). Kumar et al. found that within the pressure range of 100–200 MPa, the primary factor contributing to microbial inactivation is homogenization pressure, while pressures ≥250 MPa also result in significant thermal inactivation (Kumar et al., 2009).

Similarly, another study suggests that at pressures exceeding 200 MPa, bacterial inactivation is achieved through a combined effect of homogenization and short-term high-temperature exposure (Pathanibul et al., 2009). This is because a significant portion of the kin energy generated during UHPH is converted into heat, raising the fluid temperature (Patazca et al., 2007; Zamora & Guamis, 2015) and affecting microbial cell structure. Inlet temperature also plays a role in microbial inactivation during UHPH. Briñez et al. found that, compared to 4°C, increasing the inlet temperature to 20°C improved the inactivation of *Staphylococcus aureus* in orange juice treated at 300 MPa by at least 0.3 log CFU/mL (Briñez et al., 2007). Similarly, Carreño et al. demonstrated that raising the inlet temperature from 15°C to 30°C significantly enhanced the inactivation of *Lactobacillus plantarum* (Carreño et al., 2011). This improvement may be due to decreased fluid viscosity at higher temperatures, which strengthens fluid turbulence and cavitation effects, leading to increased microbial inactivation (Diels et al., 2004).

The type of microorganisms also influences the effectiveness of HPH. Gram-positive bacteria, which have a thicker and denser peptidoglycan layer in their cell walls compared to Gram-negative bacteria, show greater resistance to external stressors such as pressure and temperature (Dong et al., 2021; Pathanibul et al., 2009). *Lactobacillus plantarum* and *Saccharomyces cerevisiae* are highly sensitive to HPH, with inactivation levels exceeding 5 log CFU/mL at a pressure of 250 MPa (Campos & Cristianini, 2007). Mckay et al. (2009) found that UHPH at 300 MPa could inactivate more than 5 log CFU/mL of *Saccharomyces cerevisiae* ascospores, filamentous fungal conidia, and black yeast spores in apple juice (McKay, 2009).

However, highly resistant bacterial spores require higher inlet temperatures for effective inactivation (Sharma et al., 2009). Research has shown that at a homogenization pressure of 300 MPa and an inlet temperature of 50°C, less than 1 log CFU/mL of *Bacillus cereus* spores were inactivated. When the inlet temperature was raised above 70°C, nearly 5 log CFU/mL of spores were inactivated (Roig-Sagués et al., 2015). This combination of dynamic high pressure and higher inlet temperatures (resulting in valve temperatures of 120–150°C) is effective at inactivating spores in fruit and vegetable juices (Zhang et al., 2023). To optimize the efficiency of UHPH processing for fruit and vegetable juices, it is essential to consider the effects of pressure, flow rate, temperature, and the number of cycles on microbial inactivation. Adjusting these parameters can enhance the microbial safety of juice products while maintaining their quality.

Impact of UHPH on physicochemical properties of fruit juices

The rheological properties of fruit and vegetable juices are critical factors in product development and optimization. These properties influence the product's appearance, taste, texture, shelf life, and sensory quality, which are crucial for consumer acceptance (Salehi, 2020). During UHPH processing, shear stress, turbulence, cavitation, and high-speed impacts fragment suspended particles, reduce particle size, and alter the product’s microstructure. These changes ultimately affect the rheological properties of the product, improving its uniformity and stability. As a result, UHPH has gained widespread attention in the industrial production of fruit and vegetable juice products.

Research shows that UHPH treatment can effectively reduce the particle size of tomato juice (Kubo et al., 2013), orange juice (Stinco et al., 2020; Velázquez-Estrada et al., 2019), strawberry juice (Karacam et al., 2015), tart cherry puree (Lukhmana et al., 2018), cashew pear juice (Leite et al., 2015), mango juice (Zhou et al., 2017), lily juice (Liu et al., 2019), and apple juice (Szczepańska et al., 2021). The impact of UHPH on particle fragmentation follows a gradual trend: as the pressure increases, the rate of particle size reduction diminishes. This may be because larger particles and cells are more susceptible to homogenization damage, while smaller particles and cell fragments are less affected by subsequent treatments. Leite et al. examined the effects of different homogenization pressures on cashew pear juice particles, showing that both the surface area volume mean diameter (D[4,3]) and the length surface area mean diameter (D[3,2]) decreased with increasing pressure, reducing by 35% at 25 MPa and 18% at 150 MPa compared to the control sample (Leite et al., 2015).

The particle size distribution of the control ranged from 20 to 1,000 μm, while after treatment at 150 MPa, it narrowed to 0.5–150 μm. Liu et al. observed that the particle size reduction in lily pulp was more significant between 0–60 MPa than between 60–100 MPa, indicating that HPH can reduce the average particle size following a gradual behavior (Liu et al., 2019). Additionally, increasing the number of homogenization cycles can further reduce particle diameter. Leite et al. found that at 50 MPa, two or three passes through the homogenizer resulted in a particle size distribution similar to that obtained after a single pass at 100 MPa, indicating that multiple homogenization cycles can achieve similar particle size reductions at lower pressures (Leite et al., 2017). In the food industry, HPH technology is used to modify the rheological properties of products to improve their quality. Liu et al. found that HPH reduced the viscosity of lily pulp while increasing its total soluble solids (TSS) and brightness, with lily pulp treated above 60 MPa showing good suspension stability. Table 2.2 summarizes the effects of UHPH technology on quality parameters in fruit juices.

Bot et al. reported that the gelation and viscoelasticity (10.0°Brix) of tomato juice increased by 2 to 4 times after treatment at 150 MPa (Bot et al., 2017). This may be due to the disruption of suspended particles, increasing their surface area and enhancing particle interactions. Santiago et al. studied the effect of HPH on the dispersed phase in tomato puree, finding that the Bostwick uniformity index was lower in HPH-treated samples compared to control samples, indicating increased flow resistance and viscosity following homogenization (Santiago et al., 2017). Palmero et al. suggested that the release of insoluble pectin during HPH treatment could form a gel structure, thereby increasing the viscosity of fruit and vegetable juices, improving sensory acceptance, and reducing the need for added hydrophilic colloids, thus decreasing particle sedimentation and juice separation (Augusto et al., 2012; Palmero et al., 2016). However, Leite et al. found that the viscosity of HPH-treated cashew apple juice decreased to 50% of its original value, the flow behavior index nearly doubled, and the thixotropy of the juice slightly decreased, indicating that HPH reduced the pulp sedimentation rate in cashew apple juice (Leite et al., 2015).

These studies demonstrate that HPH affects the rheological properties of different fruit and vegetable juices in various ways. This variability may be due to the different compositions and structural arrangements of fruit and vegetable matrices under high shear conditions, leading to differences in the resistance of various products to shear stress (Levy et al., 2021). Furthermore, the cell contents and debris released during HPH treatment may result in unique particle-particle and particle-liquid interactions in different food matrices (Lopez-Sanchez et al., 2011). HPH can enhance the rheological properties of fruit and vegetable juices, preventing stratification, improving stability, and supporting industry development (Yu et al., 2021). Additionally, HPH treatment can have a positive effect on juice color, depending on the food matrix and processing conditions.

Research shows that after HPH treatment at 150, 200, 300, and 400 MPa, banana juice exhibited significant improvements in color, with both L* and b* values increasing, indicating that the homogenized samples were brighter and lighter than the untreated juice (Calligaris et al., 2012). High-pressure treatment can also enhance the typical green color of kiwi juice. When treated at 200 MPa and processed three times, the color of kiwi juice remained stable throughout storage (Patrignani et al., 2019). While some studies have found that HPH has minimal effects on the color of fruit and vegetable juices (Guan et al., 2016; Leite et al., 2017; Maresca et al., 2011; Wellala et al., 2020), it still outperforms thermal processing in this regard. Wellala et al. (2020) found that

HPH had no significant impact on the color of mixed fruit juices (carrot, peach, and apple). Zhou et al. reported that after HPH treatment, the L* value of mango juice decreased while the a* value increased with rising pressure, inlet temperature, and number of cycles (Zhou et al., 2017).

However, since ΔE values were all below 2, the overall color change was not detectible to the naked eye. Nevertheless, HPH has been shown to benefit the color stability of certain fruit and vegetable juices. Moreover, HPH has minimal effects on total soluble solids (TSS), titratable acidity (TA), pH, total sugars, and reducing sugars in fruit and vegetable juices, retaining their original characteristics (Salehi, 2020; Suárez-Jacobo et al., 2011; Wellala et al., 2020). HPH also improves the flavor quality of products like fruit wines (Bañuelos et al., 2020; Vaquero et al., 2022; Voce et al., 2021). Vaquero et al. investigated the effects of UHPH (300 MPa) on grape juice and its resulting wine. Compared to the control, the UHPH-treated wine had a higher concentration and sensory threshold of 2-phenylethyl acetate, a key compound contributing to the aroma of fermented wine (Vaquero et al., 2022).

Effect of UHPH on sensory quality of fruit juices

UHPH enhances the sensory quality of fruit juices by improving their physical and chemical properties. This non-thermal technique is especially effective in reducing particle size, which contributes to better physical stability and cloudiness in juices, thereby enhancing their visual appeal and mouthfeel (Abliz et al., 2020; Lima & Rosenthal, 2023; Velázquez-Estrada et al., 2019). For example, in orange juice, UHPH has been shown to increase galacturonic acid content and pectin linearity, which are positively correlated with turbidity and stability, preventing stratification and boosting consumer acceptance (Yu et al., 2021). In apple juice, UHPH at pressures up to 200 MPa effectively reduces particle size and viscosity, resulting in enhanced clarity and stability, although a slight reduction in vitamin C content may occur (Szczepańska et al., 2021).

One of UHPH's key advantages is its ability to maintain a “fresh-like” quality in juices, closely resembling freshly squeezed products—an attractive attribute that contrasts with traditional thermal processing, which often degrades flavor and nutritional value (Sharma et al., 2020; Song et al., 2022). Studies have demonstrated that UHPH improves the color and flavor of various juices, including kiwi and mango, making them more appealing to consumers (Abliz et al., 2020; Wang et al., 2019). Additionally, UHPH-treated juices benefit from improved stability and cloudiness due to particle size reduction, enhancing the juices' visual and sensory appeal.

However, the effectiveness of UHPH varies depending on the type of fruit juice and the specific processing parameters, such as pressure levels and the number of passes through the homogenizer. These parameters must be optimized to achieve the desired sensory qualities for each type of juice (Koppmaier, 2018; Wang et al., 2018). Overall, UHPH presents a promising alternative to conventional homogenization and thermal processing, delivering high-quality fruit juices with enhanced sensory attributes and greater consumer acceptability.

Conclusion

UHPH is a non-thermal processing technology in the food industry, particularly promising for producing high-quality, safe, and shelf-stable fruit juices. By applying high pressures through specially designed homogenization valves, UHPH can achieve a uniform particle size distribution, improve physical stability, and enhance sensory acceptance by minimizing sedimentation and juice separation. This process maintains fruit juices' nutritional and functional qualities, meeting the growing consumer demand for minimally processed, fresh-like products that retain natural flavor, color, and bioactive compounds.

In addition, UHPH is easy to operate, highly scalable, has high throughput, and offers reproducibility, making it particularly suitable for industrial applications. Its successful use can lead to the production of minimally processed products that retain sensory and nutritional qualities closer to those of fresh products while providing the safety and durability of pasteurized products. However, UHPH technology still faces several challenges. For instance, standalone UHPH is often insufficient to fully inactivate all microorganisms in fruit and vegetable juices, especially spores. As a result, it may need to be combined with temperature inactivation techniques or rely on cold chain transportation to prevent microbial growth. Another issue is the cost of the equipment, which is expensive, and potential equipment corrosion can negatively affect product quality. Furthermore, the equipment involves high maintenance costs over time. Therefore, continuous research and development are necessary to improve energy efficiency and reduce wear.

Additionally, most research on UHPH has been conducted at the laboratory scale, with limited validation at larger scales. Further studies are needed to demonstrate its effectiveness at pilot and industrial scales and to evaluate its impact across various food matrices. The effectiveness of UHPH is also highly dependent on the food matrix, meaning that specific products need to be carefully evaluated before industrial and commercial application to ensure the desired outcomes.

Moreover, the technology's efficiency is highly product-specific, necessitating careful assessment for each juice type to optimize processing parameters and achieve the desired sensory and microbiological outcomes. Despite these challenges, UHPH holds immense potential to redefine juice processing. Continuous research and development in equipment design and process optimization are essential for improving energy efficiency, reducing costs, and broadening the technology's applications. As UHPH evolves, it can support the development of novel juice products that offer superior sensory, nutritional, and functional characteristics, increasing consumer preference and enhancing market competitiveness in the growing sector of minimally processed foods.

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Table 2.1 Microbial inactivation by UHPH in fruit juices

Food Matrix		**Microorganism**	**T_{in} (°C)**	**Pressure (MPa)**	**Number of passes**	**Log Reduction (log CFU/mL)**	**References**
Pineapple juice	13°Brix pH 3.87	*saccharomyces cerevisiae*	2	150	4	8	(Maresca et al., 2011)
		E. coli	2	150	4	6	
		Lactobacillus delbrueckii	2	150	5	2	
Apple Juice	pH 3.8	*E. coli* K12	25	20	1	0.67	(Kumar et al., 2009)
		E. coli K12	25	100	1	1.3	
		E. coli K12	25	150	1	2.27	
		E. coli K12	25	200	1	4.11	
		E. coli K12	25	250	1	7	
Carrot juice	pH 5.2	*E. coli*	4	250	1	5	(Pathanibul et al., 2009)
		Listeria innocua	4	300	1	5	
Apple juice		*E. coli*	4	250	1	5	
		Listeria innocua	4	300	1	5	
Orange juice	12°Brix pH 3.8	*E. coli O157 :H7*	25	200	5	6	(Tahiri et al., 2006)
		Lactobacillus plantarum	25	200	5	2.34	
		Mucilaginibacter	25	200	5	1.64	
		saccharomyces cerevisiae	25	200	5	>2	
		Penicillium	25	200	5	4	
Orange juice	pH 3.6	*E. coli*	6	300	1	3.57	(Briñez et al., 2006a)
		E. coli	20	300	1	3.88	
		E. coli	6	300	1	3.37	
		E. coli	20	300	1	3.69	
Orange juice		*Listeria innocua*	20	300	1	2.7	(Briñez et al., 2006b)

Table 2.1 Microbial inactivation by UHPH in fruit juices (Cont.)

Food Matrix		**Microorganism**	**T_{in} (°C)**	**Pressure (MPa)**	**Number of passes**	**Log Reduction (log CFU/mL)**	**References**
Orange juice	10.5°Brix pH 4.1	*saccharomyces cerevisiae*	10	200	1	4.9	(Campos & Cristianini, 2007)
		saccharomyces cerevisiae	10	250	1	>5.6	
		saccharomyces cerevisiae	10	300	1	>5.6	
		Lactobacillus plantarum	10	200	1	2.1	
		Lactobacillus plantarum	10	250	1	>7	
		Lactobacillus plantarum	10	300	1	>7	
Orange juice	6°Brix pH 5.18	*Zygosaccharomyces bailii*	10	100	0.8	0.8	(Patrignani et al., 2010)
		Zygosaccharomyces bailii	10	100	8	2.6	
Apricot Juice	14°Brix pH 3.26	*Zygosaccharomyces bailii*	10	100	1	0.8	
		Zygosaccharomyces bailii	10	100	8	2.7	
Orange juice		*Bacillus cereus*	20	300	1	/	(Roig-Sagués et al., 2015)
		Bacillus cereus	50	300	1	<1	
		Bacillus cereus	60	300	1	<2	
		Bacillus cereus	70	300	1	<5	
		Bacillus cereus	80	300	1	5.3	
Apple juice	pH 3.6	*Saccharomyces cerevisiae*	20	300	1	>6	(McKay, 2009)
		Filamentous fungi spores	20	300	1	>6	
		Aureobasidium conidia	20	300	1	>6	
Banana juice	pH 4.8	*Total Plate Count*	4	150	1	1	(Calligaris et al., 2012)
		Total Plate Count	4	200	1	4	
Kiwi juice	13°Brix	*Yeast*	4	200	2	2.4 (5C storage 60 d)	(Patrignani et al., 2019)
		yeast	4	200	3	2.4 (5C storage at 40 d)	
Mango juice		*Total Plate Count*	20	190	1	0.54	(Guan et al., 2016)
		Total Plate Count	20	190	5	3.21	
		Total Plate Count	60	190	1	2.32 (5C storage 60 d)	

Table 2.2 Effect of UHPH on quality parameters of fruit juices

Food Matrix		Processing Conditions			Results	References
		T_{in} (℃)	Pressure (MPa)	Number of passes		
Apple juice		20	150	3	-pH, °Brix, vitamin C content, and color showed no significant changes	(Dumay et al., 2013)
Banana juice	pH 4.8	4	150, 200, 300, 400	1	-Viscosity decreased -L* and b* increased, a* decreased	(Calligaris et al., 2012)
Kiwi juice	13 °Brix	4	200	2,3	-pH decrease -Viscosity increases -L* increases, b* and a* decrease	(Patrignani et al., 2019)
Mango juice		20~ 60	40~190	1~5	-Compared to heat treatment (90 ℃/5 min), pH value, TSS, TA, and ascorbic acid showed no significant changes -After HPH treatment, L* and b* decreased, a* value increased, and ΔE value was less than 2, with no obvious color difference	(Guan et al., 2016)
Orange juice		-	150	1	-Ascorbic acid showed no significant difference -Carotenoids and retinol equivalents decreased by 1.37 and 1.35 times, respectively -Particle size decreased, enhancing the bioavailability of carotenoids (approximately 5 times)	(Stinco et al., 2020)
Strawberry juice	9.8°Brix, pH 3.79	-	60	2,5	-TPC, antioxidant capacity showed no significant changes -Average particle size decreased -TSS increased after 5 times -L* increased, b* and a* decreased	(Karacam et al., 2015)

Table 2.2 Effect of UHPH on quality parameters of fruit juices (Cont.)

Food Matrix		**T_{in} (℃)**	**Pressure (MPa)**	**Number of passes**	**Results**	**References**
Strawberry juice		-	100	2,5	-TPC, antioxidant capacity increased -Particle size decreased -Viscosity increased after 2 times of homogenization, decreased after 5 times -TSS showed no significant changes -L* increased, b* and a* decreased	(Karacam et al., 2015)
Cashew Apple Juice	10°Brix, pH 5.0	25	25~150	1	-Particle size decreased -Zeta potential showed no significant change Consistency decreased	(Leite et al., 2015)
Mango juice		20,40, 60	190	1~5	-pH, TSS showed no significant changes -L* decreased, a* increased -Particle size decreased -Apparent viscosity increased	(Zhou et al., 2017)
Lily pulp		-	20~100	1	-Particle size decreases -Viscosity decreases -TSS increases -L* increases, b* and a* decrease	(Liu et al., 2019)
Frozen concentrated orange juice	pH 3.8	25	50, 100, 150	1~3	-Particle size decreased -No significant color change -Viscosity reduced	(Leite et al., 2017)
Not from concentrate orange juice		25	50~150	1~3	-Turbidity increases -Particle size decreases -Viscosity decreases	(Yu et al., 2021)

Table 2.2 Effect of UHPH on quality parameters of fruit juices (Cont.)

Food Matrix		**T_{in} (℃)**	**Pressure (MPa)**	**Number of passes**	**Results**	**References**
Carrot, Apple, Peach Mixed Juice		25	140	1	-Color, TSS, TA, dry matter content, TCC showed no significant changes -Suspended solid content and particle size decreased -TPC and antioxidant activity increased	(Wellala et al., 2020)
Apple juice		4,20	100, 200, 300	1	-Viscosity increase -TSS, TA, pH, total sugar and reducing sugar content, TPC, antioxidant capacity, ascorbic acid, and dehydroascorbic acid showed no significant changes -β-carotene content decreased, with no significant difference compared to heat treatment (90 ℃, 30 min)	(Suárez-Jacobo et al., 2011)
Rosehip flower nectar	11.1°Brix, pH 3.68	4	75, 100, 125	1,3	-pH values showed no significant changes -Average particle size decreased -Apparent viscosity and thickness increased -L*, a*, and b* values increased -TPC and ascorbic acid content significantly decreased -TCC and total antioxidant capacity significantly increased	(Saricaoglu et al., 2019)
Citrus juice		31	150	1	-Carotenoid content decreased -Bioavailability of carotenoids and retinol activity equivalents increased by 6 times and 4 times, respectively -No significant difference in total flavonoid content, but the bioavailability of total flavonoids seemed to improve.	Sentandreu et al., 2020)

CHAPTER 3

INACTIVATION KINETICS OF *ESCHERICHIA COLI* K12 IN SELECTED FRUIT JUICES DETERMINED BY THERMAL-DEATH-TIME DISKS[1]

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Abstract

Inactivation kinetics of *Escherichia coli* K12 inoculated in blueberry, grapefruit, cantaloupe, and watermelon juices were evaluated at isothermal temperatures of 52 to62 °C using thermal death time disks. Juices had variations in titratable acidity, pH, viscosity, and total soluble solids. Survival curves were described by Weibull and linear models, where D- and z-values were determined using the first-order model. D-values in watermelon, cantaloupe, blueberry and grapefruit juices, were 6.57–0.64min, 4.55–0.44 min, 3.94–0.27 min, and 3.03–0.24 min, respectively. The z-values of *E. coli* K12 in tested fruit juices ranged from 5.33 to 5.89 °C. While there were no significant differences in the z-values, the D-values varied significantly. According to the results obtained, pH and heating temperature dramatically affect the thermal resistance of *E. coli* K12 under tested conditions. These findings offer a basis for developing predictive models for *E. coli* inactivation in fruit juices. Practical applications Thermal death time (TDT) kinetics is extremely useful in ensuring microbial safety of fruit juices. The D- and z-values calculated in this study can contribute to developing predictive models for inactivating *E. coli* in fruit juices with varied physicochemical attributes. Furthermore, the data and models can be used for optimization of pasteurization processes and regulatory compliance. TDT studies provide the scientific basis for process calculations and help juice manufacturers comply with regulatory requirements. Also, TDT studies help determine the minimal thermal treatments needed to inhibit spoilage organisms, ensuring the juice remains safe and palatable for longer periods. This research will help scientists understand the thermal resistance of *E. coli* in various fruit juice matrices.

Introduction

Both European and American dietary guidelines suggest substituting at least half of the daily recommended fruit intake with fruit juices to maximize nutritional benefits (Ruxton & Myers, 2021; Snetselaar et al., 2021; USDA, 2020). This recommendation aligns with consumer preferences for fruit juice over whole fruit, driven by its convenience and the diverse range of available options (Gabriel et al., 2015), consequently contributing to the increasing popularity of fruit juice consumption. Despite the natural acidic pH of many fruit juices, which serve as a microbial growth barrier, several foodborne outbreaks related to unpasteurized and pasteurized acidic fruit juices, including apple cider and orange juice, have been reported since the early 1900s. These outbreaks were linked to pathogens capable of surviving in acidic environments, such as *Salmonella enterica* and *Escherichia coli* O157:H7, underscoring the critical need for implementing rigorous safety measures (Harris et al., 2003; Krug et al., 2020; Ruxton & Myers, 2021; Usaga et al., 2014).

The US Food and Drug Administration (FDA) introduced a Hazard Analysis and Critical Control Point (HACCP) plan in response to outbreaks linked to acidic or acidified fruit juices (pH < 4.6), which mandated juice processors to apply treatments resulting in a minimum 5-log (99.999%) reduction of the most resilient disease-causing microorganism expected in the juice or the fruit that makes the juice (FDA, 2001).

In pursuit of HACCP compliance, the industry implements various treatments, including thermal processing, aiming to achieve a minimum 5-log reduction in the microbial population of the target microorganism. Understanding complex microorganism inactivation kinetics is crucial to ensure effective pasteurization without compromising quality. The first-order inactivation kinetic model, characterized by its *D*- and *z*-values, is pivotal in designing and controlling thermal pasteurization processes ensuring food safety. (Gabriel, 2012; Mazzotta, 2001).

Aluminum thermal-death-time (TDT) disks (shown in Fig. 3.1) were developed at Washington State University (Chung et al., 2008). Due to their design featuring easy sample loading and unloading, high thermal conductivity, corrosion resistance, and a broad temperature range, are widely used (Li et al., 2018) for evaluating microbiological inactivation kinetics in both solid (Dag et al., 2022; Ukuku et al., 2013), and liquid (Yuk et al., 2009) foods. Several studies employed TDT disks to determine D- and z-values of *Salmonella* spp. (Gabriel et al., 2015; Jin et al., 2008; Ukuku, Jin, et al., 2008), *Listeria* spp. (Mazzotta, 2001) and *Escherichia coli* (Gabriel et al., 2015; Jin et al., 2008; Ukuku, Geveke, et al., 2008; Yuk et al., 2009) in liquid foods, including fruit juices and liquid egg.

This research utilized a nonpathogenic wild-type *E. coli* K-12 strain that had been previously reported as an appropriate surrogate for various pathogens, including *E. coli* O157:H7 (Duffy et al., 2000; Gurtler et al., 2010; Ozen et al., 2022), *Salmonella Enteritidis* (Jin et al., 2008; Monfort et al., 2012; Ukuku, Jin, et al., 2008), in fruit juices and liquid eggs. This study evaluated the thermal resistance of stationary phase *E. coli* K12 in watermelon, cantaloupe, blueberry, and grapefruit juices, which had not been previously reported, using thermal-death-time (TDT) disks.

Materials and Methods

Extraction and preparation of fruit juice samples

Blueberry juice: Frozen Rabbiteye blueberries (*Vaccinium virgatum var. 'Rabbiteye'*) were obtained from a local farmer in Georgia (Farmer John, LLC, Alma, GA, USA). The frozen blueberries were thawed and comminuted using a chopper (Model 4612 by Hobart Corp. Troy, OH). To enhance the extraction process, the blueberries were treated with pectinase (Pectinex Ultra

SP-L, Novozymes A/S, Switzerland, distributed by Sigma-Aldrich in St. Louis, MO), at a rate of 0.0827 ml/kg of juice, and allowed to rest for one hour at a temperature of 35°C.

Grapefruit juice: Ruby Red grapefruits (*Citrus paradisi var. 'Ruby Red'*) were sourced from local grocery stores (Walmart Inc., Athens, GA). Prior to juicing, grapefruits were thoroughly washed and then cut in half. The juicing process was conducted using a commercial citrus juicer (Waring Commercial, New Hartford, CT, USA).

Cantaloupe and watermelon juice: During the summer season, locally grown Georgia Minerva cantaloupes (*Cucumis melo var. 'Minerva'*) and Troubadour seedless watermelons (*Citrullus lanatus var. 'Troubadour'*) were obtained from the Department of Horticulture at the University of Georgia (Tifton, GA, USA). The melons were washed, followed by the removal of the rinds, cut into small pieces, and comminuted using a chopper (Model 4612, Hobart Corp., Troy, OH). The pH of the melon juices was adjusted down to 4.60 using 1 g of citric acid in 1 liter of juice (0.1% w/v), ensuring the desired pH balance for the final product.

Following the initial extraction steps, the four fruit juices underwent pressing and filtration using a bladder press (Speidel Tank- und Behälterbau GmbH, Ofterdingen, Germany) in conjunction with a 6-layer grade-90 cheesecloth. A batch pasteurization step was implemented in a water bath at 95°C for 15 seconds to eliminate potential background microflora.

Physicochemical characteristics of fruit juices

The fruit juices were characterized using several analytical techniques. The viscosity of the juices was measured using a viscometer (model LV DV-E; Brookfield Engineering Laboratories, Middleboro, MA, USA) at a constant shear rate (73.4 s^{-1}) with UL-adapter (spindle No. S00). The total soluble solids, expressed in degrees Brix (°Brix), were measured with a digital refractometer (PR-201 Palette, Atago Co. Ltd., Tokyo, Japan). The titratable acidity, expressed as a percent citric acid, was determined through acid-base titration with 0.1 N NaOH to the phenolphthalein endpoint (pH = 8.2 ± 0.1). The pH of the juices was measured using a pH meter (Accumet AB15, Fisher Scientific Inc., USA), which was calibrated using pH 4, 7, and 10 buffers to ensure accuracy. All measurements were performed in triplicate at room temperature (25 °C).

Bacterial strain

Escherichia coli (Migula) Castellani and Chalmers (ATCC 25404), a nonpathogenic wild-type K12 strain, was obtained from the American Type Culture Collection (ATCC®; Manassas, VA, US, 20110-2209). The strain was obtained in freeze-dried form for use in this study as a surrogate for *E. coli* O157:H7. The selection of this strain as a surrogate of *E. coli* O157:H7 was driven by the intention of conducting future studies in pilot plants. The pilot plant facility maintains strict safety protocols that mandate the use of non-pathogenic microorganisms. Freeze-dried stock cultures were rehydrated and activated according to ATCC's instructions, and working cultures were stored in 10 ml of Tryptic Soy Broth (TSB; Becton, Dickinson and Company Sparks, MD 21152 USA) at 4 °C.

Inoculum preparation and inoculation

The *E. coli* K12 strain was grown to the stationary phase in Tryptic Soy Broth (TSB) at 37 °C for 18-24 hours under static conditions. The cells were harvested by centrifuging in an Eppendorf 5810 centrifuge equipped with S-4-104 swing-bucket rotor containing 4 × 750 ml round buckets (Eppendorf AG, Hamburg, Germany). Centrifugation was performed at 3180 × *g* (3900 rpm) for 10 min at room temperature, using the Eppendorf adapter designed for 50 ml conical tubes (5825 733.002). The resulting cell pellets were washed using 0.1% peptone water. The supernatant was emptied and replaced with 30 ml fruit juice to obtain a cell population of ca. 7-8 log *E. coli* K12 cells/ml test juice. The cells were allowed to acclimatize in the juice, a process known as acid habituation, for 24 h at 4 °C before undergoing thermal treatments. The acclimation period allowed the cells to adapt to the acidic environment of the juice. This pre-treatment aimed to simulate the real environment conditions and assess the cells' response to acid exposure before subjecting them to further thermal treatments. The initial viable counts were counted before and after the acclimation period.

Heating apparatus for thermal inactivation

Chung et al. (Chung et al., 2008) developed the air-tight aluminum thermal-death-time (TDT) disks used in this study at Washington State University (Engineering Shop, Pullman, WA). These innovative disks were designed to facilitate the rapid heating of samples in water baths to create the best isothermal conditions for investigating the thermal death kinetics of microorganisms in various food matrices. The TDT disks consist of two parts, a base and a screwed-on cap (Fig. 3.1), enabling easy filling and unloading of the samples. A rubber O-ring between the parts ensures a hermetic air-tight seal when closed and can hold up to 1.27 ml of samples. The TDT disks were autoclaved after each use and sanitized using the following steps: washed with soapy water, rinsed with deionized (DI) water, sprayed with 70% ethanol, and air-dried at room temperature under a biological safety cabinet equipped with a UV light, which was turned on for at least 15 minutes or until the disks were completely dried (Jin et al., 2008).

Temperature-time profiles

In these experiments, two thermocouple-connected thermal-death-time (TC-TDT) disks with a T-type thermocouple inserted in the center were used to monitor the temperature change inside the disks during thermal treatments. TC-TDT disks were used to determine the come-up times (CUT, the time required to reach the set temperature), holding, and cooling times (to the RT) at specific target temperatures for each test juice. During the treatments, the TC-TDT disks were immersed in a water bath, along with twelve other regular TDT disks, and the temperature-time profile was recorded using a data logger (model: HH378, Omega Engineering Inc., Norwalk, CT, USA). In addition, another T-type thermocouple, connected to the same thermometer, was submerged in the water bath to check its temperature throughout the experiments.

Isothermal inactivation of E. coli K12

The thermal inactivation of *E. coli* K12 was carried out by immersion of the TDT disks for different time intervals (selected between 15 s and 5 min) in a water bath (Model: 18802A, Barnstead International, Dubuque, IA, USA), which was kept at 52, 54, 56, 58, 60, or 62 °C target temperatures. After acclimation, 1 ml inoculated test juice was loaded to previously sterilized TDT disks. Prior to thermal treatment, all the disks were kept at 30 °C to standardize the come-up times. Each combination of the temperature and time was conducted in duplicates (sets of twelve disks for six-time points). After the treatment times, the TDT disks were taken out from the water bath and cooled at once to room temperature using an iced water bath.

Enumeration of survivors

Survivor populations were enumerated by subjecting the samples taken from the TDT disks at each time and temperature (or non-treated for the initial count) to appropriate dilutions (1:10) with 0.1% buffered peptone water (Difco, Sparks, MD) before spread plating in duplicate onto pre-solidified injury-recovery tryptic soy agar (TSAYE) containing 0.6% yeast extract (Difco, Sparks, MD). The plates were incubated at 37 °C for 24 h. Enumerated viable surviving *E. coli* K12 populations (pale-yellow colonies) were reported as log CFU/ml. Uninoculated test juice was plated to check for background microflora. After the acclimation period, inoculated test juice served as a non-treated control for the initial count.

Modeling of isothermal inactivation kinetics

The study involved modeling the thermal inactivation kinetics of *E. coli* K12 in tested fruit juices using primary survival models, namely log-linear Eq. (1) and Weibull models Eq. (2).

First-order inactivation model: This model is for determining first-order linear thermal inactivation kinetics to obtain *D*- and *z*-values, which are used to characterize the heat resistance of a microorganism.

$$\log S(t) = -\frac{t}{D_T} \quad (1)$$

For the linear model, *S* is the survival ratio (N/N_0); where *N* and N_0 are the populations at time *t* and time 0 (CFU/ml), respectively; t is the isothermal heating time (min), and D_T is the thermal death time aka *D*-value (min) which is the time needed to reduce the population by 10-fold at a constant temperature *T* (°C). Survival curves were obtained by plotting the survivor population ($\log_{10}$ CFU/ml) versus heating time (min). The log-survival data were fitted by linear regression using Microsoft Excel (Microsoft Corp., Redmond, WA), and *D*-values were calculated using the negative reciprocals of the slopes (Corradini & Peleg, 2004; Dag et al., 2022; Ozturk et al., 2020).

The *z*-value (temperature change to alter *D*-value by 10-fold) was obtained by plotting log *D*-values against the temperature so-called “Thermal Death Time (TDT) curve.” The *z*-values were calculated using the negative reciprocals of the slopes of the linear regression of the TDT curves (Li et al., 2018).

$$z = \frac{T_2 - T_1}{\log D_{T_1} - \log D_{T_2}} \quad (2)$$

Where D_{T_1} and D_{T_2} are the *D*-values at temperatures T_1 and T_2, respectively.

Weibull model (Mafart rendition)

$$\log S(t) = -\left(\frac{t}{D}\right)^{\alpha} \quad (3)$$

Where S is the survival ratio *(N/N_0)*; N_0 and N are initial and real-time bacterial counts (log 10); and α is the survival curve factor, which shows whether it follows a non-linear ($\alpha \neq 1$) or linear ($\alpha = 1$) trend. When $\alpha < 1$, the curve has a convex trend, indicating a decreasing inactivation rate with time. When $\alpha > 1$, the curve has a concave trend, indicating an increasing inactivation rate with time (Corradini & Peleg, 2004; Huang, 2013a; Li et al., 2018).

To verify the goodness of fit and accuracy of the fitted model, the root mean square error (RMSE) and the coefficient of determination (R^2) were assessed (Ozturk et al., 2020; Ozturk et al., 2019; Takhar et al., 2009). The lower RMSE and higher R^2 values indicate the goodness of the fitted model. In this study, RSME values for both linear and Weibull models were obtained using the Integrated Pathogen Modeling Program (IPMP) developed by USDA-ARS (Huang, 2013b, 2014; Ozen et al., 2022).

Statistical analysis

The experiments were independently carried out in triplicate, with duplicate samples analyzed at each time point. Linear regression trendlines were generated using Microsoft® Excel (Version 16.73; Microsoft® Corporation). Statistical analysis was performed using SPSS version 29.0.1, one-way analysis of variance (ANOVA) followed by Tukey's pairwise comparison as a post hoc test to identify significant differences ($p \leq 0.05$) in mean *D*- and *z*-values. (IBM, SPSS® Corporation).

Results and Discussion

Physicochemical characteristics of tested fruit juices

Table 1 provides an overview of the average values for total soluble solids (°Brix), titratable acidity (% citric acid), pH, and viscosity measured in tested juices. The composition of the tested juices complied with the Codex standard for fruit juices (CXS-247-2005, 2022). Grapefruit and blueberry juices are inherently high acid (pH < 4.5), while cantaloupe and watermelon juices are acidified to achieve a pH of 4.6 using citric acid (0.1% w/v). The titratable acidity of tested juices ranged from 0.25% (watermelon juice) to 1.06% citric acid (grapefruit juice). The tested juices had minimal pulp content, except for grapefruit juice, which had some suspended insoluble solids affecting its viscosity (2.19 cP). Like the other physicochemical parameters, the soluble solids content of the juices varied significantly, ranging from 7.56 (cantaloupe juice) to 10.02 (grapefruit juice). Considering these intrinsic attributes during the design of product-specific thermal processes is essential, as they significantly impact the thermal inactivation of microorganisms (Gabriel et al., 2015). The fruit juices had a pH of 3.14-4.64, titratable acidities of 0.31-2.80% citric acid, viscosity of 1.40-1.94 cP, and soluble solids of 7.50-10.00 °Brix at room temperature.

Inoculation and initial E. coli K12 population

The average initial population of stationary phase *E. coli* K12 in the inoculum was approximately 9.08 ± 0.16 log CFU/ml, and the population after 24 h of acclimation period at 4 °C (acid habituation) in tested fruit juices was approximately 8.48 ± 0.44 log CFU/ml. The change and slight decrease in the population after 24 h appeared to be caused by the acidic pH of the juice samples.

Temperature-time profiles

A representative temperature-time profile and come-up time of TDT disks containing fruit juices at a 60 °C water bath is shown in Figure 3.2. The come-up time, described as the time needed to reach a temperature within 0.5 °C (Yuk et al., 2009), or 99% of the set temperature (Jin et al., 2008) in a water bath, was measured to be around 45 s for all the target temperatures in the tested juices. Previous studies reported a similar come-up time of 45 s for liquid egg (Jin et al., 2008) and 35 s for apple cider (Yuk et al., 2009) in TDT disks.

Inactivation kinetics of E. coli K12 in tested fruit juices

This study evaluated the heat resistance of nonpathogenic wild-type *E. coli* K-12 strain, a validated surrogate for two disease-causing foodborne pathogens (*E. coli* O157:H7 and *S. enterica*), commonly linked with fruit juice-related outbreaks. Two primary survival models, namely Weibull and linear models were used. Table 2 shows the adequacy of the linear and Weibull models to represent *E. coli* K12 inactivation kinetics in tested fruit juices by comparing the goodness of the fit described by RMSE values. Both models demonstrated similar RMSE values. Therefore, the widely accepted log-linear inactivation model was employed to determine the *D*- and *z*-values to describe the inactivation behaviors of *E. coli* K12 in watermelon, cantaloupe, blueberry, and grapefruit juices at four different temperatures with different physicochemical attributes.

Figure 3.3 and 3.4 illustrates the survival curves used to calculate *D*-values of *E. coli* K12 in tested fruit juices at 56, 58, 60, and 62 °C (cantaloupe and watermelon juices) and 52, 54, 56, and 58°C (grapefruit and blueberry juices), exhibited log-linear population reduction trend within the applied exposure periods. The lower temperatures were selected to determine the *D*-values in grapefruit and blueberry juices because, at 60 and 62 °C, microbial populations decreased drastically by the first time point, making it inadequate for plotting thermal inactivation graphs. The *E. coli* K12 inactivation curves had R^2 values of 0.988-0.995 at 52 °C, 0.988-0.993 at 54 °C, 0.973-0.999 at 56 °C, 0.942-0.998 at 58 °C, 0.931-0.980 at 60 °C, and 0.989-0.994 at 62 °C. Previous studies reported similar log-linear inactivation behavior (Velliou et al., 2012; Velliou et al., 2011; Yuk et al., 2009) for K12 strain in fruit juices including apple juice, apple cider, and acidic medium.

Figure 3.5 demonstrates the thermal death time curves for K12 in juices. The *z*-values were calculated using the reciprocal of the slope in linear regression model ($R^2 > 0.98$). The calculated mean *D*- and *z*-values for *E. coli* K12 in tested fruit juices at different target temperatures are summarized in Table 3.

E. coli K12 was more resistant at all tested temperatures in blueberry juice than grapefruit juice, but was only significant ($p \leq 0.05$) at 52 and 54 °C. Similarly, K12 was more resistant in watermelon compared to cantaloupe juice except at 58 °C; however, the differences were only significant ($p \leq 0.05$) at 56, and 62 °C. The lowest D_{56} value of 0.46 min for *E. coli* K12 in grapefruit juice was 15 times lower than the highest D_{56} of 6.75 min in watermelon juice. The highest D_{58} value of 2.61 min in cantaloupe juice was almost 11 times higher than 0.24 min in grapefruit juice. The *z*-values for *E. coli* K12 were not significantly different ($p > 0.05$) in tested juices, with 5.89, 5.85, 5.52, and 5.33 °C in watermelon, cantaloupe, grapefruit, and blueberry juices, respectively.

Previous studies reported similar *D*- and *z*-values for non-acid and acid-adapted *E. coli* in fruit juices. Usaga et al. (2014) reported the D_{56} of 3.1 min for non-acid adapted *E. coli* in apple-carrot blend juices adjusted to pH 3.7 and 10.7 °Brix, with a *z*-value of 6.3 °C (Usaga et al., 2014). Similarly, another study reported the D_{58} of non-acid adapted *E. coli* in fruit juices adjusted to pH 3.9 were at 1.9 for apple, 3.2 for orange, 1.6 min for white grape with *z*-values ranging from 4.8 to 5.6 °C, and for acid adapted *E. coli*, were at 5 for orange, 2.7 min for white grape, and 3.5 for apple with *z*-values ranging from 4.9 to 5.9 °C (Mazzotta, 2001).

Conclusions

This work assessed the thermal inactivation kinetics of *E. coli* K12 in watermelon, cantaloupe, blueberry, and grapefruit juices, each having varied physicochemical properties. In the context of thermal inactivation kinetics, this research adds valuable information to these less-investigated fruit juices. The pH of juices and heating temperature dramatically affected the thermal resistance of *E. coli* K12 undertested conditions. Furthermore, the survival behavior of *E. coli* K12 in tested fruit juices displayed a linear trend, and both primary survival models demonstrated good fit with R2 > .93 for the linear model and similar RMSE < .50 for both linear and Weibull models. The D- and z-values calculated in this study can contribute to developing predictive models for inactivating *E. coli* in fruit juices with varied physicochemical attributes. However, generating additional data on D- and z-values of different fruit juices is advisable to establish robust and comprehensive inactivation models. Future research should extend the inactivation kinetics investigation to other relevant pathogens and spoilage microorganisms in various fruit juices, exploring a broader temperature range to refine predictive models and thermal processing guidelines. Additional studies could examine the effects of other physicochemical factors like sugar content, organic acids, and phytochemicals on microbial thermal resistance. Combining thermal treatment with other preservation methods, such as high-pressure processing or natural antimicrobials, could offer synergistic effects. Assessing the impact of these treatments on sensory qualities and consumer acceptability is crucial for commercial viability. Validating the findings in industrial settings and investigating the long-term storage stability and microbial safety of treated juices would provide practical insights for the fruit juice industry, enhancing safety and quality.

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Table 3.1 Physicochemical properties of tested fruit juices.

Fruit juices	Physicochemical characteristics			
	°Brix	pH	%TA	Viscosity (cP)
Blueberry	10.01 ± 0.50[a]	3.39 ± 0.13[b]	0.34 ± 0.10[b]	1.47 ± 0.10[c]
Grapefruit	10.02 ± 0.52[a]	3.14 ± 0.12[c]	1.06 ± 0.13[a]	2.19 ± 0.41[a]
Watermelon	8.58 ± 0.33[b]	4.60 ± 0.06[a]	0.24 ± 0.03[c]	1.49 ± 0.06[c]
Cantaloupe	7.56 ± 0.31[c]	4.66 ± 0.10[a]	0.25 ± 0.02[c]	1.55 ± 0.05[b]

Values are the average of three independent measurements ± SD. All TA (titratable acidity) values are expressed as % citric acid. Values in the same column followed by different letters are significantly different ($p \leq 0.05$).

Table 3.2 Parameter estimates for the primary models fitted to the survival data of *E. coli* K12 in fruit juices during isothermal treatment at different temperatures.

Juice Sample	Linear Model			Weibull Model (Mafart rendition)		
	T (°C)	D-value (min)	RSME	δ (min)	α	RSME
Blueberry	52	3.94 ± 0.13	0.13	4.76 ± 0.25	1.24 ± 0.07	0.09
	54	2.17 ± 0.23	0.35	1.91 ± 0.54	0.88 ± 0.21	0.35
	56	0.67 ± 0.09	0.72	0.88 ± 0.32	1.25 ± 0.40	0.73
	58	0.41 ± 0.13	0.58	0.31 ± 0.07	1.10 ± 0.17	0.57
Grapefruit	52	3.02 ± 0.29	0.47	2.93 ± 0.93	0.98 ± 0.22	0.48
	54	0.98 ± 0.07	0.55	0.89 ± 0.29	0.95 ± 0.17	0.56
	56	0.44 ± 0.02	0.33	0.40 ± 0.08	0.92 ± 0.09	0.35
	58	0.23 ± 0.02	0.64	0.21 ± 0.08	0.93 ± 0.18	0.64
Cantaloupe	56	4.54 ± 0.17	0.31	4.71 ± 0.78	1.02 ± 0.09	0.32
	58	2.61 ± 0.17	0.45	4.93 ± 0.40	1.67 ± 0.14	0.24
	60	1.11 ± 0.08	0.48	2.27 ± 0.13	1.90 ± 0.13	0.19
	62	0.44 ± 0.06	0.38	0.62 ± 0.09	1.25 ± 0.12	0.34
Watermelon	56	6.75 ± 0.49	0.39	10.31 ± 1.52	1.46 ± 0.22	0.34
	58	2.56 ± 0.13	0.37	2.56 ± 0.54	1.00 ± 0.12	0.38
	60	1.20 ± 0.08	0.49	1.85 ± 0.34	1.34 ± 0.19	0.44
	62	0.64 ± 0.04	0.52	0.62 ± 0.17	0.99 ± 0.14	0.53

The root mean square error (RMSE) was determined by IPMP software. Values are mean (n = 3) ± standard error. Parameters were estimated separately for each data set. Smaller RMSE values indicate a better fitness of the model.

Table 3.3 *D*- and *z*-values for *E. coli* K12 at different temperatures in tested fruit juices.[a]

Fruit juice	*D* values (min)						*z* values (°C)
	52 °C	54 °C	56 °C	58 °C	60 °C	62 °C	
Watermelon	ND[b]	ND	6.75 ± 0.13^a	2.56 ± 0.14^a	1.20 ± 0.06^a	0.64 ± 0.04^a	5.89 ± 0.15^a
Cantaloupe	ND	ND	4.55 ± 0.22^b	2.61 ± 0.14^a	1.11 ± 0.03^a	0.44 ± 0.06^b	5.85 ± 0.24^a
Blueberry	3.94 ± 0.13^a	2.17 ± 0.23^a	0.67 ± 0.50^c	0.27 ± 0.14^b	ND	ND	5.33 ± 0.53^a
Grapefruit	3.03 ± 0.02^b	0.98 ± 0.10^b	0.46 ± 0.03^c	0.24 ± 0.03^b	ND	ND	5.52 ± 0.23^a

[a] Values represent mean ± SD of three experiments with duplicate determinations. Mean values in the same column followed by different letters are significantly different ($p \leq 0.05$).
[b] not determined.

(a) (b)

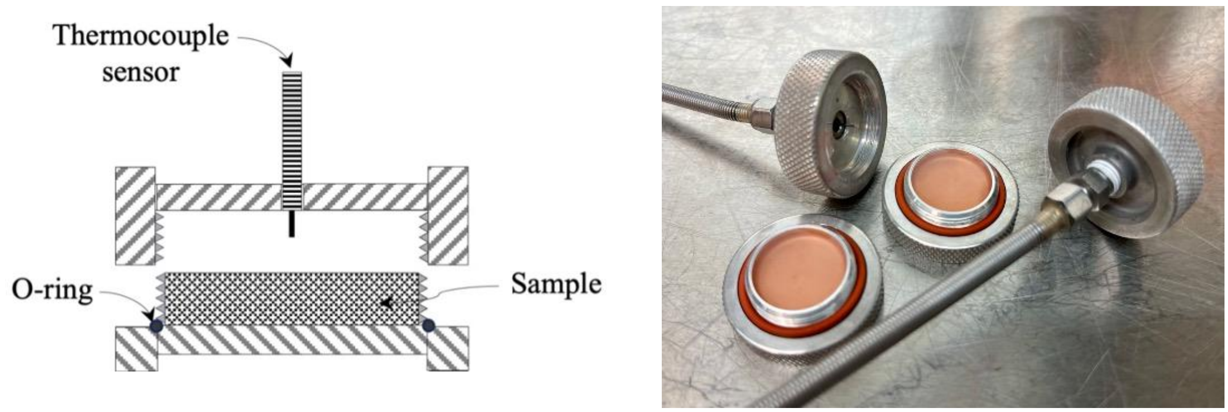


Figure 3.1 Schematic cross-section representation of thermocouple-connected thermal-death-time (TC-TDT) disks (a); TC-TDT disk containing watermelon juice (b).

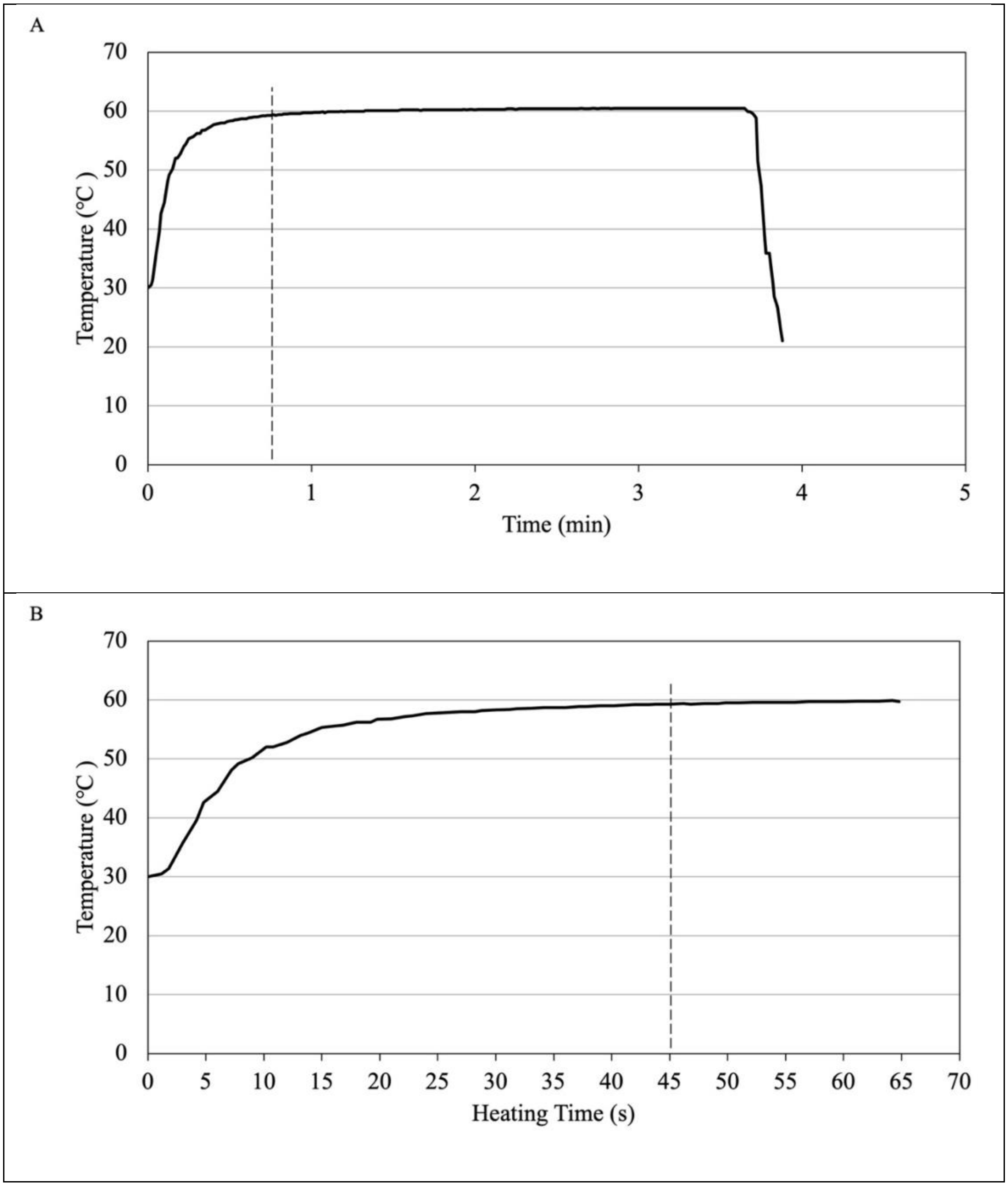


Figure 3.2 Representative temperature-time profile of tested juices in TDT disks subjected to heating in the water bath at 60 °C and cooling in ice water, which includes come-up, hold, and cooling times (A), and with a focused view on the come-up time (B). The vertical dashed line represents the come-up time determined when the juice's center temperature inside the TDT disk reached within 0.5 °C or 99% of the set temperature (59.5 °C at 60 °C target temperature).

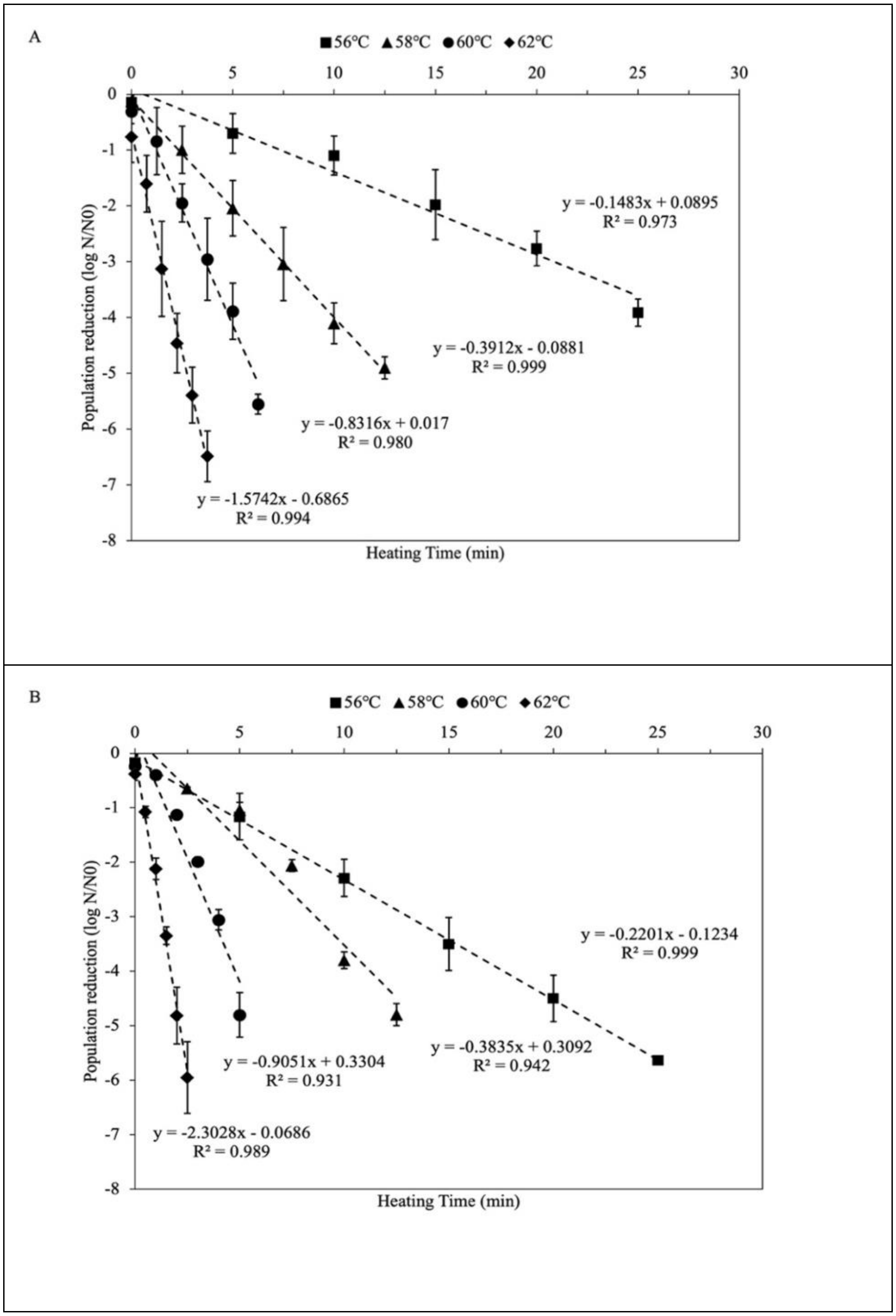
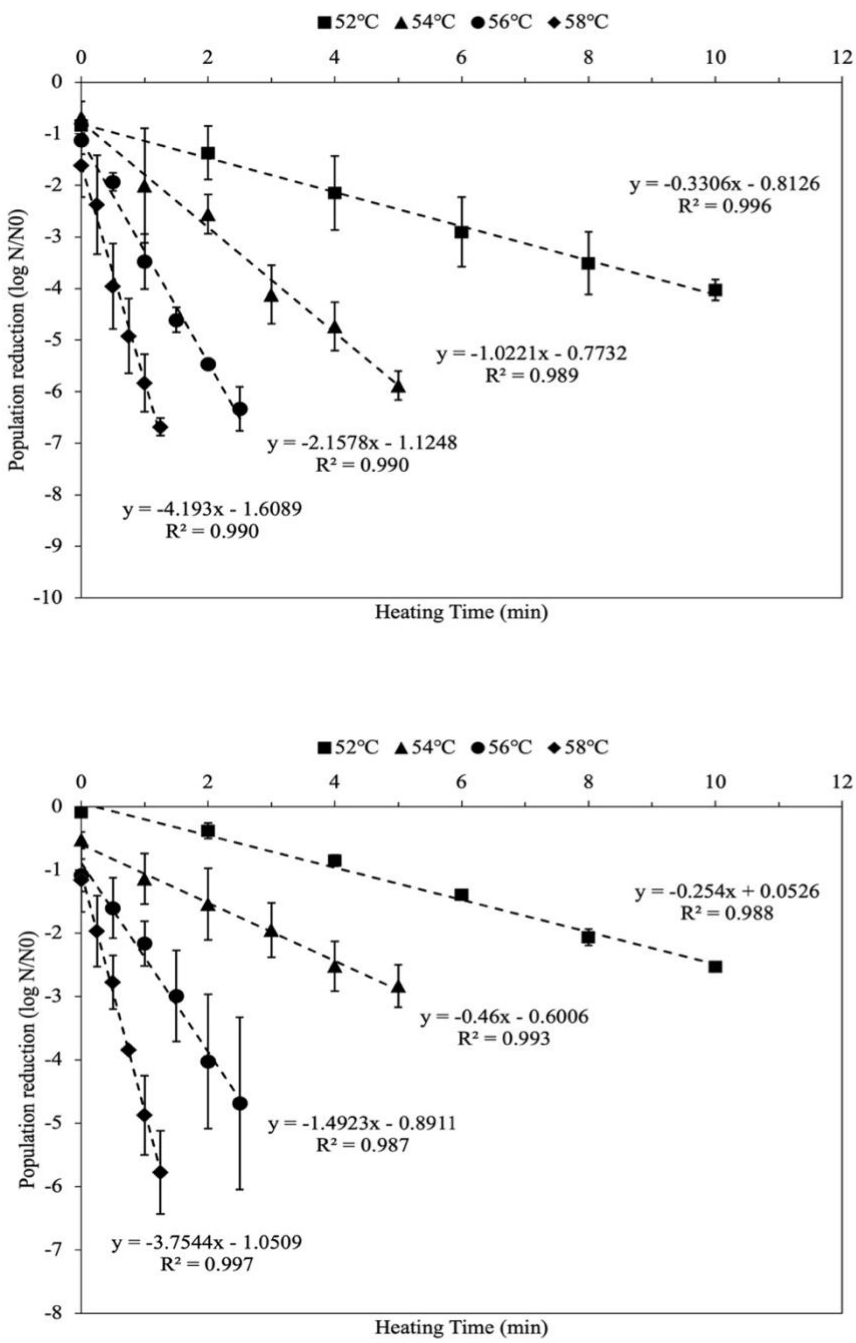


Figure 3.3 Survivor curves of *E. coli* K12 population. The semi-logarithmic graph displays the log-survivor population (n = 3; mean ± SD) over time (min) at 56 ℃, 58 ℃, 60 ℃, and 62 ℃ in (A) watermelon juice (B) cantaloupe juice. *D*-values were derived from the negative reciprocals of linear regression slopes.

A



B

Figure 3.4 Survivor curves of *E. coli* K12 population. The semi-logarithmic graph displays the log-survivor population (n = 3; mean ± SD) vs. time (min) at 52 ℃, 54 ℃, 56 ℃, and 58 ℃ in (A) grapefruit juice (B) blueberry juice. D-values were derived from the negative reciprocals of linear regression slopes.

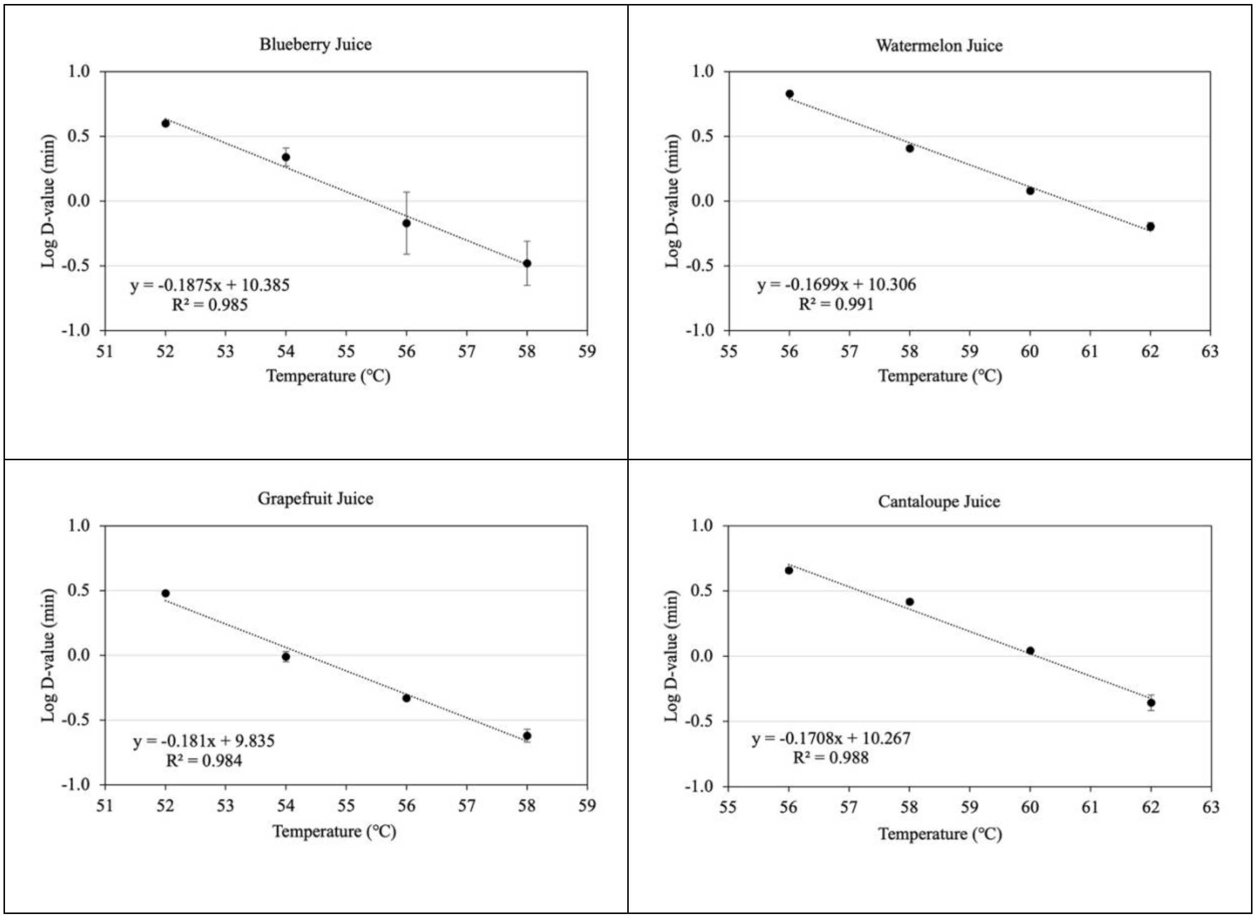


Figure 3.5 Thermal death time (TDT) curves. Log D-values vs. temperature (°C) linear regression curves (*n* = 3; mean ± SD) used for calculating *z*-values of *E. coli* K12 in blueberry, watermelon, cantaloupe, and grapefruit juices.

CHAPTER 4

EVALUATION OF PHYSICOCHEMICAL PROPERTIES, MICROBIOLOGICAL SAFETY AND SHELF-LIFE OF FRUIT JUICES AFTER ULTRA-HIGH-PRESSURE HOMOGENIZATION IN COMPARISON TO HIGH TEMPERATURE SHORT TIME PASTEURIZATION[1]

[1]Araghi, L. R., Mishra, A., Adhikari, K., Singh, R. K. To be submitted to *Journal of Food Process Engineering*,

Abstract

The seasonal maturity, short shelf-life, and risks posed by foodborne pathogens limit the consumption of fresh fruit juices without processing. As a result, traditional thermal treatments are commonly applied to extend shelf life and ensure safety. However, these methods can negatively impact sensory and nutritional qualities, particularly in heat-sensitive fruit juices. To address these limitations, innovative technologies like ultra-high-pressure homogenization (UHPH) offer a promising solution. UHPH involves the passage of pressurized fluid through a narrow gap, resulting in both homogenization and an increase in fluid temperature. This technique provides a significant advantage by integrating homogenization and preservation into a single operation. By controlling the initial temperature and applied pressure, UHPH can be effectively applied for pasteurization or sterilization of fruit juices, ensuring their safety while retaining their quality.This study began with evaluating the impact of ultra high-pressure homogenization (UHPH) on the inactivation of *E. coli* K12 and later evaluated the effect of UHPH on the indigenous microflora and physicochemical properties of watermelon, cantaloupe, blueberry, and grapefruit juices, comparing microbial shelf-life and physicochemical properties with traditional thermal high temperature short time pasteurization – High Temperature Short Time (HTST) during 45 days of cold storage (4°C). The effect of varying pressure (200, 250, 300 MPa), flow rate (0.75, 1.125, 1.5 L/min), and inlet temperature (4 or 22°C), compared with HTST at different target temperatures (75, 85, 95°C) for 15 s. The findings reveal that UHPH effectively reduces microbial counts and maintains the shelf-life of fruit juices, offering a promising alternative to thermal pasteurization. Our findings highlight the efficacy of UHPH in reducing *E. coli* K12 populations, with potential implications for improving food safety in juice processing.

This research aimed to investigate the impact of UHPH on the quality and safety attributes of cantaloupe juice by comparing with thermal pasteurization - High Temperature Short Time (HTST) based on physicochemical characteristics (pH, %TA, ºBrix, PSD, cloud stability and viscosity), and microbial indicators (total mesophylls, and yeasts and molds) before and after treatments and during 45 days of refrigerated storage (4ºC).

Introduction

Preserving the microbiological and physicochemical quality of fruit juices is essential for consumer safety and extending shelf life. Microbial outbreaks in fruit juices are still a significant public health concern due to the potential presence of pathogenic bacteria such as *Salmonella* spp., *Escherichia coli* O157, and *Listeria monocytogenes*. These pathogens can survive in the acidic environments of fruit juices, leading to outbreaks despite the unfavorable conditions for their growth (Neggazi et al., 2024). Indigenous microflora, while naturally present in fruit juices, can contribute to spoilage, reduced shelf life, and potential health risks if not adequately controlled (Tiwari et al., 2009). Therefore, ensuring the safety and quality of fruit juices remains a critical concern. The Food and Drug Administration (FDA) mandates a 5-log (CFU/mL) reduction of the pertinent microorganism during juice processing under the Juice HACCP Regulation (21 CFR 120), in response to outbreaks of pathogens in the 1990s (US FDA, 2001) associated with raw juices (Danyluk et al., 2012).

Fruit juice preservation methods have evolved significantly, incorporating both traditional and innovative techniques to maintain nutritional value and extend shelf life. Conventional heat-based methods, such as High Temperature Short Time (HTST) pasteurization, are effective for microbial inactivation. However, they often lead to the degradation of bioactive compounds and undesirable changes in juice quality, which can reduce consumer acceptance, particularly in heat-sensitive juices (Roobab et al., 2023). As a result, there has been a shift towards exploring non-thermal technologies that ensure microbiological safety while maintaining product quality.

To address these limitations, innovative technologies like Ultra-High-Pressure Homogenization (UHPH) offer a promising solution. Dynamic High-Pressure Homogenization (HPH), or the more intense UHPH, operates by forcing a fluid under high pressure through a narrow micrometric gap, inducing cavitation, shear, and turbulence, which produces both homogenization and a controlled temperature increase due to depressurization. This technique provides a significant advantage by integrating homogenization and preservation into a single operation, reducing the need for additional heating and processing equipment. By controlling initial parameters like temperature, pressure, and flow rate, UHPH can optimize microbial inactivation and quality preservation, making it an appealing choice for pasteurization and potential sterilization (Rastogi et al., 2007). HPH effectively reduces particle size, inactivates microorganisms, and preserves bioactive compounds, thus maintaining the sensory and nutritional quality of juices like apple, mango, and strawberry (Lardinois, 2022). UHPH achieves microbial inactivation levels exceeding 6-log cycles and can destroy thermoresistant spores without significant thermal damage, preserving sensitive compounds such as terpenes and anthocyanins (Morata & Guamis, 2020).

This study aims to assess the effectiveness of UHPH in preserving the microbiological and physicochemical quality of several fruit juices. Initially, this study focuses on evaluating the efficacy of UHPH in inactivating *E. coli* K12 as a representative indicator microorganism. Following this, the study explores UHPH's broader effects on indigenous microflora and physicochemical properties—such as pH, Brix, titratable acidity, particle size distribution (PSD), viscosity, and color—and natural microflora, including total mesophylls, total coliforms, yeasts, and molds, in watermelon, cantaloupe, blueberry, and grapefruit juices. The effects of varying pressure (200, 250, 300 MPa), flow rate (0.75, 1.125, 1.5 L/min), and inlet temperature (4 or 22°C) were evaluated, with results compared to untreated (UT) samples and HTST-treated samples processed at target temperatures of 75, 85, and 95°C for 15 seconds. This comparison was conducted over a 45-day cold storage period at 4°C to assess shelf life and quality retention.

Materials and Methods

Juice preparation

Blueberry juice: Frozen Rabbiteye blueberries (Vaccinium virgatum var. ‘Rabbiteye’) were obtained from a local farmer in Georgia (Farmer John, LLC, Alma, GA, USA). The berries were thawed and macerated using a commercial chopper (Model 4612 by Hobart Corp. Troy, OH). To enhance juice extraction, blueberries were treated with pectinase (Pectinex Ultra SP-L, Novozymes A/S, Switzerland, distributed by Sigma-Aldrich in St. Louis, MO, USA) at a rate of 0.0827 ml/kg of juice. The mixture was allowed to rest for one hour at 35°C before further processing.

Watermelon juice: Locally grown Georgia Troubadour seedless watermelons (Citrullus lanatus var. ‘Troubadour’) were sourced from the Department of Horticulture at the University of Georgia (Tifton, GA, USA). The watermelons were washed, the rinds removed, and the flesh cut into pieces, and comminuted using a chopper (Model 4612, Hobart Corp., Troy, OH, USA) to prepare for juice extraction.

Cantaloupe juice: Minerva cantaloupes (*Cucumis melo* var. 'Minerva') were also sourced from the University of Georgia's horticulture department (Tifton, GA, USA). The cantaloupes were washed, halved, deseeded, and cut into 1-inch slices. The slices were blanched by submerging them in boiling water for two minutes, followed by rapid cooling in an ice bath. The rinds were then removed, and the fruit was chopped using a chopper (Model 4612, Hobart Corp., Troy, OH, USA).

Grapefruit juice: Ruby Red grapefruits (*Citrus paradisi var. 'Ruby Red'*) were sourced from local grocery stores (Walmart Inc., Athens, GA). Prior to juicing, grapefruits were thoroughly washed and then cut in half. The juicing process was conducted using a commercial citrus juicer (Waring Commercial, New Hartford, CT, USA).

Fruit juice extraction

After the initial processing, all fruit juices were pressed using a hydraulic bladder press (Speidel Tank- und Behälterbau GmbH, Ofterdingen, Germany) lined with a 6-layer grade-90 cheesecloth to remove pulp. The pH of the melon juices was adjusted down from 6.1 for cantaloupe and 5.2 for watermelon juice were to 4.60 (pH units) using 1 g of citric acid in 1 L of juice (.1% w/v), ensuring the desired pH balance for the final product. The acidification of juices with citric acid to a pH of 4.6 reduces the thermal treatment required for 5-log reduction of pathogens for pasteurization (FDA, 2001) and has been shown to maintain the original flavor (Tarazona-Diaz & Aguayo, 2013). The sugar content (ºBrix) of all juices was standardized to meet industry specifications in alignment with Codex standards. Overview of the production and analysis is summarized in Fig. 4.1.

In the study's first phase, a portion of the juice was separated for inoculation and microbial inactivation analysis. Therefore, thermal pasteurization was performed using a pilot-scale pasteurizer (MicroThermics, model E-Veros DH, Raleigh, NC, USA). The juice was preheated, followed by pasteurization at 95°C for 15 seconds in a holding tube designed to ensure uniform heating. After pasteurization, the juice was immediately cooled to below 10°C to prevent thermal damage and microbial growth, and to eliminate any potential background microflora. For each experiment, 7 L of pasteurized juice were aseptically transferred into a 10-L autoclaved carboy jug and stored at 4°C until inoculation. Samples were taken before inoculation to confirm the absence of background microflora.

In the second phase, the rest of the fresh, untreated fruit juices were used for a shelf-life study over 45 days at 4°C. The juices' physicochemical quality and natural microflora were monitored throughout storage and compared with untreated control and thermally pasteurized samples.

Bacterial strain for inactivation

Escherichia coli (Migula) Castellani and Chalmers (ATCC 25404), a nonpathogenic wild-type K12 strain, was obtained from the American Type Culture Collection (ATCC®; Manassas, VA, 20110-2209). The strain was obtained in freeze-dried form for use in this study as a surrogate for *E. coli* O157:H7. The selection of this strain as a surrogate of *E. coli* O157:H7 was driven by the pilot plant facility maintains strict safety protocols that mandate the use of non-pathogenic microorganisms. Freeze-dried stock cultures were rehydrated and activated according to ATCC's instructions, and working cultures were stored in 10 mL of Tryptic Soy Broth (TSB; Becton, Dickinson and Company Sparks, MD) at 4ºC.

Inoculum preparation and inoculation

The *E. coli* K12 strain was grown to the stationary phase in Tryptic Soy Broth (TSB) at 37ºC for 18–24 h under static conditions inside two 500 mL glass media bottles each containing 350 mL TSB (total 700 mL). The cells were centrifuged at 3180 x g (3900 rpm) for 10 min at room temperature. The resulting cell pellets were washed using 0.1% peptone water and were suspended in 700 mL processing medium (watermelon, cantaloupe, blueberry juices). Then, 700 mL culture was added into 6300 mL of the juice (1:10 dilution) to obtain a cell population of ca. 7–8 log *E. coli* K12 cells/ mL in the juice. The cells were allowed to acclimatize in the juice, a process known as acid habituation, for 24 h at 4ºC before undergoing UHPH treatments. The acclimation period allowed the cells to adapt to the acidic environment of the juice. This pre-treatment aimed to simulate the real environment conditions and assess the cells' response to acid exposure before subjecting them to further UHPH treatments. The initial viable counts were counted before and after the acclimation period.

Ultra high-pressure homogenization (UHPH) treatment

As the first part of the study, the level of *E. coli* K12 reduction in inoculated juices by UHPH was evaluate. UHPH conditions varied across three pressures (200, 250, 300 MPa), two inlet temperatures (4 or 22ºC), and three flow rates (0.75, 1.125, 1.5 L/min), with exit temperatures between 53-83ºC and residence times of 10-20 s using a pilot-scale dual-intensifier continuous high-pressure homogenizing system (Stansted nm-gen 7900, Stansted Fluid Power, Stansted, England) equipped with a Micrometering needle valve (Model 60VRMM4882, Autoclave Engineers, Fluid Components, Erie, PA, USA). The theoretical processing details are summarized in Tables C. 29 (a-c).

Thermal Pasteurization – High Temperature Short Time (HTST) treatment

Thermal pasteurization was implemented using a pilot-scale HTST pasteurizer (MicroThermics model: E-Veros DH, Raleigh, NC, USA), operated at temperatures of 75°C, 85°C, and 95°C for 15 seconds. The juice was preheated before entering the pasteurization unit, where it flowed through a holding tube designed to maintain the desired temperature for the specified duration. Following pasteurization, the juice was immediately cooled to below 10°C using a builtin cooling system to prevent thermal degradation and microbial regrowth. The system utilized a tubular heat exchanger to ensure uniform heating and cooling of the juice. Flow rates and residence times were calibrated to guarantee consistent processing conditions.

Storage conditions and sampling

Untreated control and UHPH- and HTST-treated fruit juice samples were collected in 100-mL sterile plastic bottles and kept in a walk-in fridge (4ºC) for shelf-life study and analyzed at 1st, 15th, 30th and 45th days to determine physicochemical properties and background microflora changes during storage.

Physicochemical analysis

The fruit juices were characterized using several analytical techniques. All measurements were performed in triplicate at room temperature (22°C).

Titratable acidity (TA) and pH analysis: The titratable acidity was determined through acid-base titration. 10 mL of juice sample was diluted with 90 mL DI water and poured in 250 mL beaker with a magnetic stir bar and titrated with 0.1 N NaOH to the phenolphthalein endpoint (pH = 8.2 ± 0.1). The results were expressed as percent citric acid and calculated using the Eq. (1). The pH of the juices was measured using a pH meter (Accumet AB15, Fisher Scientific Inc., USA), which was calibrated using pH 4, 7, and 10 buffers to ensure accuracy.

$$\%TA = \frac{VxNx0.064x100}{m} \tag{1}$$

Where *V* is the titer volume of NaOH in mL, *N* is the normality of NaOH, 0.064 is the milliequivalent/conversion factor for citric acid, and *m* is the volume of the juice in mL.

Total soluble solids (TSS): The total soluble solids, expressed as grams of sucrose in 100 g of juice in degrees Brix (°Brix), were measured with a digital refractometer (PR-201 Palette, Atago Co. Ltd., Tokyo, Japan) at 20°C.

Apparent viscosity: The viscosity of the juices was measured using a viscometer (model LV DV-E; Brookfield Engineering Laboratories, Middleboro, MA, USA) at a constant shear rate (73.4 s^{-1}) with UL-adapter (spindle No. S00). 16mL of the juice poured into the adapter and the spindle was immersed for 2 min in the juice for thermal equilibrium before recording the viscosity (aghajanzadeh et al., 2017).

Turbidity and cloud stability determination: The turbidity and cloud stability of the juice samples were assessed following the method described by Bhat and Goh (2017). Briefly, 10 mL of juice was centrifuged (Sorvall SM-24 Fixed Angle Rotor) at 4200 × g for 10 min at room temperature (25°C). The supernatant was carefully transferred to 3 mL cuvettes and its absorbance was measured using a spectrophotometer (Model #1200, Cole-Parmer Instrument Co., Chicago, USA) with distilled water serving as the blank (zero absorbance). Cloud stability was quantified by measuring absorbance at 660 nm both before and after centrifugation to compute transmittance using Eq. (2). This value was then used to calculate turbidity, as outlined in Eq. (3). Relative turbidity (*%T*) was defined as the ratio of turbidity after centrifugation (T_1) to turbidity before centrifugation (T_0), as expressed by Eq. (4). All measurements were conducted in triplicate.

$$Transmittance = 100 * 10^{-Abs} \quad (2)$$

$$Turbidity\ (T) = 100 - Transmittance \quad (3)$$

$$\%T = \frac{T_1}{T_0} x100 \quad (4)$$

Color analysis: A Hunter Lab colorimeter (Hunter Associates Laboratory Inc., Reston, VA, USA, Model EZ 4500L) was used to measure the color of fresh untreated juice and treated samples throughout the storage period (45 days at 4°C), with D65 illuminant, which simulates natural noon daylight in order to mimic the vision of the human eye and a 10° observation angle (Commission Internationale de l'eclairage) at 20°C. The colorimeter was calibrated with white and black tiles before each analysis. The colorimeter was adjusted to measure L^* (lightness; black = 0, white = 100), a^* (redness > 0, greenness < 0), and b^* (yellowness > 0, blue < 0) values (CIELab color system) three times for each sample and the average value was recorded. 35 mL of juice was poured in white opaque foam cup and scanned inside a protective box o mitigate environmental light interference. The total color difference (ΔE*) between untreated and treated juices was computed using Eq. (5) to assess the impact of treatments.

$$AE^* = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (5)$$

The parameters a^* and b^* were used to calculate Chroma (C^*) and Hue angle (°Hue) to provide additional details on color intensity (chroma, 0 at the center of the color sphere) and hue with Eq. (6) and (7). The hue angle describes the color's position on the color wheel (0° = red, 90° = yellow, 180° = green, 270° = blue).

$$C^* = \sqrt{(a^{*2} + b^{*2})} \quad (6)$$

$$°Hue = \arctan\left(\frac{b^*}{a^*}\right) \quad (7)$$

Particle size distribution (PSD) analysis: The particle size distribution was measured using Malvern Laser Particle Size Analyzer, Mastersizer S with 300 mm lens (Malvern Instruments Ltd., UK, Model 2000) via light scattering, equipped with small volume sample dispersion unit (Malvern Instruments Ltd., UK, Model DIF2023). The particle size range was between 0.1 and 1000 µm, measured by laser light diffraction. Samples were diluted in deionized water to achieve an appropriate laser obscuration level of 10-20% at a pump speed of 2020 rpm. The analysis utilized the Mie scattering model, with a refractive index of 1.47 for the sample and 1.33 for water. The PSD was characterized by the volume-weighted mean diameter (*D[4,3]*) and the surface-weighted mean diameter (*D[3,2]*), with *D[3,2]* being more sensitive to smaller particles and *D[4,3]* more influenced by larger particles. Additionally, the diameters below which 90%, 50%, and 10% of particles were found ($D_{(v,0.9)}$, $D_{(v,0.5)}$, $D_{(v,0.1)}$), along with the span (relative width of the distribution), were calculated using the software. Three measurements from three replications were used for the analyses to ensure accuracy.

Microbial analysis

E. coli K12 enumeration: To count the bacteria, present in each treated apple juice, one ml from each treated juice was serially diluted in 9 ml of 0.1% peptone water. Trypticase Soy Agar with 0.6% Yeast Extract (TSAYE) (Difco; Becton Dickinson Co., Sparks, MD) was used as a non-selective medium to enumerate all bacteria. MacConkey (MAC) agar (Difco; Becton Dickinson Co., Sparks, MD) was used as a selective media for enumeration of *E. coli* K12. Every medium was plated with 0.1 ml of either sample or diluent. The number of colony-forming units (CFU) was determined by counting the colonies on the plates after 24 h incubation at 37 °C. When no colonies were detected (below the limit of detection, 1-log CFU/ml) after the processing, the samples were incubated at 37°C overnight and then plated on trypticase soy agar with 0.6% yeast extract (TSAYE) plates for bacterial detection. Only positive samples (when detected) were reported. the microbial reduction $log (N/N_0)$ was calculated, where N_0 is the number initial of cells in the untreated samples and N is the microorganism counts after the treatments.

Natural microflora analysis: To evaluate the shelf-life and the efficacy of UHPH treatments in reducing microbial growth, fruit juice samples were tested for aerobic mesophilic organisms, yeasts, molds, and coliforms at 0, 15, 30, and 45 days under refrigerated storage and compared with HTST treatments and UT samples. For total plate counts, 0.1 mL of each sample was spread onto Plate Count Agar (PCA; Difco, BD Detroit, MI, USA) plates and incubated at 35°C, with colonies counted after 24 and 48 hours. Coliforms were assessed using 1 mL samples plated on 3M Petrifilm coliform (3M Science Applied to Life, Detroit, MI, USA), incubated at

35°C, and counted after 24 and 48 hours. Yeasts and molds were enumerated using 1 mL samples plated on 3M Petrifilm yeast and mold (3M Science Applied to Life, MI, USA), incubated for 7 days at 25°C. All results were reported as log CFU/mL (colony-forming units per milliliter) of juice, with a detection limit of (LOD) 1 log CFU/mL.

Statistical analysis

To assess the impact of UHPH and HTST treatments on physicochemical stability of fruit juices after treatment as well as the change during 45 days of storage, were analyzed separately for each fruit juice using a one-way analysis of variance (ANOVA). The level of statistical significance was set at 5%, and Tukey's Honest Significant Difference (HSD) test was applied to identify significant differences between mean scores ($p \leq 0.05$). All statistical analyses were carried out using IBM SPSS Statistics for Macintosh, Version 29.0.(IBM Corp. Armonk, NY, U.S.A.).

Results and Discussion

Effect on E. coli K12 inactivation

The results of the UHPH treatments on *E. coli* K12 in various fruit juices (watermelon, cantaloupe, grapefruit, and blueberry) are shown in Fig. 4.1. The results demonstrate that UHPH is effective in achieving >5 log (CFU/mL) reduction of *E. coli* K12 at higher pressures (250 MPa and 300 MPa), and higher inlet temperatures (22°C). MAC (selective media), which only allows fully viable cells to grow, showed higher log reductions compared to TSAYE (general media), where sublethally injured cells can still grow. This difference in performance between the two media indicates that UHPH effectively inactivated *E. coli*, though some cells were sublethally injured but not fully killed, particularly at lower pressures with lower inlet temperature, as seen by 1-2 log lower reductions on TSAYE compared to MAC, which suggests that these injured cells could still grow on general media. The best microbial control was observed with the combination of 250 MPa or 300 MPa, and 22°C inlet temperature, achieving reductions of up to 8.00 log CFU/mL on both media across all juice types. Lower pressures (200 MPa) with lower inlet temperature (4°C) were less effective, particularly on TSAYE, highlighting the presence of sublethally injured cells. Overall, the UHPH process, particularly at higher pressures and inlet temperatures, was highly effective at inactivating *E. coli* K12, with grapefruit and blueberry juices showing slightly better inactivation than watermelon and cantaloupe juices due to their composition and pH.

Studies have shown that HPH can significantly reduce microbial counts, including pathogens like *Escherichia coli* and yeasts, in various fruit juices such as pomegranate and composite pear juice (Lardinois, 2022; Liu et al., 2022; Benjamin & Gamrasni, 2020).

<u>Effect of UHPH on natural microflora during storage</u>

The results indicated that UHPH at higher pressures, flow rates, and inlet temperatures provided superior microbial control, suggesting that mechanical forces such as shear, cavitation, and turbulence were key factors in microbial inactivation, as detailed in Appendix C.

In watermelon juice (Figure 4.5), the UT samples exhibited rapid microbial growth, reaching 5.60 log CFU/mL for aerobic mesophiles and 5.17 log CFU/mL for yeasts and molds by Day 45, indicating high spoilage susceptibility despite a pH reduction from 5.20 to 4.60. HTST treatments initially controlled microbial populations, but regrowth was evident over time, with

95°C/15s showing the best control among HTST options. UHPH at 250 and 300 MPa, particularly with 1.125 and 1.5 L/min flow rate and 22°C inlet temperature, was most effective in controlling microbial counts, maintaining minimal regrowth. These conditions outperformed lower UHPH pressures and the HTST treatments, suggesting that mechanical forces generated by UHPH were more impactful than heat alone. How do these results compare with the literature values? Need to discuss the results.

Results of blueberry juice (Fig 4.3) showed spoilage in UT samples, though at a slower rate compared to watermelon juice. HTST at 95°C/15s effectively inhibited microbial growth, while UHPH at 300 MPa and high flow rates (1.125, 1.5 L/min) and inlet temperatures (22°C) provided comparable control, keeping microbial counts low through Day 45. The lower UHPH pressures (200 MPa) and lower flow rates allowed some microbial regrowth, particularly in yeasts and molds, indicating that pressure and flow rate optimization is crucial for microbial control in blueberry juice.

Cantaloupe juice was highly susceptible to microbial growth, as observed in UT samples (Fig 4.2). HTST at 85°C/15s and 95°C/15s provided effective microbial control. UHPH at 300 MPa with a 1.125, and 1.5 L/min flow rate and 22°C inlet temperature maintained low microbial counts over 45 days, showing limited regrowth. In contrast, UHPH at 200 MPa permitted some microbial proliferation, particularly at lower inlet temperature (4°C). The results indicate that UHPH can achieve microbial stability in cantaloupe juice, especially under optimized high-pressure conditions.

Grapefruit juice showed slower microbial spoilage in UT samples compared to other juices, though significant microbial growth occurred by Day 45 (Fig 4.4). HTST treatments effectively controlled microbial populations. UHPH at 300 MPa, particularly with higher flow rates and 22°C inlet temperature, maintained microbial stability, showing minimal regrowth through the storage period. This aligns with previous studies demonstrating that higher pressures and flow rates in UHPH can achieve microbial control comparable to HTST, suggesting UHPH as an effective non-thermal alternative for grapefruit preservation.

Across all juices, UHPH at 300 MPa with high flow rates (1.125, 1.5 L/min) and elevated inlet temperatures (22°C) provided the best microbial control, surpassing HTST in maintaining microbial stability over time. The higher flow rates led to rapid juice movement through the homogenization valve, exposing microbes to intense mechanical forces while minimizing heat exposure. This suggests that mechanical forces, rather than thermal effects, are the primary drivers of microbial inactivation in UHPH-treated juices. Rapid cooling post-UHPH further prevented potential heat damage, highlighting that mechanical disruption is crucial for effective microbial reduction. These findings align with studies on dynamic high-pressure homogenization (DHPH), where microbial inactivation ranged from 0.89 to 4.72 log CFU/mL for total aerobic bacteria and 0.40 to 3.03 log CFU/mL for yeasts and molds in composite pear juice (Liu et al., 2022). Similarly, in strawberry juice, DHPH up to 205 MPa reduced indigenous microorganisms by over 6 log CFU/mL, comparable to HTST (Won et al., 2015). This study supports the potential of UHPH as a viable non-thermal preservation method, effectively extending the shelf life of fruit juices by leveraging intense mechanical forces for microbial inactivation.

Effect of UHPH on pH, TA, Brix, viscosity

The results for all juices are summarized in Figures 4.6 to 4.14 and are detailed in Appendix C. UHPH have diverse effects on pH levels in fruit juices, dependent on juice type and specific processing conditions. In this study, UHPH-treated grapefruit, watermelon, blueberry, and cantaloupe juices demonstrated relative pH stability over a 45-day storage period at 4°C, with minor fluctuations noted in specific juices. Grapefruit juice maintained a pH range between 3.2 to 3.4, while watermelon juice showed stability within 4.8 to 5.1. This pH stability in treated fruit juices suggests that UHPH preserves acidity balance under optimal conditions. Blueberry juice exhibited a stable pH range from approximately 2.93 to 3.36, while cantaloupe juice ranged between 4.5 to 4.75, showing minimal fluctuations over 45 days, which is consistent with findings in other studies where high-pressure treatments maintained pH stability. For instance, UHPH treatments did not significantly alter pH in apple and orange juices, indicating that high-pressure processes typically do not impact pH under controlled conditions (Marszałek et al., 2023; Velázquez-Estrada et al., 2019). However, certain juice types, like composite pear juice, have shown a slight decrease in pH with UHPH, which was linked to enhanced antioxidant activity and improved quality attributes (Liu et al., 2022). Additionally, juices such as goji, mango, and carrot exhibited pH variations depending on specific DHPH parameters, indicating a more pronounced effect in certain juice matrices (Abliz et al., 2020). These observations suggest that while UHPH can maintain pH stability in some fruit juices, the effect varies based on juice composition and processing parameters. This variability highlights the need to tailor UHPH parameters for each juice type to achieve the desired stability in pH and other quality attributes.

The titratable acidity (TA) in UHPH-treated grapefruit, watermelon, blueberry, and cantaloupe juices remained mostly stable over the storage period, showing minor increases over time. Grapefruit juice displayed a TA range of approximately 0.9% to 1.0%, while watermelon juice showed stability between 0.12% and 0.15%. Blueberry juice's TA values ranged from approximately 0.17% to 0.32%, and cantaloupe juice demonstrated consistent TA levels with slight increases at higher pressures (250–300 MPa). This stability in TA is consistent with previous findings in orange juice, where UHPH treatments maintained TA levels similar to fresh and thermally treated samples, except when the inlet temperature was notably low (20°C), which led to a reduction in TA (Velázquez-Estrada et al., 2019). In contrast, studies on apricot juice revealed significant changes in TA with high-pressure homogenization (HPH), largely influenced by processing factors such as pressure, temperature, and additional elements like citral, which emphasizes that these conditions can affect acidity depending on the juice matrix (Patrignani et al., 2012). The minimal changes in TA observed in our study suggest that UHPH can effectively maintain the acidity balance of various fruit juices under optimal conditions. However, the sensitivity of TA to specific processing parameters highlights the importance of carefully adjusting UHPH settings to avoid undesirable shifts in juice acidity.

The °Brix levels, which indicate the soluble solids content, in UHPH-treated grapefruit, watermelon, blueberry, and cantaloupe juices remained stable throughout storage, suggesting effective preservation of sweetness and sensory quality. Grapefruit juice maintained a °Brix range of 10.5 to 11, while watermelon juice ranged between 7.9 and 8.1. Blueberry juice consistently showed a °Brix range around 9.9 to 10, with minimal decreases over time likely due to microbial activity. Similarly, cantaloupe juice's °Brix values were stable between 7.5 and 8 across different storage conditions. These findings are in line with studies on apple and orange juices, where high-pressure homogenization (HPH) at pressures up to 300 MPa had negligible effects on °Brix, despite other physicochemical changes such as reduced enzyme activity and polyphenol bioaccessibility (Marszałek et al., 2023; Velázquez-Estrada et al., 2019). Conversely, certain treatments like dynamic high-pressure microfluidization (DHPM) on goji, mango, and carrot juices showed variable effects on °Brix, indicating that under specific processing conditions, DHPH could influence the concentration of soluble solids (Abliz et al., 2020). The stable °Brix values observed in our study demonstrate the capability of UHPH to preserve the soluble solids content in fruit juices, which is essential for maintaining their sweetness and overall sensory attributes during storage.

The viscosity in UHPH-treated grapefruit, watermelon, blueberry, and cantaloupe juices remained stable throughout storage, with slight increases observed under specific conditions, such as higher pressures and flow rates, indicating that UHPH can reinforce the structural integrity of the juice matrix. Grapefruit juice maintained a viscosity range between 1.8 to 2.0 cP, while watermelon juice showed a slight increase over time, remaining within 1.2 to 1.3 cP. Blueberry juice had a consistent viscosity of around 1.4 to 1.5 cP, with minor variations across the storage period, suggesting that UHPH stabilizes the juice matrix. Similarly, cantaloupe juice exhibited slight increases in viscosity, particularly at higher UHPH pressures, which may be attributed to particle size distribution changes and mild aggregation effects. In untreated samples, more noticeable changes in viscosity were observed, potentially due to structural breakdown or microbial activity impacting texture. These results align with other studies where high-pressure homogenization (HPH) decreased viscosity in certain juices, like apple and orange, due to tissue disintegration and particle size reduction (Szczepańska et al., 2021; Leite et al., 2014). Conversely, in mango juice, HPH increased apparent viscosity, likely due to the presence of water-soluble pectin, suggesting that the effects of high-pressure processing on viscosity can vary with juice composition (Linyan et al., 2017). Additionally, HPH-treated mixed fruit juices demonstrated improved cloud stability and rheological properties, indicating that high-pressure homogenization can be tailored to achieve desirable consistency and mouthfeel (Wellala et al., 2020). The minor increases in viscosity observed across all juice types in this study suggest that UHPH can effectively maintain or enhance the textural and rheological properties of fruit juices, contributing to a more favorable mouthfeel and potentially enhancing consumer acceptance.

Effect of UHPH on color change

The lightness (L*) of UHPH-treated watermelon, blueberry, cantaloupe, and grapefruit juices remained stable across storage, with minimal changes in comparison to untreated (UT) and thermally pasteurized – High Temperature Short Time (HTST) samples (Appendix C). For watermelon and cantaloupe juices, UHPH treatments at 300 MPa and an inlet temperature of 22°C led to the least reduction in L* values over the 45-day period, with lower flow rates (0.75 L/min) being more effective in preserving lightness than higher flow rates (1.5 L/min). This indicates that UHPH, especially at optimized pressures and flow rates, can effectively prevent oxidation and browning, which are common issues in color degradation during storage. In untreated samples, lightness showed a more significant decline, particularly after Day 15, likely due to oxidation and browning reactions that intensified over time. Blueberry and grapefruit juices exhibited similar trends, with UHPH-treated samples retaining their lightness better than untreated samples, especially at 300 MPa and 22°C. Lower flow rates also contributed to preserving the lightness in these juices, supporting findings in other studies that pressure and flow rate play crucial roles in maintaining juice color (Abliz et al., 2020; Wang et al., 2017).

The redness (a*) parameter in UHPH-treated watermelon and cantaloupe juices showed stability over time, particularly under conditions of 300 MPa, 22°C inlet temperature, and 0.75 L/min flow rate. These UHPH-treated samples demonstrated minimal reductions in redness up to Day 30, with only minor fading observed thereafter. In contrast, untreated samples experienced a substantial loss of redness by Day 30, indicating degradation of the vibrant color over time. The stability in redness seen in UHPH-treated samples can be attributed to the protective effects of high-pressure homogenization, which preserves pigment integrity by reducing oxidative degradation. In blueberry and grapefruit juices, similar trends were observed, where UHPH-treated samples maintained a stable red hue, especially at 300 MPa and 0.75 L/min. This preservation of redness in UHPH-treated samples compared to untreated and HTST samples suggests that UHPH effectively maintains the visual appeal of these juices by stabilizing anthocyanins and other color pigments. These results align with previous findings on color stability in high-pressure treated juices (Wellala et al., 2020).

The yellowness (b*) of UHPH-treated juices showed considerable stability across all storage intervals. In watermelon and cantaloupe juices, UHPH at 300 MPa and lower flow rates (0.75 L/min) effectively preserved the b* values, with minimal changes observed by Day 45. Higher flow rates and lower pressures (200 MPa) led to slightly greater losses in yellowness, indicating that both pressure and flow rate are key factors in maintaining this color attribute. Blueberry and grapefruit juices treated with UHPH also demonstrated stable b* values over 45 days, particularly at 300 MPa and 22°C. In untreated samples, yellowness declined more rapidly by Days 30 and 45, highlighting the role of UHPH in color preservation by mitigating degradation processes. These observations are consistent with other studies on DHPH and HPH, where higher pressures have been shown to improve color stability in various juices by limiting pigment degradation (Kruszewski et al., 2023; Marszałek et al., 2023).

The findings indicate that UHPH treatments at 250–300 MPa, with an inlet temperature of 22°C and lower flow rates (0.75 L/min), are highly effective in preserving the color stability of watermelon, blueberry, cantaloupe, and grapefruit juices. UHPH-treated juices maintained their lightness, redness, and yellowness better than untreated and HTST samples, with the most significant color degradation observed in untreated samples after Day 15. Thermally pasteurized samples also showed color degradation over storage, although to a lesser extent than untreated samples.

The effectiveness of UHPH in preserving color can be attributed to its ability to reduce oxidative reactions and maintain pigment integrity. This preservation aligns with findings in other fruit juices, such as goji, mango, and carrot, where high-pressure processes have enhanced color attributes and extended shelf life (Abliz et al., 2020; Liu et al., 2022). These results highlight the potential of UHPH as a promising non-thermal technology for maintaining the aesthetic and sensory qualities of fruit juices during extended storage, which is essential for consumer acceptance and marketability.

Effect of UHPH on particle size distribution (PSD) and turbidity (cloud stability)

The application of UHPH significantly impacted particle size distribution (PSD) and turbidity/cloud stability across blueberry, cantaloupe, watermelon, and grapefruit juices, as shown in Figure 4.8 and Figure 4.9. Overall, at Day 0, UHPH-treated juices resulted in more homogenous particle sizes and higher turbidity values compared to HTST and UT samples, specially, treatments at higher pressure (250, and 300 MPa), with moderate flow rates (1.125, and 1.5 L/min) and higher inlet temperature (22°C). For instance, blueberry juice treated at 300 MPa displayed an average particle size reduction of approximately 60% compared to untreated (UT) samples, while cantaloupe juice exhibited a 55% reduction. This substantial decrease in particle size reflects the effective mechanical disruption provided by UHPH, which breaks down larger particles into a finer, more stable suspension through shear forces, cavitation, and turbulence. Conversely, lower pressures (200 MPa) and lower inlet temperature (4°C) resulted in larger particle sizes, indicating less effective mechanical disruption.

During the storage period (Days 15, 30, and 45), UHPH-treated samples maintained their particle size stability better than UT and thermally pasteurized – High Temperature Short Time (HTST) samples. UHPH treatments at 250 MPa and 300 MPa were particularly effective, with minimal PSD changes even after 45 days. This stability was less evident in UT samples, where particle aggregation led to significant increases in particle size by Day 30, resulting in noticeable sedimentation and cloud loss. Similarly, in grapefruit juice, UHPH-treated samples at 300 MPa retained smaller particle sizes and stable cloudiness over time, with a clear difference from UT and HTST samples, which displayed faster aggregation and settling, especially after Day 15. Studies have shown that DHPH can effectively reduce the particle size in various fruit juices, including apple, mango, and kiwi, resulting in a more uniform distribution and improved cloud stability (Marszałek et al., 2023; Abliz et al., 2020; Wang et al., 2017). For instance, in apple juice, DHPH at pressures of 200 to 300 MPa significantly altered the particle size distribution, leading to a more stable juice with reduced pulp sedimentation (Zhu et al., 2019). Similarly, in mango juice, DHPH reduced the particle size from 138 to 6 µm, demonstrating its efficacy in disrupting juice particles and enhancing the juice's rheological properties (Linyan et al., 2017). The reduction in particle size not only improves the visual and sensory attributes of the juice but also affects other properties such as viscosity and color, which are crucial for consumer acceptance (Szczepańska et al., 2021; Velázquez-Estrada et al., 2019).

UHPH-treated juices also exhibited superior turbidity retention, particularly at higher pressures, which contributed to a stable cloudy appearance over the 45-day storage period. For instance, cantaloupe, grapefruit and blueberry juices treated at 250 MPa and 300 MPa maintained above 90% of initial turbidity by Day 45, compared to about 50% turbidity loss in untreated samples. Overall, UHPH treatments retained cloudiness more effectively than HTST and UT samples, which saw rapid decreases in turbidity due to particle settling and separation.

These findings are consistent with other studies showing that high-pressure homogenization (HPH) enhances cloud stability by modifying particle size distribution and maintaining a more uniform suspension in various fruit juices In not-from-concentrate orange juice, HPH increases the galacturonic acid content and linearity of pectin while reducing its molecular weight and branching, which enhances the juice's stability and prevents stratification, thereby improving turbidity and consumer acceptance (Yu et al., 2021). Similarly, in apple juice, HPH at pressures up to 300 MPa results in significant changes in particle size distribution and zeta potential, which are critical for maintaining cloud stability. The process also reduces enzyme activities such as polyphenol oxidase and peroxidase, contributing to improved turbidity and stability (Marszałek et al., 2023, Szczepańska et al., 2021). In the case of blackcurrant juice, HPH parameters such as pressure and the number of passes are crucial, with optimal conditions enhancing cloud stability without compromising color stability (Kruszewski et al., 2021). For mixed juices, including carrot, apple, and peach, HPH at 140 MPa significantly enhances cloud stability and reduces microbial counts, indicating its effectiveness in maintaining juice quality (Wellala et al., 2020). Furthermore, in frozen concentrated orange juice, HPH disrupts suspended particles, reducing serum phase absorbance and slightly affecting viscosity, although it does not significantly alter color or sensory properties (Leite et al., 2016). (Marszałek et al., 2023; Abliz et al., 2020; Wang et al., 2017). The effectiveness of UHPH in preserving particle size and turbidity across juice types supports its potential as a non-thermal processing method that maintains the physical stability and visual appeal of fruit juices, offering improved cloud retention and suspension stability during extended storage.

Conclusion

Based on the extensive results presented in this study, UHPH demonstrates substantial potential as a non-thermal technology for the preservation of fruit juices, providing significant microbial inactivation, and maintained physicochemical stability over refrigerated storage period. Specifically, UHPH at pressures of 250–300 MPa, with an inlet temperature of 22°C and moderate to higher flow rates, was effective in achieving more than a 5 log CFU/mL reduction in *E. coli* K12, highlighting its potential for pathogen control without relying on high-temperature treatments. The findings also indicate that UHPH effectively managed natural microflora, particularly when applied to watermelon, blueberry, cantaloupe, and grapefruit juices, with higher pressures and inlet temperatures showing superior microbial stability over 45 days.

In addition to microbial control, UHPH preserved essential physicochemical properties across all tested juices, including stable pH, Brix, viscosity, color, and particle size distribution. Notably, UHPH-treated juices displayed minimal changes in color, cloud stability, and texture, suggesting that UHPH effectively prevents oxidative degradation and structural breakdown. The stable particle size distribution and cloud retention observed in UHPH-treated juices further underscore its efficacy in maintaining the visual and textural quality of fruit juices, aligning with consumer demand for fresh-like, minimally processed beverages. Future research could focus on optimizing UHPH parameters for various juice types, facilitating its scalability in industrial applications and its use as a viable alternative to traditional thermal pasteurization in the juice industry.

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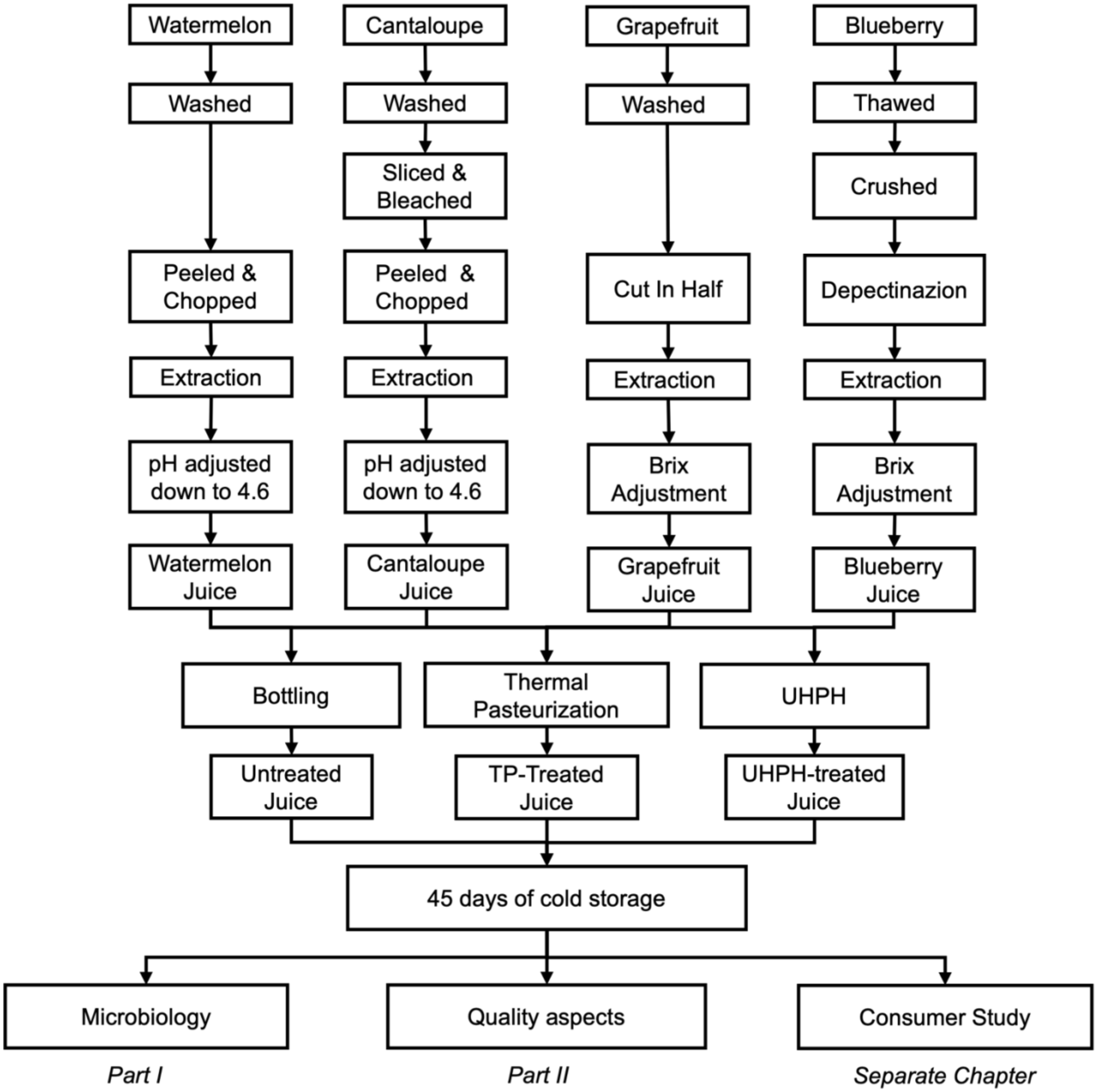


Figure 4.1 Overview of the production and analysis of watermelon, cantaloupe, blueberry, and grapefruit juice samples.

Table 4.1 Log reduction of *E. coli* K12 in watermelon juice (WJ), cantaloupe juice (CJ), grapefruit juice (GJ), and blueberry juice (BJ) following UHPH treatments on general (TSAYE) and selective (MAC) media.

T_{in} (°C)	P (MPa)	FL (L/min)	Log Reduction of *E. coli* K12 on TSAYE *(Log N/N₀)*				Log Reduction of *E. coli* K12 on MAC *(Log N/N₀)*			
			WJ	CJ	GJ	BJ	WJ	CJ	GJ	BJ
4	200	0.75	3.89 ± 2.54^{abc}	4.56 ± 2.81^{ab}	4.20 ± 2.70^{ab}	3.90 ± 2.90^{ab}	5.00 ± 3.10^{abc}	5.44 ± 3.63^{ab}	5.10 ± 3.40^{ab}	4.80 ± 3.50^{ab}
		1.125	3.80 ± 0.35^{ab}	3.02 ± 1.49^{a}	3.50 ± 0.80^{a}	3.00 ± 1.60^{a}	3.95 ± 0.59^{ab}	3.19 ± 1.52^{a}	3.70 ± 0.80^{a}	3.20 ± 1.40^{a}
		1.5	3.26 ± 2.09^{a}	3.95 ± 0.59^{a}	3.00 ± 2.00^{a}	2.80 ± 1.00^{a}	3.08 ± 2.24^{a}	3.95 ± 0.64^{a}	3.50 ± 2.10^{a}	3.30 ± 1.00^{a}
	250	0.75	6.31 ± 1.56^{de}	4.77 ± 2.76^{ab}	6.50 ± 2.30^{c}	6.00 ± 2.90^{bc}	$>7.00 \pm 0.00^{de}$	5.38 ± 3.71^{ab}	$>7.00 \pm 0.20^{bc}$	$>7.00 \pm 0.40^{bc}$
		1.125	6.07 ± 1.68^{cde}	6.50 ± 0.73^{a}	6.00 ± 1.50^{bc}	5.60 ± 1.00^{bc}	$>7.00 \pm 1.26^{cde}$	$>7.00 \pm 0.10^{b}$	$>7.00 \pm 0.20^{bc}$	6.90 ± 0.30^{bc}
		1.5	5.63 ± 2.13^{bcde}	6.27 ± 0.38^{a}	5.80 ± 2.20^{bc}	5.50 ± 0.60^{bc}	6.69 ± 2.26^{bcde}	$>7.00 \pm 0.10^{b}$	6.60 ± 0.30^{bc}	6.30 ± 0.30^{bc}
	300	0.75	5.01 ± 3.20^{abcd}	6.36 ± 0.26^{b}	6.30 ± 2.80^{c}	5.90 ± 0.50^{c}	5.84 ± 3.74^{abcd}	$>7.00 \pm 0.10^{b}$	7.00 ± 0.50^{c}	$>7.00 \pm 0.30^{c}$
		1.125	6.97 ± 1.79^{de}	6.28 ± 0.37^{b}	6.80 ± 1.50^{c}	6.40 ± 0.50^{c}	$>7.00 \pm 0.10^{de}$	$>7.00 \pm 0.10^{b}$	$>7.00 \pm 0.50^{c}$	$>7.00 \pm 0.30^{c}$
		1.5	6.76 ± 1.45^{de}	5.36 ± 1.67^{ab}	6.50 ± 1.50^{c}	6.20 ± 1.80^{bc}	$>7.00 \pm 0.15^{de}$	6.37 ± 2.31^{ab}	$>7.00 \pm 0.30^{c}$	$>7.00 \pm 2.10^{bc}$
22	200	0.75	$>7.00 \pm 0.45^{e}$	6.82 ± 0.43^{b}	$>7.00 \pm 0.60^{c}$	$>7.00 \pm 0.50^{c}$	$>7.00 \pm 0.10^{e}$	$>7.00 \pm 0.10^{b}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.20^{c}$
		1.125	$>7.00 \pm 0.68^{de}$	6.97 ± 0.89^{b}	$>7.00 \pm 0.80^{c}$	$>7.00 \pm 0.90^{c}$	$>7.00 \pm 1.18^{de}$	$>7.00 \pm 0.10^{b}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.30^{c}$
		1.5	$>7.00 \pm 0.79^{de}$	$>7.00 \pm 0.85^{b}$	$>7.00 \pm 0.80^{c}$	$>7.00 \pm 0.90^{c}$	$>7.00 \pm 0.83^{de}$	$>7.00 \pm 0.70^{b}$	$>7.00 \pm 0.80^{c}$	$>7.00 \pm 0.70^{c}$
	250	0.75	6.33 ± 0.79^{de}	$>7.00 \pm 0.75^{b}$	$>7.00 \pm 0.90^{c}$	6.80 ± 0.80^{c}	$>7.00 \pm 0.10^{de}$	$>7.00 \pm 0.10^{b}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.10^{c}$
		1.125	$>7.00 \pm 0.10^{e}$	6.87 ± 1.00^{b}	$>7.00 \pm 0.30^{c}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.10^{e}$	$>7.00 \pm 0.10^{b}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.10^{c}$
		1.5	$>7.00 \pm 0.82^{e}$	$>7.00 \pm 0.68^{b}$	$>7.00 \pm 0.80^{c}$	$>7.00 \pm 0.70^{c}$	$>7.00 \pm 0.10^{e}$	$>7.00 \pm 0.10^{b}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.10^{c}$
	300	0.75	$>7.00 \pm 0.00^{e}$	$>7.00 \pm 0.79^{b}$	$>7.00 \pm 0.30^{c}$	$>7.00 \pm 0.70^{c}$	$>7.00 \pm 0.10^{e}$	$>7.00 \pm 0.10^{b}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.10^{c}$
		1.125	$>7.00 \pm 0.65^{e}$	$>7.00 \pm 0.85^{b}$	$>7.00 \pm 0.70^{c}$	$>7.00 \pm 0.90^{c}$	$>7.00 \pm 0.10^{e}$	$>7.00 \pm 0.10^{b}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.10^{c}$
		1.5	$>7.00 \pm 0.45^{e}$	$>7.00 \pm 0.58^{b}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.10^{e}$	$>7.00 \pm 0.10^{b}$	$>7.00 \pm 0.10^{c}$	$>7.00 \pm 0.10^{c}$

Mean log reductions (n=3) with standard deviations (SD), based on the enumeration of *E. coli* K12 on two media: TSAYE (Tryptic Soy Agar with Yeast Extract) and MAC (MacConkey Agar). Sharing the same letters within each column indicates the absence of significant differences according to Tukey's HSD test. For calculations, *E. coli* counts below the limit of detection (LOD) were considered as 10 CFU/mL.

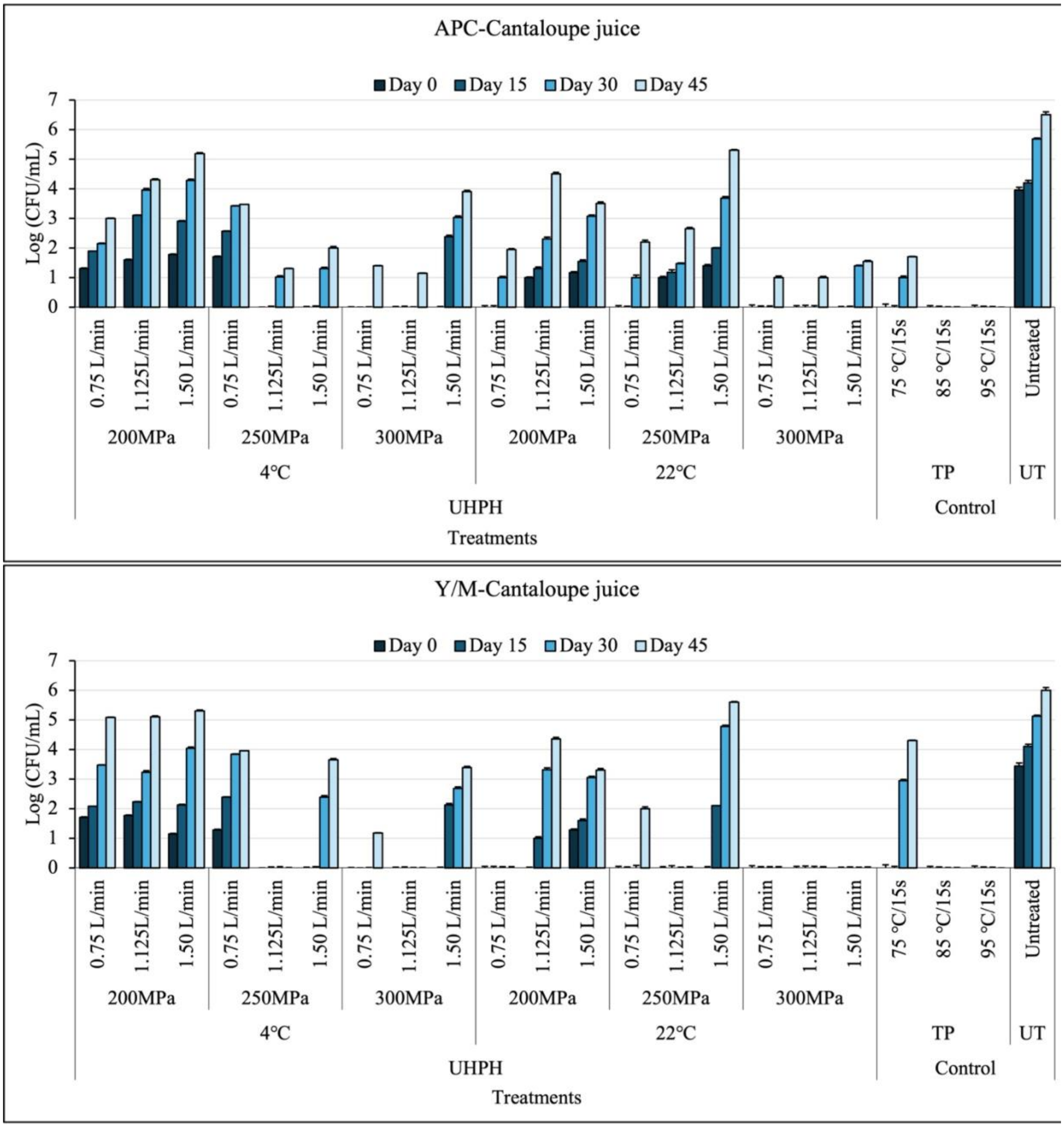


Figure 4.2 Microbicidal effects of UHPH and HTST on total aerobic plate count population (PCA) and yeast and mold (Y/M) in cantaloupe juice during 45 days of storage at 4 ºC. The data are provided as mean value ± standard deviation (n = 3). LOD: 1 Log CFU/mL

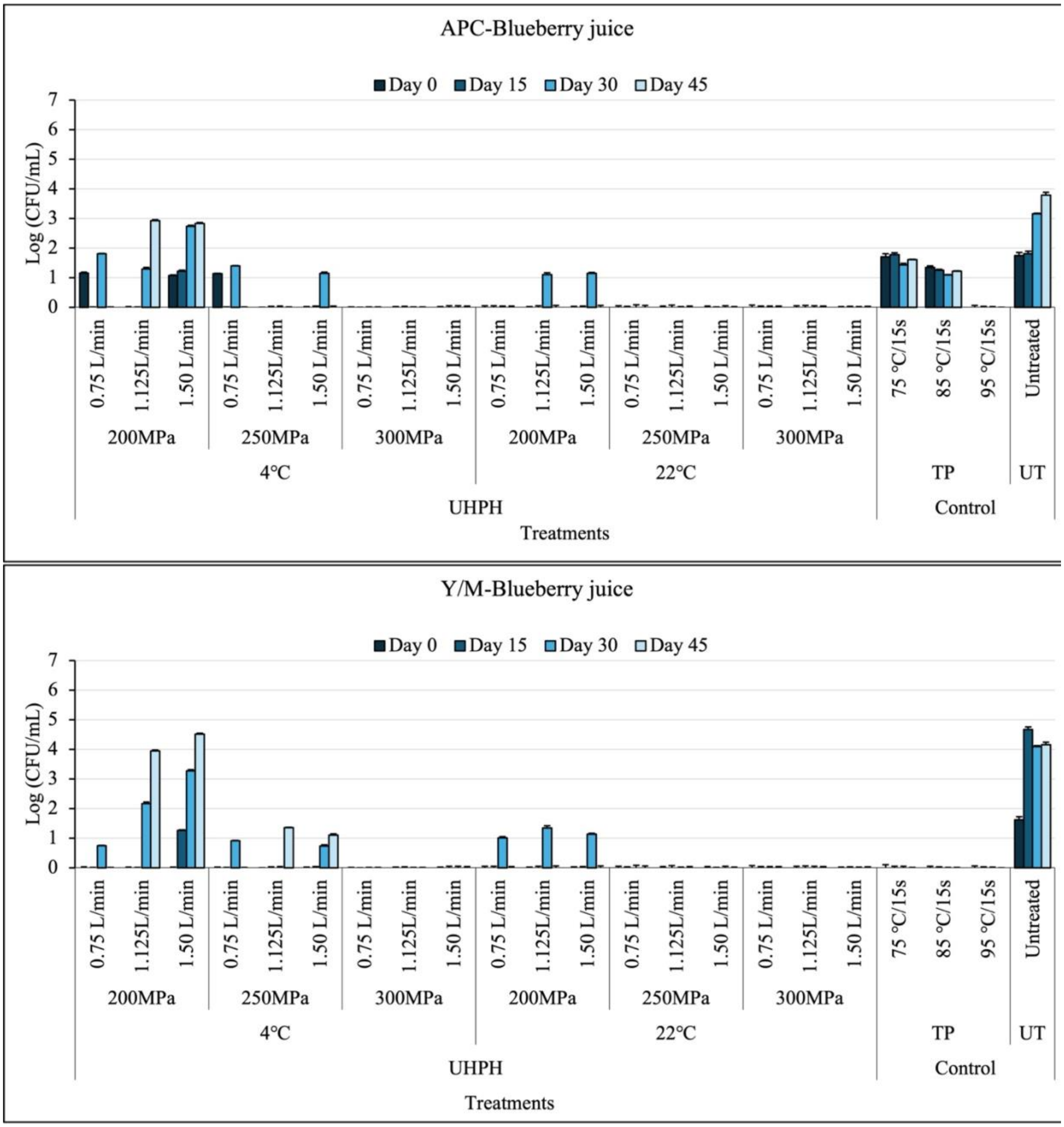
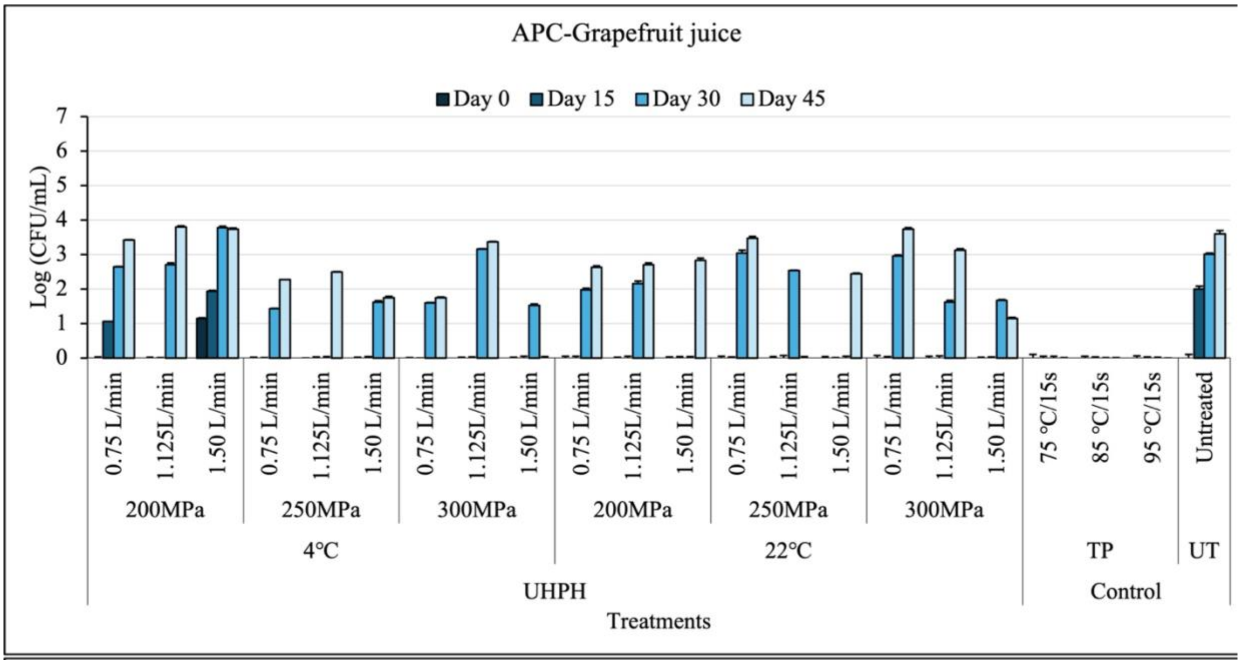


Figure 4.3 Microbicidal effects of UHPH and HTST on total aerobic plate count population (PCA) and yeast and mold (Y/M) in blueberry juice during 45 days of storage at 4 ºC. The data are provided as mean value ± standard deviation (n = 3). LOD: 1 Log CFU/mL



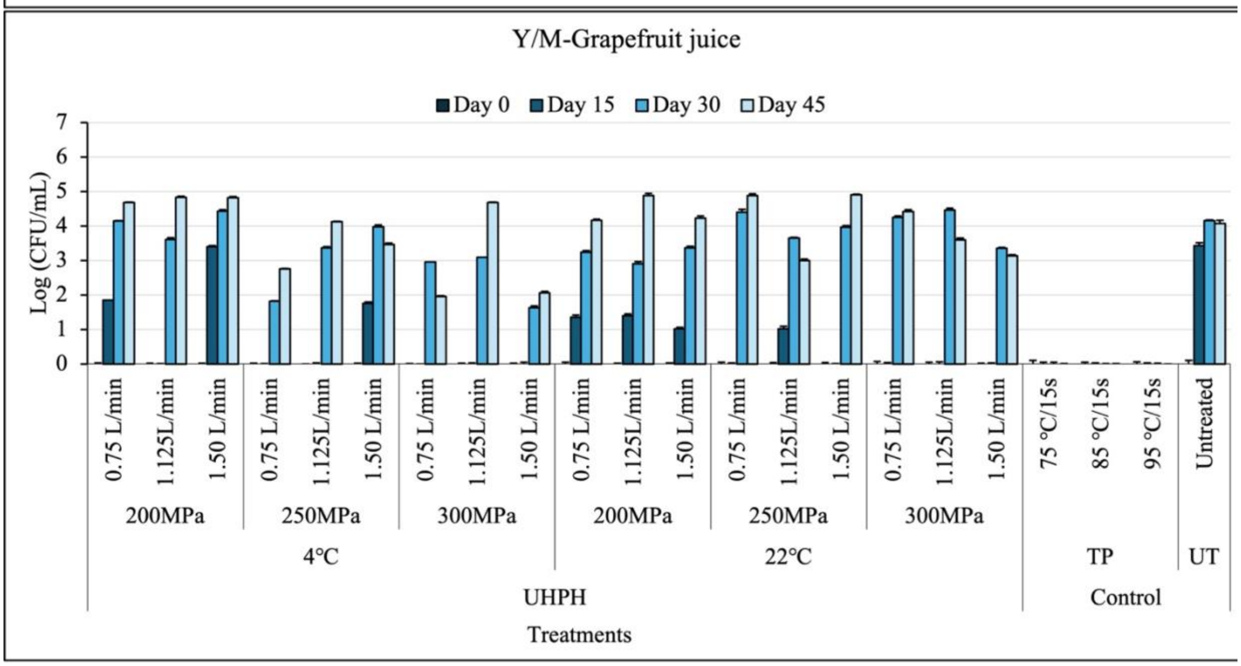


Figure 4.4 Microbicidal effects of UHPH and HTST on total aerobic plate count population (PCA) and yeast and mold (Y/M) in grapefruit juice during 45 days of storage at 4 ºC. The data are provided as mean value ± standard deviation (n = 3). LOD: 1 Log CFU/mL.

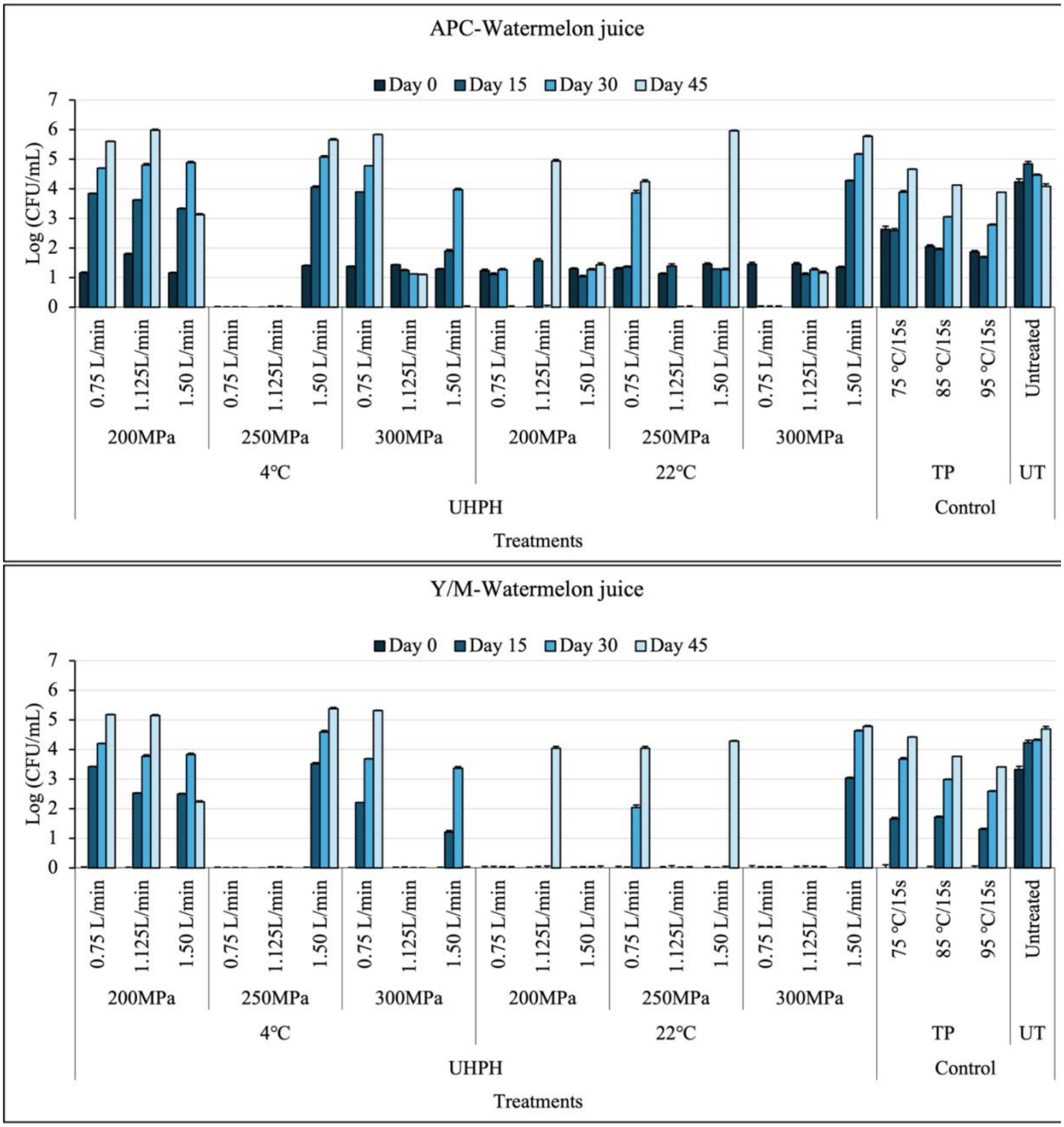


Figure 4.5 Microbicidal effects of UHPH and on total aerobic plate count population (PCA) and yeast and mold (Y/M) in watermelon juice during 45 days of storage at 4 ºC. The data are provided as mean value ± standard deviation (n = 3). LOD: 1 Log CFU/mL

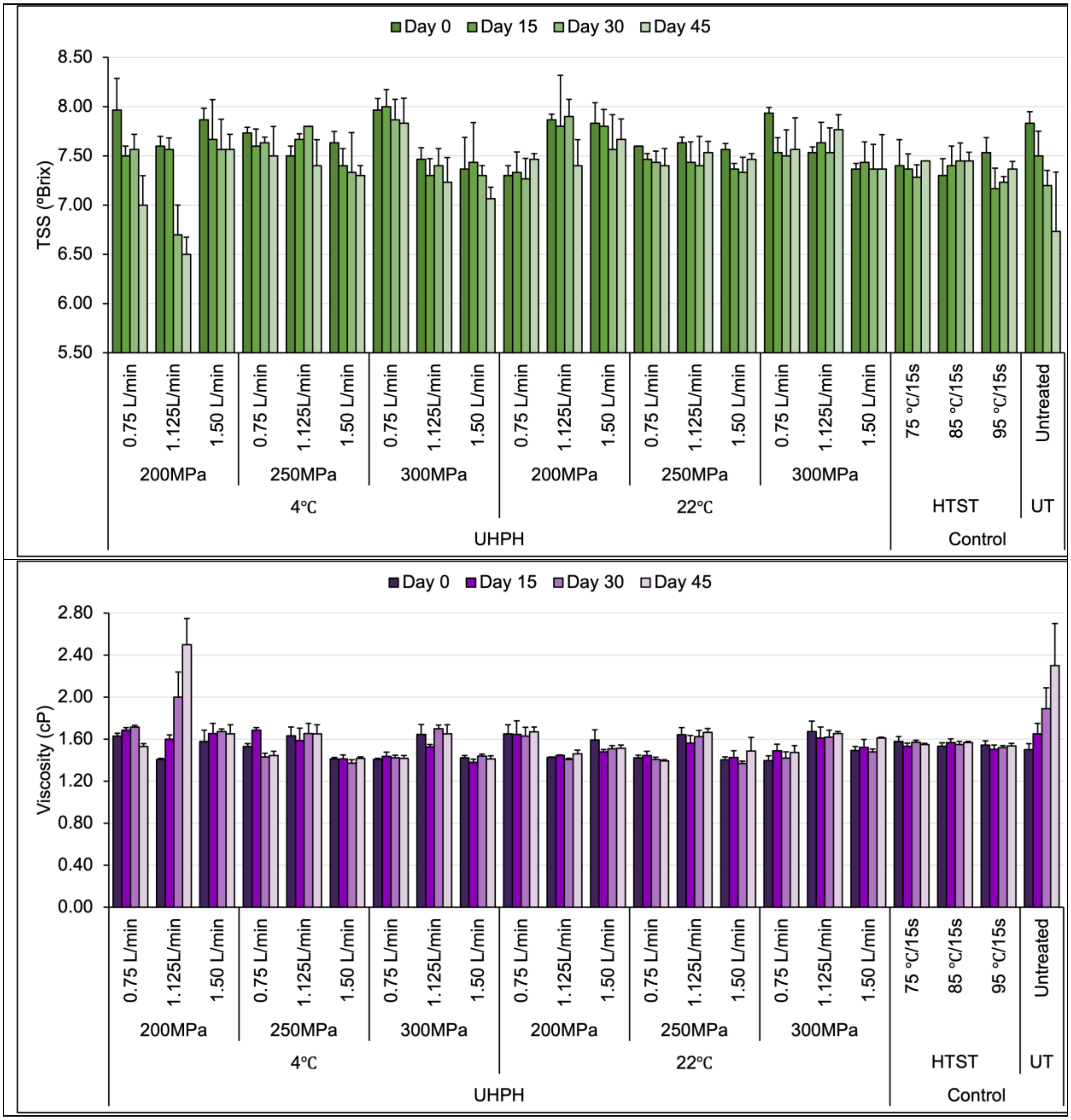


Figure 4.6 Evolution of total soluble solids (TSS), viscosity of untreated and treated cantaloupe juice during 45 days of storage at 4°C. Mean (n=3) ± SD.

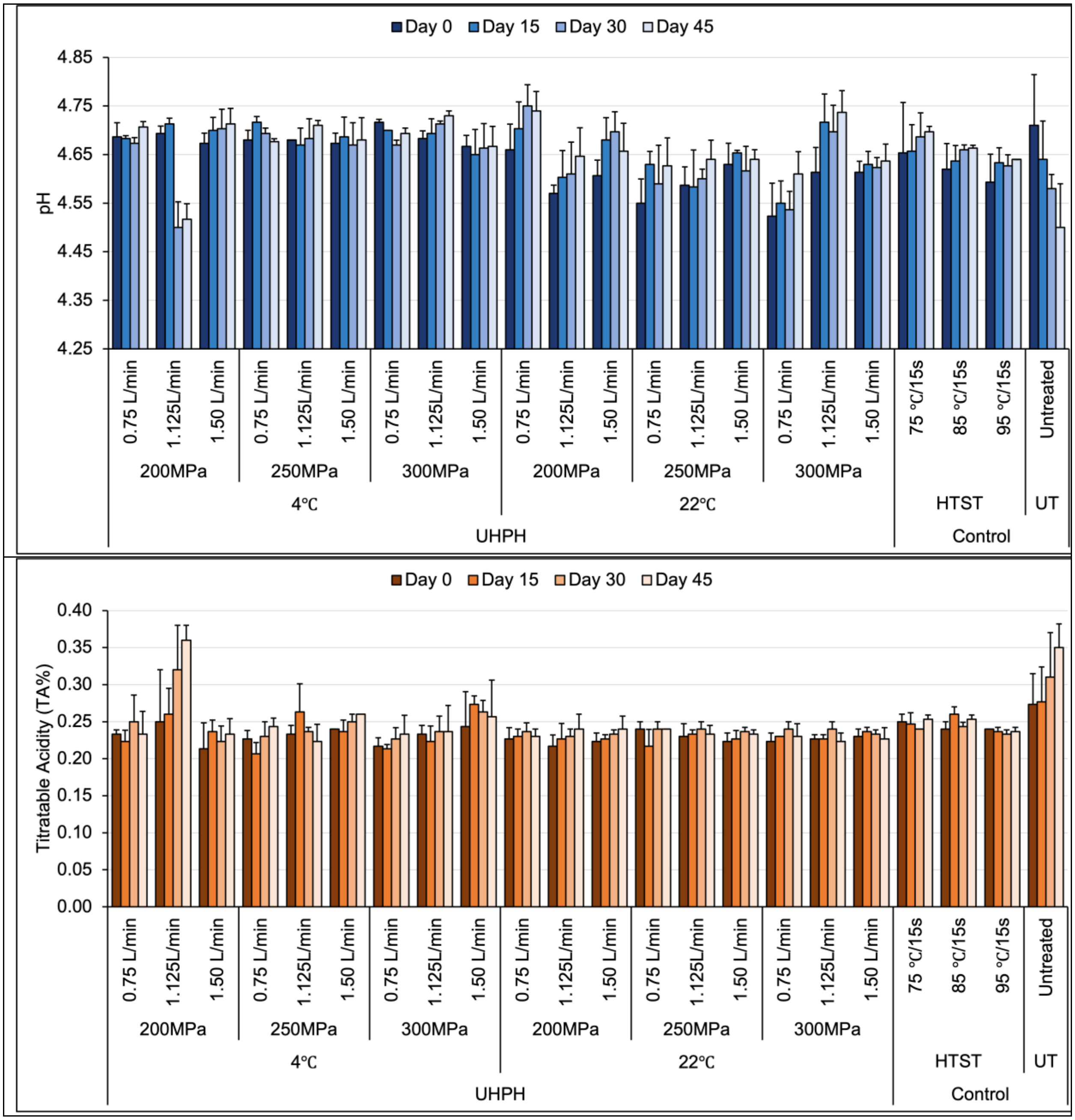


Figure 4.7 Evolution of pH, and titratable acidity (TA%) of untreated and treated cantaloupe juice during 45 days of storage at 4°C. Mean (n=3) ± SD.

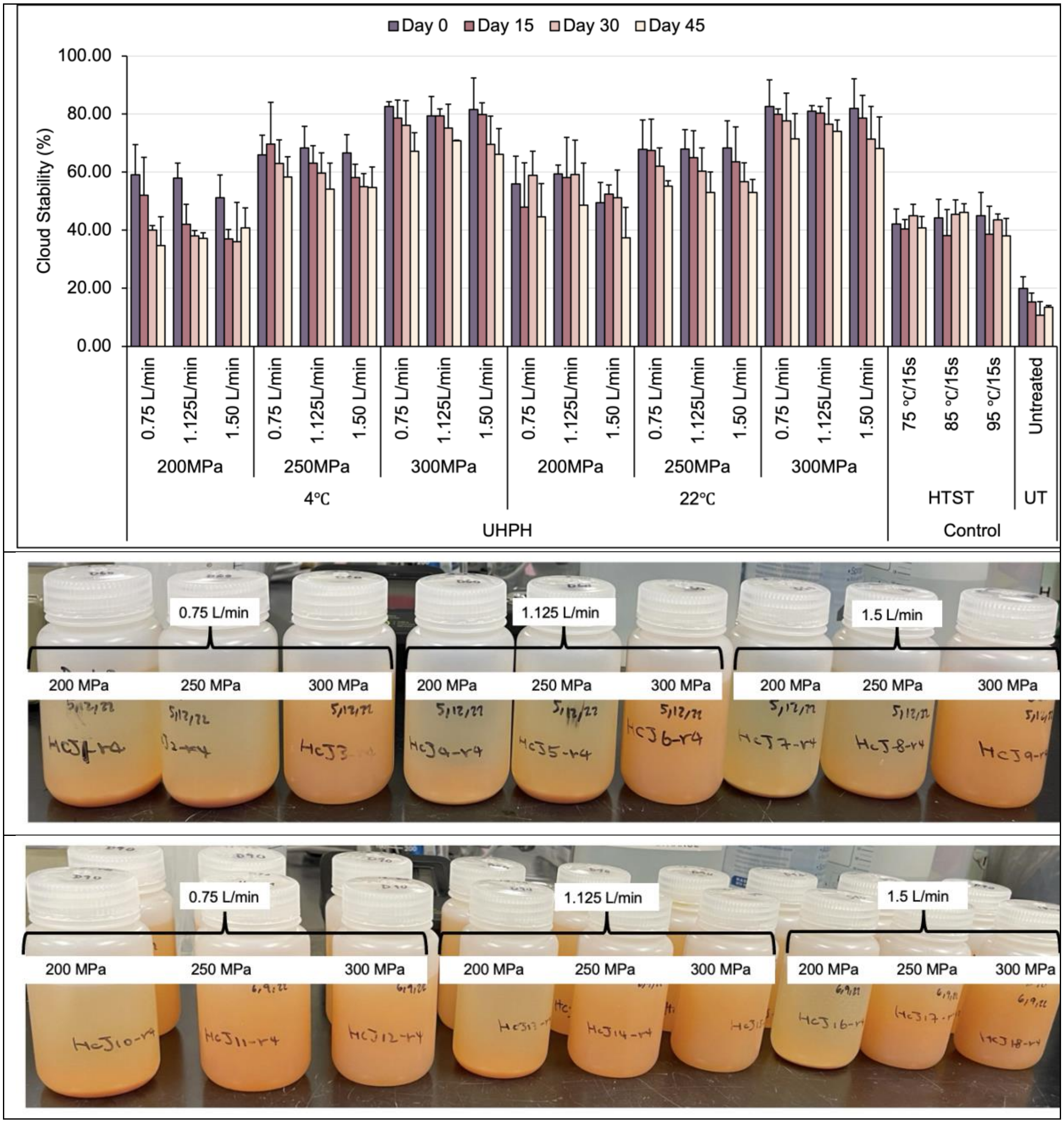


Figure 4.8 Effect of UHPH at different pressure, flow rate, and inlet temperatures of 4°C (top) and 22°C (bottom) on the cloud stability of cantaloupe juice after 90 days of storage at 4°C.

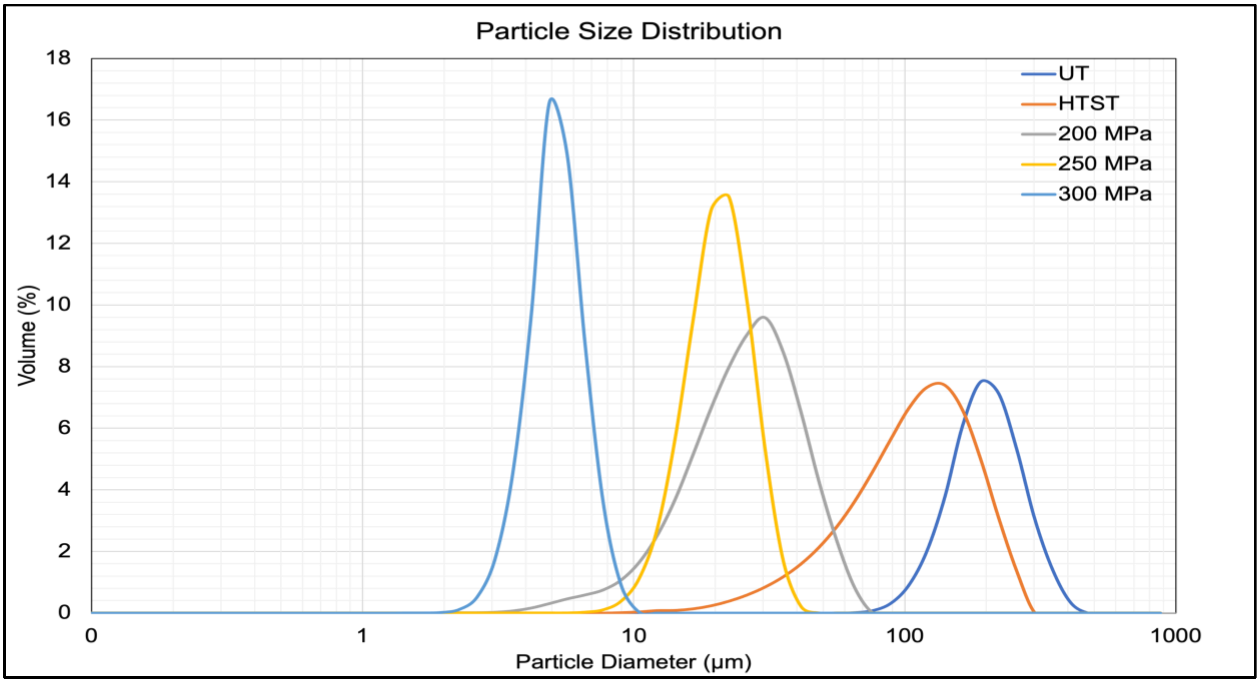


Figure 4.9 Influence of UHPH and HTST on turbidity (A) and particle size distribution(B) of cantaloupe juice during 45 days of storage at 4 ºC.

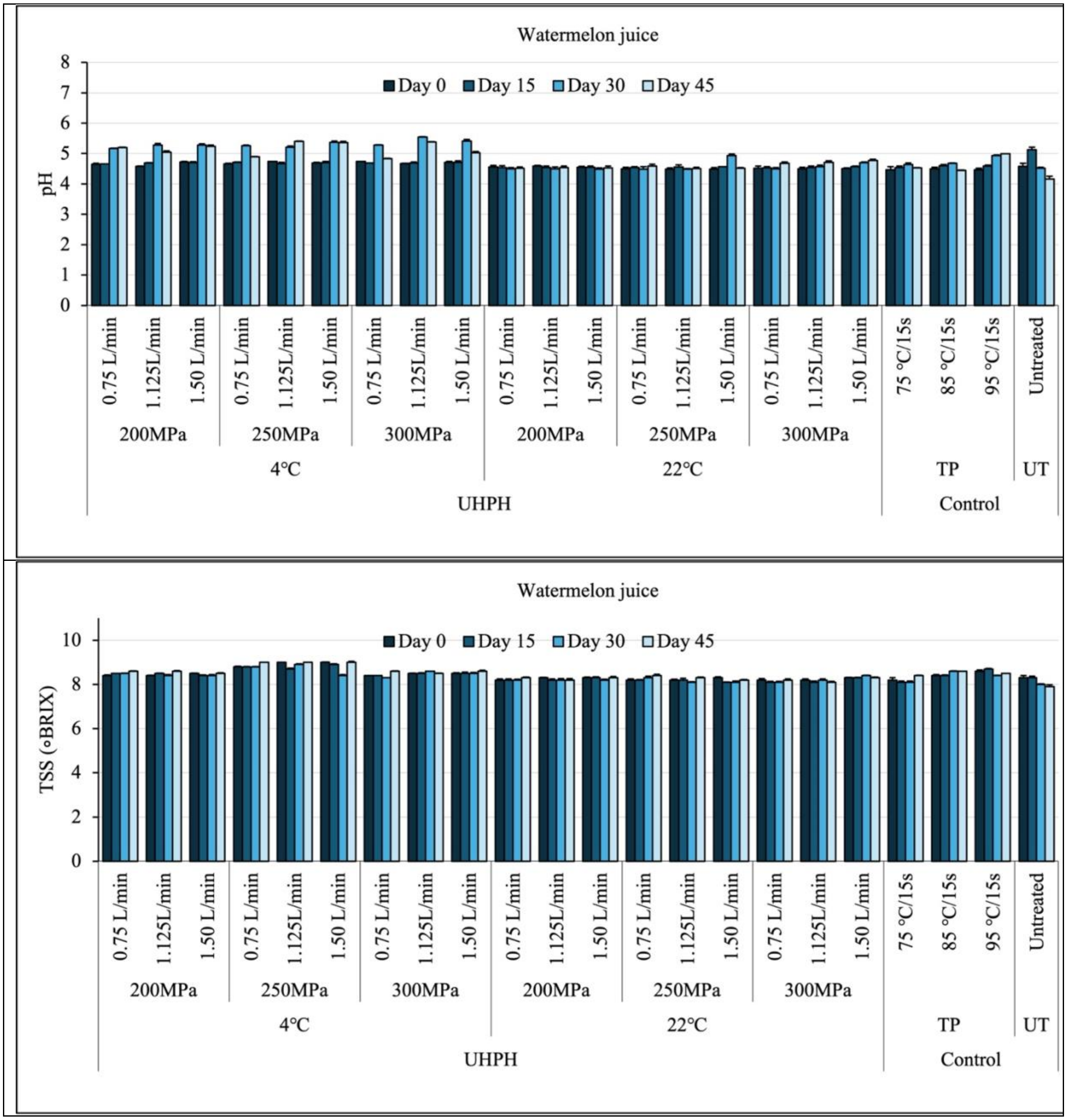


Figure 4.10 Evolution of pH, and TSS of untreated and treated watermelon juice during 45 days of storage at 4°C. Mean (n=3) ± SD.

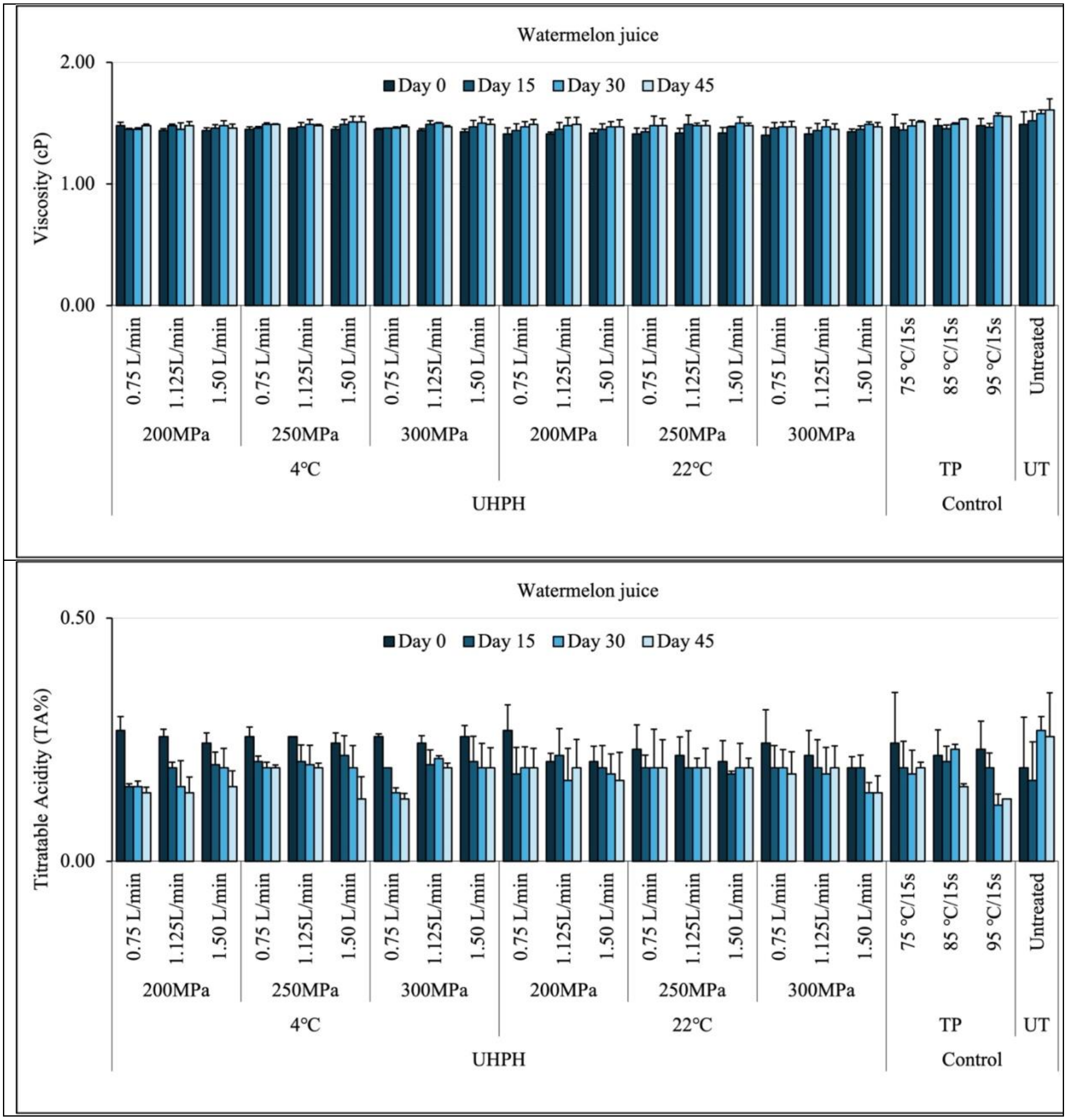


Figure 4.11 Evolution of viscosity and TA of untreated and treated watermelon juice during 45 days of storage at 4°C. Mean (n=3) ± SD.

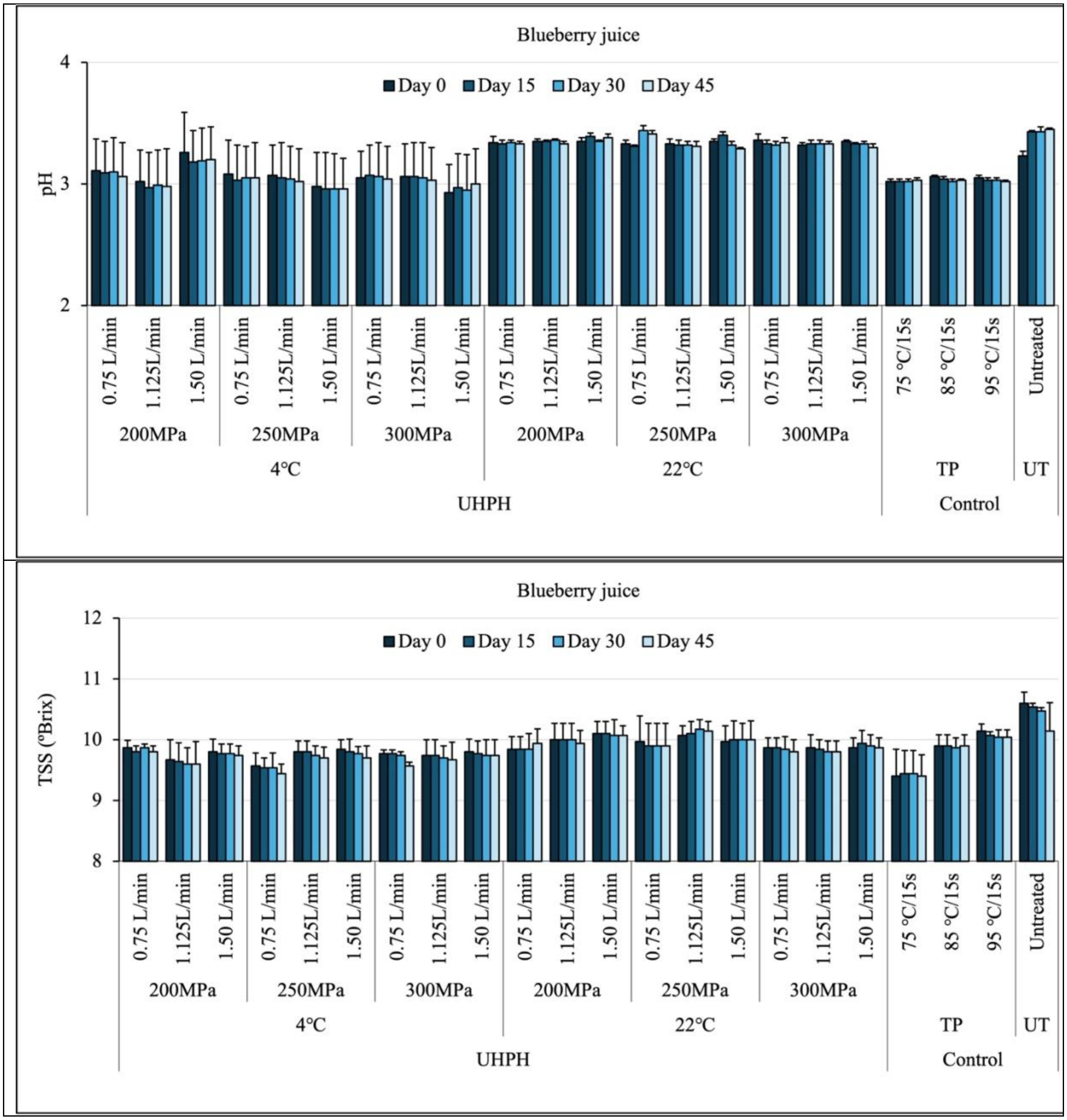


Figure 4.12 Evolution of pH, and TSS of untreated and treated blueberry juice during 45 days of storage at 4°C. Mean (n=3) ± SD.

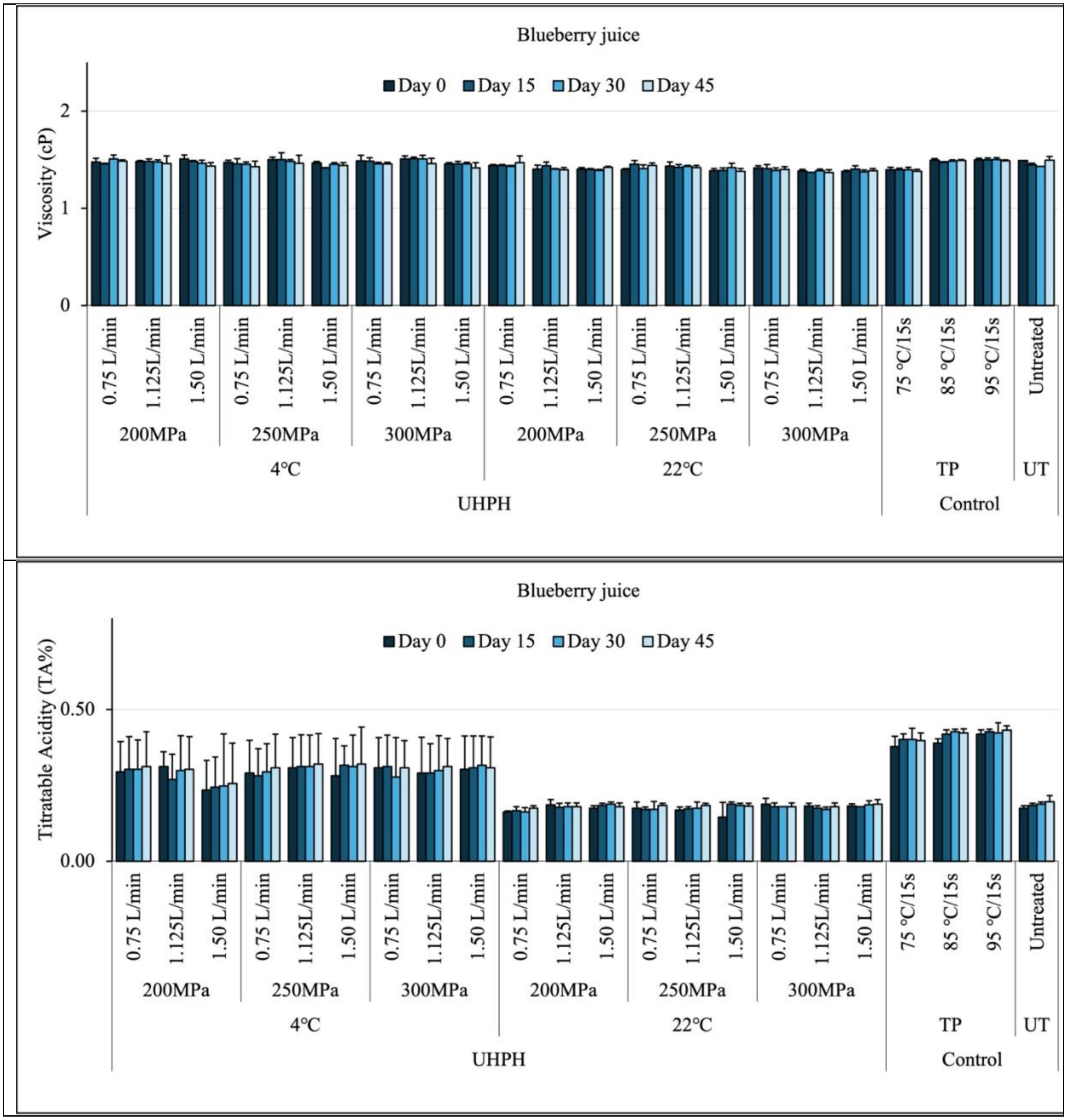


Figure 4.13 Evolution of viscosity and TA of untreated and treated blueberry juice during 45 days of storage at 4°C. Mean (n=3) ± SD.

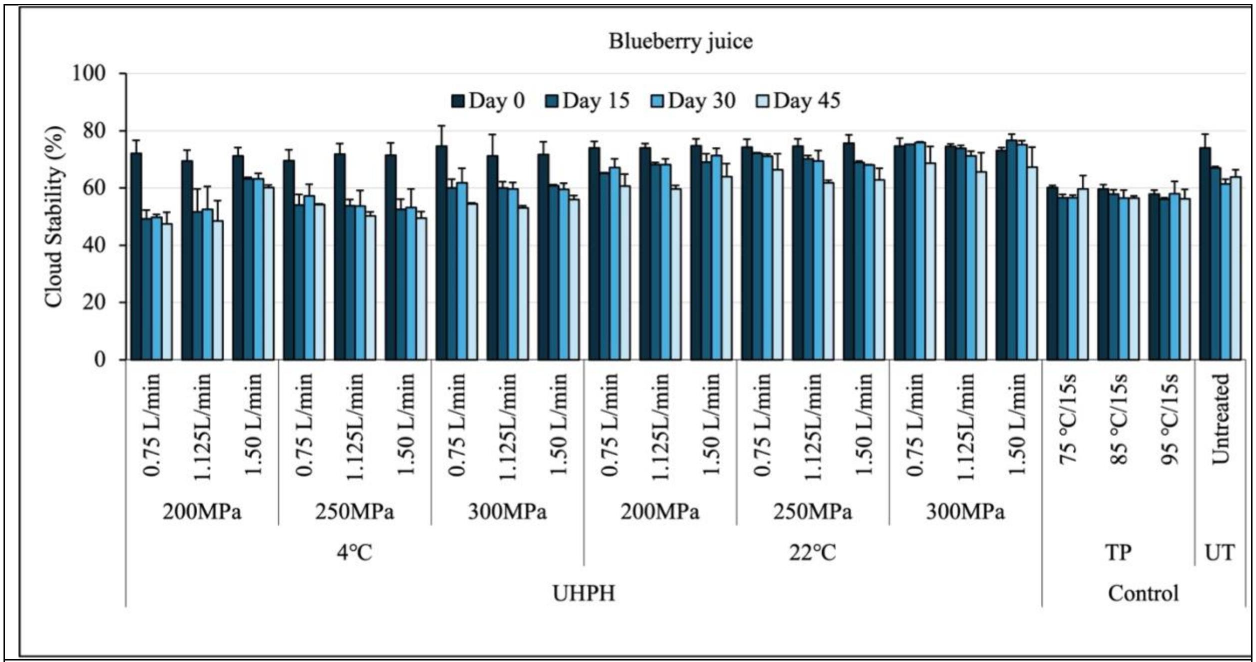


Figure 4.14 Evolution of turbidity of untreated and treated blueberry juice during 45 days of storage at 4°C. Mean (n=3) ± SD.

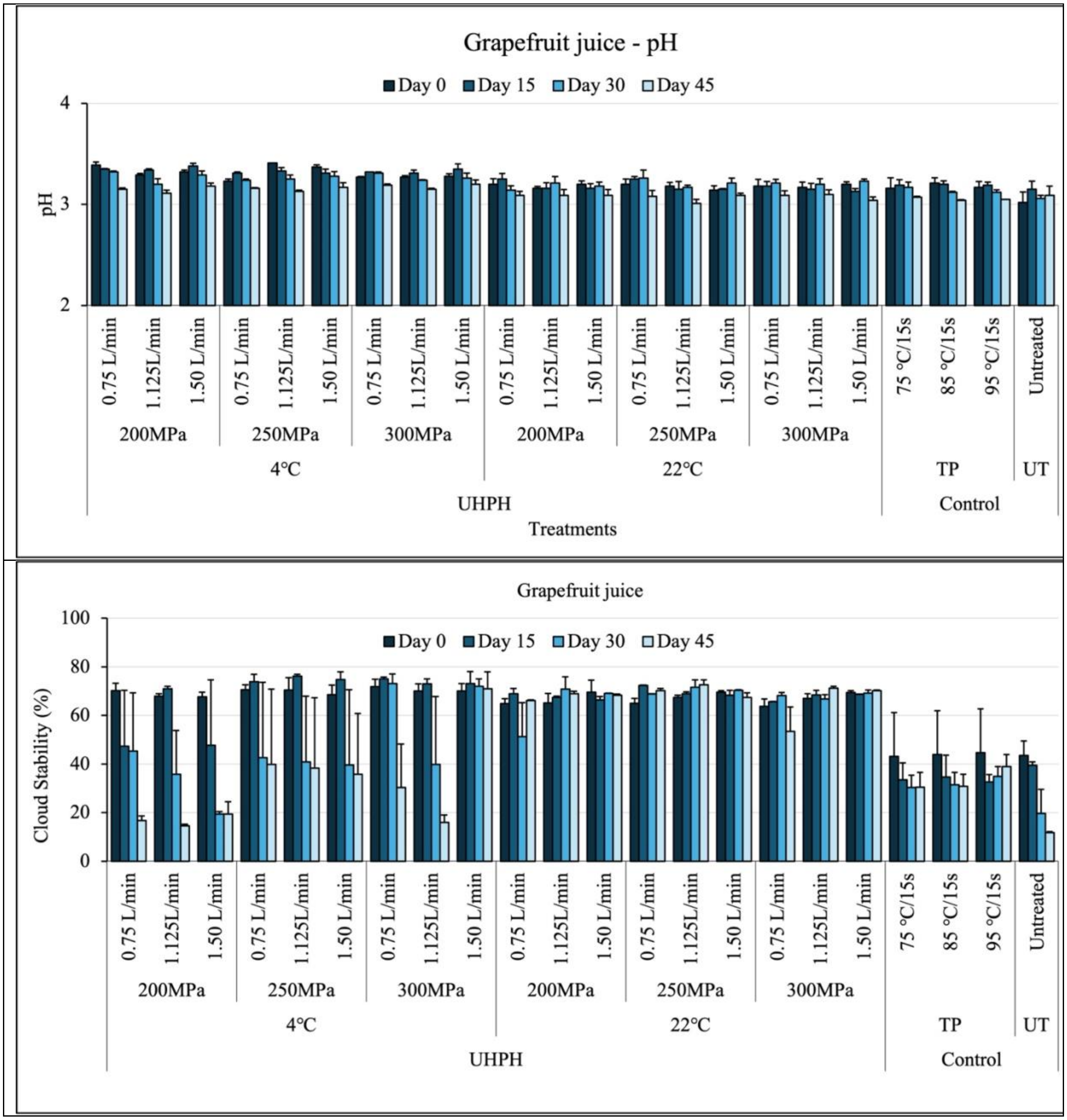


Figure 4.14 Evolution of pH and cloud stability of untreated and treated blueberry juice during 45 days of storage at 4°C. Mean (n=3) ± SD.

CHAPTER 5

IMPACT OF ULTRA-HIGH-PRESSURE HOMOGENIZATION ON CONSUMER ACCEPTANCE OF SEVERAL FRUIT JUICES: A COMPARATIVE ANALYSIS WITH THERMAL PASTEURIZATION[1]

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[1]Rahimi Araghi, L., Adhikari, K., Patil, B.S., Singh, R.K. To be submitted to *FRI (Elsevier)*.

Abstract

The sensory attributes of fruit juices are critical in determining consumer preference and marketability. This study investigates the potential of ultra-high-pressure Homogenization (UHPH) to preserve 'fresh-like' sensory qualities in fruit juices and its influence on consumer acceptance. UHPH-treated watermelon, blueberry, cantaloupe, and grapefruit juices were evaluated against conventional thermal pasteurization – High Temperature Short Time (HTST) and untreated (UT) controls, using sensory panels of approximately 120 consumers per juice type. Attributes such as appearance, flavor, mouthfeel, aftertaste, and overall liking were assessed. UHPH consistently preserved sensory attributes more effectively than HTST. UHPH-treated samples, mainly watermelon, cantaloupe, and grapefruit juices, received higher consumer acceptance scores, whereas HTST-treated juices were rated lower.

Further analysis through Principal Component Analysis (PCA) and penalty analysis confirmed that UHPH treatments closely resembled UT samples in all four juices, maintaining key sensory qualities with minimal impact. Blueberry juice showed resilience across both UHPH and HTST treatments, while UHPH enhanced the balance of sweet and sour flavors in grapefruit juice. Treatments using higher inlet temperatures (22°C) combined with higher pressures (250 and 300 MPa) and moderate to high flow rates (1.125 and 1.5 L/min) led to superior sensory qualities. These findings suggest that UHPH effectively maintains 'fresh-like' sensory attributes, which are increasingly favored by consumers, making it a viable non-thermal alternative to conventional thermal treatment, aligning with modern consumer preferences for high-quality, minimally processed beverages.

Introduction

Thermal processing methods, such as pasteurization, have been widely employed in the food industry to inactivate microorganisms and ensure the safety of fruit juices. However, this processing method often leads to the degradation of essential nutrients, sensory attributes, and bioactive compounds, negatively impacting both the health benefits and consumer acceptability of these products (Kruszewski et al., 2023; Lima & Rosenthal, 2023). Specifically, heat treatments can cause significant alterations in the flavor, appearance, texture, and mouthfeel of fruit juices, as well as reduce the bioavailability of heat-sensitive bioactive compounds, which are essential for promoting human health (Niu et al., 2022; Rawson et al., 2011). Consequently, the food industry is actively seeking alternative technologies that can preserve both the nutritional value and sensory qualities of fruit juices while maintaining their microbiological safety (Hinestroza-Córdoba et al., 2021).

In recent years, non-thermal processing technologies have emerged as promising alternatives to traditional thermal treatments. Among these, Ultra-High-Pressure Homogenization (UHPH) has gained significant attention due to its ability to preserve the sensory and nutritional qualities of fruit juices more effectively than thermal pasteurization (Jiménez-Sánchez et al., 2017; Patrignani et al., 2019). UHPH works by reducing particle size and improving the homogeneity of the juice, leading to better preservation of flavor, color, and texture, which are critical to consumer acceptance (Joly et al., 2022; Martínez-Sánchez et al., 2016). Furthermore, UHPH has been shown to inactivate spoilage microorganisms without the adverse effects associated with heat treatments, such as the loss of vitamins and antioxidants (Moisés et al., 2022; Zamora & Guamis, 2015).

The growing consumer demand for minimally processed, fresh-tasting, and nutritious beverages has further driven the exploration of UHPH as a viable alternative to thermal processing

(Adhikari, Araghi, et al., 2024; Ravichandran et al., 2023; Waghmare, 2024). Health-conscious consumers increasingly seeking products that retain their "fresh-like" sensory qualities, including the natural taste, color, and texture associated with freshly squeezed juice, while providing extended shelf life (Patrignani et al., 2019; Salehi, 2020). UHPH technology aligns well with these market trends, offering producers a way to meet consumer preferences while maintaining product safety and quality (Marszałek et al., 2023). Despite growing consumer awareness of the health benefits of fruit products, the primary reason for purchasing these items remains sensory acceptance, even for functional products claiming health advantages (Skąpska et al., 2020).

UHPH has been found to preserve the natural appearance of juices, aligning with consumer preferences for clean-label products (Sentandreu et al., 2020; Zamora & Guamis, 2015). The preservation of natural color is a key factor in consumer acceptance, enhancing the visual appeal of the product (Adhikari, Singh, et al., 2024; Szczepańska et al., 2022). UHPH processing reduces particle size, leading to a smoother texture and improved mouthfeel, as supported by studies that found these characteristics to be desirable in beverages like plant-based milk (He & Xu, 2024). Similarly, plant-based milk products processed with UHPH exhibited enhanced sensory qualities, including increased lightness and viscosity, contributing to higher consumer acceptance, particularly for adzuki bean and oat-based variants (He & Xu, 2024).

This study aims to evaluate the effects of UHPH on the consumer acceptance of watermelon, cantaloupe, blueberry, and grapefruit juices by comparing UHPH treatments with conventional thermal pasteurization - High Temperature Short Time (HTST) and untreated control (UT) samples. The objective of this project was to assess the impact of four different UHPH treatment combinations, varying in pressure (200, 250, 300 MPa), inlet temperature (4°C, 22°C), and flow rate (0.75, 1.125, 1.5 L/min), on the consumer acceptance of these juices, and to compare them with HTST (85°C for 15 s) and UT samples.

A set of six samples was presented to approximately 120 untrained consumers for each juice type. They rated their overall liking, as well as their liking of appearance, flavor, mouthfeel, and aftertaste, using a 9-point hedonic scale. Freshness and naturalness were rated on a 9-point interval scale, while the ideal intensities of prominent attributes were assessed using a 5-point Just-About-Right (JAR) scale. The study also gathered data on consumer purchase intent, demographic information, and opinions on minimally processed juices. This research provides insights into consumer acceptance of UHPH-treated fruit juices, contributing to the scientific understanding of how UHPH compares to HTST and UT in terms of consumer acceptability. It is hypothesized that UHPH can preserve "fresh-like" and "natural-like" sensory attributes more effectively than HTST, resulting in consumer acceptance and liking scores comparable to those of UT samples.

Materials and Methods

Fruit Juice Preparation

The juice preparation process was standardized for the different fruits studied: watermelon, blueberry, cantaloupe, and grapefruit. Below are the details for each juice type:

Watermelon juice: Locally grown Georgia Troubadour seedless watermelons (Citrullus lanatus var. ‘Troubadour’) were sourced from the Department of Horticulture at the University of Georgia (Tifton, GA, USA). The watermelons were washed, the rinds removed, and the flesh cut into pieces, and comminuted using a chopper (Model 4612, Hobart Corp., Troy, OH, USA) to prepare for juice extraction.

Blueberry juice: Frozen Rabbiteye blueberries (Vaccinium virgatum var. ‘Rabbiteye’) were obtained from a local farmer in Georgia (Farmer John, LLC, Alma, GA, USA). The berries were thawed and macerated using a commercial chopper (Model 4612 by Hobart Corp. Troy, OH). To enhance juice extraction, blueberries were treated with pectinase (Pectinex Ultra SP-L, Novozymes A/S, Switzerland, distributed by Sigma-Aldrich in St. Louis, MO, USA) at a rate of 0.0827 mL/Kg of juice. The mixture was allowed to rest for one hour at 35°C before further processing.

Cantaloupe juice: Minerva cantaloupes (*Cucumis melo* var. 'Minerva') were sourced from the University of Georgia's horticulture department (Tifton, GA, USA). The cantaloupes were washed, halved, deseeded, and cut into 1-inch slices. The slices were blanched in boiling water for two minutes, followed by rapid cooling in an ice bath. The rinds were removed, and the fruit was chopped using a chopper (Model 4612, Hobart Corp., Troy, OH, USA).

Grapefruit juice: Ruby Red grapefruits (Citrus paradisi var. ‘Ruby Red’) were sourced from local grocery stores (Walmart Inc., Athens, GA, USA). The fruits were thoroughly washed, halved, and juiced using a commercial citrus juicer (Waring Commercial, New Hartford, CT, USA).

Fruit Juice Extraction

After the initial processing, all fruit juices were pressed using a hydraulic bladder press (Speidel Tank- und Behälterbau GmbH, Ofterdingen, Germany) lined with a 6-layer grade-90 cheesecloth to remove pulp. The pH of the watermelon and cantaloupe juices was adjusted down to 4.60 ± 0.10 using citric acid (0.1% w/v), reducing the pH from 5.2 and 6.0, respectively. Citric acid was used as an acidity regulator, and this adjustment ensured taste uniformity and food safety.

All juices' sugar content (ºBrix) was standardized to meet industry specifications in alignment with Codex standards.

Processing treatments

This study previously explored the effects of untreated, HTST, and UHPH techniques on the quality of fruit juices over 45 days of refrigerated storage (data not shown). UHPH conditions varied across three pressures (200, 250, 300 MPa), two inlet temperatures (4 or 22ºC), and three flow rates (0.75, 1.125, 1.5 L/min). These conditions resulted in exit temperatures ranging from 53ºC to 83ºC, with residence times between 10 and 20 seconds. UHPH treatments were conducted using a pilot-scale dual-intensifier continuous high-pressure homogenizer (Stansted nm-gen 7900, Stansted Fluid Power, Stansted, England) equipped with a Micro-metering needle valve (Model 60VRMM4882, Autoclave Engineers, Fluid Components, Erie, PA, USA). Thermal pasteurization was conducted at three temperatures (75°C, 85°C, and 95°C) for 15 seconds using a pilot-scale HTST pasteurizer (MicroThermics model: E-Veros DH, Raleigh, NC, USA). The juice, initially at 10°C, was preheated to the desired pasteurization temperature before passing through a holding tube calibrated to maintain precise temperature and residence time. After the 15-second holding period, the juice was rapidly cooled back to 10°C using an integrated cooling system to minimize thermal degradation and preserve sensory and nutritional qualities. The system's tubular heat exchanger ensured consistent and uniform heating and cooling across all treatments.

Based on the results of the previous quality analysis (Adhikari, Araghi, et al., 2024; Adhikari, Singh, et al., 2024) a subset of six juice samples for each fruit juice were selected for consumer testing. These included one untreated (UT) control, one HTST-treated sample at 85ºC for 15 seconds, and four UHPH-treated samples for each fruit juice type (see Table 1 for treatment combinations). All samples were aseptically filled into 5-liter plastic jugs, refrigerated, and shipped to the UGA Griffin campus for sensory evaluations the following day.

Consumer Acceptability Study

Ethics approval: The consumer acceptability test was reviewed and approved by the University of Georgia's (UGA) Institutional Review Board (IRB; STUDY00006357). On the day of evaluation, written informed consent was obtained from all consumer panelists before they participated in the study.

Participants: Participants, both male and female (Table 2), were recruited from the UGA Sensory Evaluation and Consumer Lab's (Griffin, GA) consumer database. Participants were screened for food allergies and fruit juice consumption using a Qualtrics (qualtrics^{XM}, Seattle, WA) screening questionnaire. All participants were 18 years of age or older.

Sensory evaluation procedure and data collection: The consumer tests were carried out in partitioned individual sensory booths under incandescent lighting at 21 °C. Each session accommodated up to 18 participants, and a total of eight sessions per juice type were conducted over two consecutive days. Sensory data were collected using Compusense20 (Compusense Inc., Guelph, Ontario, Canada), a cloud-based data collection software.

Sample preparation and presentation: All juices were prepared and processed at the UGA Food Processing Research Laboratory (Athens, GA) and transported in ice-filled coolers to the UGA Griffin campus the following day. A randomized 6×6 Williams Latin Square design was used for sample presentation and repeated 21 times to give 126 presentation orders per juice. Each panelist evaluated six samples, served in sequential monadic order. Approximately 30 mL of each juice sample was decanted into 59.1 mL plastic cups with lids (Dart Container Corporation, Mason, MI, USA), coded with 3-digit random numbers, and stored at 4°C until evaluated and served cold (10 °C). Each panelist was provided with deionized water as a palate cleanser between samples.

Consumer test design and ballot: Each participant received detailed oral instructions before entering the sensory booths for testing. Participants were instructed to evaluate the appearance of each sample first, followed by a tasting phase where they rated attributes such as flavor, mouthfeel, aftertaste, and overall liking using a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely). Additional attributes, including naturalness and freshness, were rated using a 9-point interval scale (1 = not at all, 5 = moderate, 9 = extremely). The ideal intensities of prominent attributes, i.e., flavor intensity, sweetness, sourness, and balance of sweet and sour were also assessed using a 5-point Just-About-Right (JAR) scale (1=too little, 3=just-about-right, 5=too much). Participants were asked to indicate their purchase intent on a 5-point scale (1 = definitely no, 3 = maybe, 5 = definitely yes). Demographic information, juice consumption, purchasing motives and habits, natural juice perception, opinion and interest towards minimally processed/functional juices, preference of homogenous or a juice with pulp sediment and consideration as more natural and less processed were collected through a questionnaire after the sensory evaluations were completed.

Statistical analysis

To assess the impact of UHPH and HTST treatments on consumer acceptance, the data were analyzed separately for each fruit juice using a one-way analysis of variance (ANOVA). The level of statistical significance was set at 5%, and Tukey's Honest Significant Difference (HSD) test was applied to identify significant differences between mean scores ($p \leq 0.05$). Penalty analysis was performed on JAR scores to assess how deviations from the ideal sensory intensity (i.e., too little or JAR or too much) affected the overall liking of each sample. Principal Component Analysis (PCA) using the correlation matrix was also performed to explore the relationships between sensory attributes and treatments across different fruit juices. Prior to PCA, the data underwent normalization through Min−Max scaling. Data were averaged across treatments for PCA analysis. Pearson correlations were used to remove cross correlations within the data. Factors one and two were presented in biplots. All statistical analyses were carried out using XLSTAT (2024; Addinsoft, New York City, NY, USA).

Results and Discussion

Effect of UHPH on Sensory Attributes of Fruit Juices

The sensory attributes of watermelon, blueberry, cantaloupe, and grapefruit juices were evaluated, and the results are summarized in Table 3. The sensory attributes evaluated include appearance, flavor, mouthfeel, aftertaste, overall liking, and "fresh-like" qualities (naturalness and freshness). These attributes were assessed across untreated (UT), thermally pasteurized – High Temperature Short Time (HTST), and ultra high-pressure homogenized (UHPH)-treated samples. The results indicate that across the four juices tested, significant differences were observed in the impact of processing methods on flavor, mouthfeel, and overall consumer acceptance, with UHPH-treated samples maintaining scores closer to the UT controls, particularly those at higher inlet temperatures (UHPH3 and UHPH4).

In blueberry juice no significant differences were observed in sensory attributes across the different treatments ($p > 0.05$), indicating that the juice's sensory characteristics were more resilient to both thermal and high-pressure processing methods. The appearance, flavor, and mouthfeel scores for blueberry juice remained relatively stable, with no substantial deviations from the UT control across all treatments. This could be attributed to the specific composition of blueberry juice, making it less susceptible to changes from thermal degradation or high-pressure treatments. Despite losses in volatiles and anthocyanins, Beaulieu et al. (2017) reported that pasteurized blueberry juices retained desirable sensory attributes, with no significant differences in key flavor properties, suggesting that some juices may resist more aggressive processing methods, consistent with the findings of this study (Beaulieu et al., 2017). However, further research is needed to fully understand the underlying factors contributing to this stability across different processing methods.

For watermelon juice, significant differences ($p \leq 0.05$) were observed for appearance liking, flavor liking, mouthfeel liking, aftertaste liking, and overall liking. Flavor and mouthfeel scores were significantly lower in HTST samples compared to UT samples ($p \leq 0.05$). However, no significant differences were found between UHPH-treated and UT samples for these attributes ($p > 0.05$). Additionally, while appearance, aftertaste, and overall liking scores were lower in HTST-treated samples compared to UT and UHPH-treated samples, these differences were not statistically significant. Overall, UHPH-treated samples maintained sensory qualities closer to UT, particularly for flavor, and overall liking. In contrast, HTST-treated samples exhibited significantly lower scores for flavor and mouthfeel, which were different from both UHPH-treated and UT samples ($p \leq 0.05$). This suggests that thermal pasteurization negatively impacts the organoleptic qualities of watermelon juice. Additionally, UHPH-treated samples scored significantly higher ($p \leq 0.01$) in "fresh-like" attributes such as naturalness and freshness compared to HTST-treated samples, aligning with consumer preferences for minimally processed beverages that retain sensory qualities associated with fresh juice.

Significant differences were observed in all sensory attributes for cantaloupe juice, with all scores being significantly ($p \leq 0.05$) lower in HTST-treated than in UT juices. UHPH-treated samples consistently scored higher than HTST-treated samples, particularly in flavor and overall liking. For instance, UHPH-treated samples scored significantly higher in flavor compared to HTST-treated samples, demonstrating that UHPH preserved the delicate flavor profile of cantaloupe more effectively than HTST ($p \leq 0.05$). Appearance and mouthfeel scores for UHPH-treated cantaloupe juice were also closer to those of the UT control, indicating that UHPH can maintain the texture and visual appeal of the juice. On the other hand, HTST negatively impacted flavor and appearance, suggesting that it is less effective in preserving the sensory attributes of cantaloupe juice. The improved sensory performance of UHPH-treated cantaloupe juice, particularly in terms of flavor, suggests that UHPH is a viable non-thermal processing alternative. Additionally, UHPH-treated samples scored significantly higher ($p \leq 0.01$) in "fresh-like" attributes such as naturalness and freshness compared to HTST-treated samples, aligning with consumer preferences for minimally processed beverages that retain sensory qualities associated with fresh juice.

For grapefruit juice, significant differences were observed in most sensory attributes, including flavor, mouthfeel, aftertaste, and overall liking ($p \leq 0.05$), but not in appearance. UHPH-treated samples received higher scores for flavor and overall liking compared to HTST-treated samples, which scored significantly lower in these attributes ($p \leq 0.05$). Although appearance scores did not differ significantly between treatments, the "fresh-like" attributes, such as naturalness and freshness, were significantly higher in UHPH-treated samples than in HTST-treated ones ($p \leq 0.001$). These results indicate that UHPH can effectively preserve the sensory qualities that contribute to the perception of freshness and naturalness in grapefruit juice, which are key factors in consumer acceptance.

Similar outcomes have been documented in studies on other fruit juices, such as apple and orange juices. For instance, the sensory quality of apple juice and pear juice (Liu et al., 2022) remained unaffected by UHPH processing (Suárez-Jacobo et al., 2011), while a similar result was observed for orange juice (Leite et al., 2016; Velázquez Estrada, 2012). In consumer acceptance tests, UHPH-treated apple juices were preferred over pasteurized juices, with attributes like fruity, natural, sweet, and fresh being the most frequently noted by consumers (Suárez-Jacobo et al., 2011). Moreover, research by Cerdán-Calero et al. (2013) and Leite et al. (2016) on high-pressure homogenization of orange juice demonstrated that samples processed at 150 MPa showed no significant difference ($p > 0.05$) in sensory perception compared to untreated fresh samples (Cerdán-Calero et al., 2013), which is consistent with the findings in this study for watermelon, cantaloupe, blueberry and grapefruit juices processed with UHPH. This further emphasizes the effectiveness of UHPH as a non-thermal processing method that can preserve the desirable sensory attributes of fruit juices. In summary, UHPH treatments, particularly those with a higher inlet temperature (UHPH3 and UHPH4), were effective in maintaining fresh-like sensory qualities across watermelon, cantaloupe, blueberry, and grapefruit juices, with results closely aligning with UT juices. In contrast, HTST had a consistently negative impact on sensory qualities for these juices, except blueberry juice, which showed more resilience to processing, with no significant differences observed between treatments.

<u>*Penalty analysis of fruit juices*</u>

Watermelon juice: The penalty analysis for watermelon flavor and sweetness/sourness balance across different treatments (shown in Table 4) highlights how deviations from the "Just-

About-Right" (JAR) level impacted overall liking scores. UHPH treatments performed better than HTST for watermelon flavor, with more panelists rating the flavor as JAR. Both UHPH3 and UHPH4 had higher overall liking scores, and penalties for being "too little" or "too much" resulted in significant drops in liking ($p < 0.0001$). UHPH1 and UHPH2 showed slightly lower overall liking scores when the flavor was JAR, while HTST had the lowest overall liking score when the flavor was rated JAR. The UT watermelon juice also performed well, with 51.67% of panelists rating the flavor as JAR and an overall liking score of 6.35, although deviations from JAR resulted in significant drops in liking ($p < 0.001$). For the sweetness/sourness balance, UHPH3 and UHPH4 again outperformed the other treatments, with more panelists rating the balance as JAR. These treatments achieved higher overall liking scores, with significant penalties observed when the balance was perceived as either too little or too much ($p < 0.0001$). HTST had the poorest performance in terms of sweetness/sourness balance, with lower overall liking scores and higher penalties for deviations from JAR. The UT juice performed similarly to UHPH3 and UHPH4, with 59.17% of panelists rating the balance as JAR and an overall liking score of 6.44.

In summary, UHPH3 and UHPH4 preserved the watermelon flavor and sweetness/sourness balance most effectively, leading to the highest overall liking scores and minimal penalties when attributes deviated from JAR. In contrast, HTST resulted in the largest penalties and lowest overall liking, while UT juice performed well but slightly below UHPH3 and UHPH4. This analysis underscores the superior ability of UHPH treatments, particularly UHPH3 and UHPH4, to maintain desirable sensory qualities in watermelon juice.

Blueberry juice: The penalty analysis for blueberry flavor and sweetness/sourness balance across different treatments (Table 5) shows that when panelists rated these attributes as "Just-About-Right" (JAR), the overall liking scores were consistently higher. At the same time, deviations from JAR resulted in significant penalties. For blueberry flavor, UHPH3 and UHPH4 had the highest percentage of panelists rating the flavor as JAR, with high overall liking scores. Penalties for flavor rated as "too little" or "too much" were significant, with UHPH3 and UHPH4 showing mean drops of 2.01 and 1.58 in overall liking, respectively ($p < 0.0001$). UHPH1 and UHPH2 also showed good performance, with JAR ratings for flavor leading to overall liking scores of 6.60 for both treatments, though penalties were slightly higher when the flavor was rated as "too little." In contrast, thermal pasteurization – High Temperature Short Time (HTST) had a lower percentage of panelists rating flavor as JAR, with a large penalty for "too little" flavor, resulting in a significant mean drop in overall liking ($p < 0.0001$).

For sweetness/sourness balance, UHPH3 and UHPH4 performed the best, with 58.4% and 61.6% of panelists rating the balance as JAR, leading to high overall liking scores. Penalties for deviations from the JAR level were significant but smaller than other treatments. UHPH1 and UHPH2 also preserved the balance well, with over 50% of panelists rating the balance as JAR and overall liking scores of 6.60 and 6.78, though penalties were slightly higher when the balance was perceived as "too little" or "too much." HTST showed the poorest performance, with only 44% of panelists rating the sweetness/sourness balance as JAR and 43.2% perceiving it as "too much," resulting in a large penalty in overall liking ($p < 0.0001$). UT juice performed similarly to UHPH-treated juices, with 53.6% of panelists rating the sweetness/sourness balance as JAR, though penalties for deviations from JAR were slightly higher than for UHPH3 and UHPH4.

In conclusion, UHPH3 and UHPH4 were the most effective treatments for maintaining both blueberry flavor and sweetness/sourness balance, resulting in the highest overall liking scores and minimal penalties when attributes deviated from JAR. In contrast, thermal pasteurization –

High Temperature Short Time (HTST) performed the worst, with significant penalties in overall liking for deviations from JAR. Untreated (UT) juice performed similarly to the UHPH-treated samples, though with slightly higher penalties for sweetness/sourness balance deviations. These results indicate that UHPH treatments, particularly UHPH3 and UHPH4, were superior in preserving the desirable sensory qualities of blueberry juice.

Cantaloupe juice: The penalty analysis for cantaloupe flavor and sweetness/sourness balance across different treatments (Table 6) reveals that when the attributes were rated as "Just-About-Right" (JAR), overall liking scores were consistently higher. UHPH2 achieved the highest overall liking score for cantaloupe flavor rated as JAR, while UHPH1, UHPH3, and UHPH4 also performed well. However, when the flavor was rated as "too little," significant penalties were observed, with mean drops in overall liking of 1.69 to 2.17 for UHPH treatments. HTST performed the worst, with 63.72% of panelists rating flavor as "too little," leading to a significant drop in overall liking ($p < 0.0001$). UT juice also performed well, with 46.02% of panelists rating the flavor as JAR and a high overall liking score of 6.37, though penalties for deviations from JAR were still significant.

For sweetness/sourness balance, UHPH4 and UT treatments had the highest percentages of panelists rating the balance as JAR, resulting in high overall liking scores. Deviations from JAR, particularly when the balance was rated as "too little" or "too much," resulted in significant penalties in overall liking, with mean drops of 1.89 to 2.14. UHPH1, UHPH2, and UHPH3 also showed good performance, with over 50% of panelists rating the balance as JAR, though penalties for deviations were slightly higher than UHPH4 and UT. HTST performed the worst, with only 40.71% of panelists rating the balance as JAR and significant penalties for deviations, leading to large drops in overall liking.

In summary, UHPH2, UHPH4, and UT juices most effectively preserved the desirable sensory qualities of cantaloupe flavor and sweetness/sourness balance, resulting in higher overall liking scores. Deviations from JAR led to significant penalties across all treatments, but HTST showed the largest penalties, indicating its poorer performance in preserving cantaloupe juice's sensory attributes. UHPH treatments, particularly UHPH2 and UHPH4, outperformed HTST in maintaining optimal flavor and balance, while the untreated juice also performed well.

Grapefruit juice: The penalty analysis for grapefruit flavor and sweetness/sourness balance across the treatments (Table 7) demonstrates that when these attributes were rated as "Just-About-Right" (JAR), the overall liking scores were consistently higher, while deviations from JAR led to significant penalties. UHPH3 and UHPH4 had the highest percentage of panelists rating flavor as JAR, with high overall liking scores. However, when flavor was perceived as "too little," there were significant penalties. Similarly, UHPH1 and UHPH2 had over 50% of panelists rating flavor as JAR, with overall liking scores of 6.22 and 6.24. However, penalties for deviations were still significant, with UHPH1 showing a drop of 2.22 for "too little" flavor. Thermal pasteurization – High Temperature Short Time (HTST) performed the worst, with only 42.37% of panelists rating flavor as JAR, and the largest penalty for "too little" flavor, with a mean drop of 2.41. Untreated (UT) juice performed better, with 63.56% of panelists rating flavor as JAR and an overall liking score of 6.49.

For sweetness/sourness balance, UT performed the best, with 50.85% of panelists rating the balance as JAR and an overall liking score of 6.97. Penalties for deviations from JAR were significant, with mean drops of 2.28 to 2.30 for "too little" or "too much" balance. UHPH3 and

UHPH4 also performed well, with over 40% of panelists rating the balance as JAR, leading to high overall liking scores of 6.67 for UHPH3 and 6.90 for UHPH4, but penalties for deviations were still significant, with drops of around 2.17 to 2.35 for "too little" or "too much" balance. Thermal pasteurization (HTST) again showed the poorest performance, with only 27.12% of panelists rating the balance as JAR and large penalties for deviations, with a mean drop of 2.74 for "too much" balance.

In conclusion, UHPH3, UHPH4, and UT treatments were the most effective in maintaining grapefruit juice's desirable flavor and sweetness/sourness balance, resulting in higher overall liking scores and fewer penalties for deviations from JAR. In contrast, HTST consistently led to the largest penalties and lower overall liking due to greater deviations from the JAR level. This analysis highlights the superior performance of UHPH treatments, particularly UHPH3 and UHPH4, in preserving the sensory attributes of grapefruit juice.

Just About Right (JAR) penalty analysis focuses on consumer perceptions by assessing deviations from the ideal level of specific sensory attributes. This method identifies penalties for not reaching the optimal JAR level, pinpointing the sensory factors that impact overall liking (Iserliyska et al., 2017). Studies applying JAR analysis to orange, apple, and peach juices have shown that balancing sweetness and acidity is critical to consumer preferences, with distinct segments displaying varied preferences based on these attributes (Włodarska et al., 2016). For instance, in peach juices, consumer acceptance increases with higher sweetness levels until a saturation point is reached, reinforcing the importance of sensory attributes to maximize consumer satisfaction (Crisosto et al., 2004).The application of penalty analysis in consumer studies of orange juice has revealed that deviations from the "Just About Right" (JAR) attributes, such as taste and pulp content, can negatively impact consumer acceptance, highlighting the importance of maintaining desirable sensory characteristics during processing (Iserliyska et al., 2017).

Principal Component Analysis (PCA)

The correlation-based Principal Component Analysis (PCA) biplots for watermelon (Fig. 1), blueberry (Fig. 2), cantaloupe (Fig. 3), and grapefruit juices (Fig. 4) reveal patterns in how different treatments impacted sensory attributes and consumer acceptance. Across all four juices, the UT samples consistently aligned with desirable sensory attributes such as flavor, freshness, overall liking, and naturalness, suggesting that untreated juices retained the most favorable qualities for consumer preference. HPH treatments, particularly UHPH3 and UHPH4, closely mirrored untreated juices' fresh-like and natural qualities, effectively preserving key sensory qualities such as flavor, freshness, and overall liking. In contrast, UHPH1 and UHPH2, while still performing better than HTST, were generally positioned farther from the desirable sensory attributes, indicating slightly lower consumer acceptance. HTST consistently resulted in the lowest sensory performance, with samples positioned far from the positive sensory attribute cluster, indicating significant degradation of sensory characteristics.

Watermelon juice: The first principal component (PC 1), which accounts for 89.8% of the total variance, captures most of the variation in the data, while the second principal component (PC 2) explains 6.4%, indicating smaller differences among the samples. Sensory attributes like flavor, naturalness, freshness, overall liking, aftertaste, and mouthfeel are clustered closely together on the right side of the biplot, suggesting high correlation among them. Appearance and purchase intent are positioned slightly farther from the main sensory cluster, indicating they are less correlated but still positively associated with the UT juice. UT watermelon juice is positioned near the cluster of positive sensory attributes, indicating high sensory quality, while UHPH3 and UHPH4 are situated near the UT sample, suggesting these treatments effectively preserved the fresh-like and natural-like qualities of the juice. In contrast, UHPH1 and UHPH2 are farther from the positive sensory attributes, particularly UHPH1, which is isolated in the bottom-left quadrant. HTST-treated samples are the farthest from the desirable sensory attributes, implying lower sensory quality compared to both UHPH-treated and UT samples. In summary, UHPH3 and UHPH4 treatments produced watermelon juice with sensory qualities closely resembling the UT juice, while UHPH1, UHPH2, and HTST-treated samples exhibited significantly lower consumer acceptance. This suggests that UHPH can preserve fresh-like and natural-like sensory attributes better than HTST, with UHPH3 and UHPH4 being particularly effective.

Blueberry juice: The PCA biplot for blueberry juice shows that PC 1 explains 86.0% of the variance, while PC 2 accounts for 7.7%. Sensory attributes like flavor, overall liking, aftertaste, freshness, and purchase intent are clustered together, indicating high correlation. Naturalness is more separated but still positively associated with other sensory attributes, while mouthfeel and appearance contribute differently to consumer perception. UHPH3 and UHPH4 are positioned near the cluster of positive sensory attributes, suggesting these treatments preserved desirable sensory qualities, especially in terms of flavor, overall liking, and freshness. HTST and UHPH2 are farther from the sensory attributes, indicating lower consumer acceptance, while UHPH1 is the most isolated, suggesting it performed the poorest in maintaining sensory quality. The lack of significant differences in blueberry juice suggests that certain fruit juices may be less sensitive to processing methods.

Cantaloupe juice: For cantaloupe juice, PC 1 accounts for 97.6% of the variance, and PC

2 explains 1.3%, capturing most of the variation along PC 1. Sensory attributes, including flavor, naturalness, overall liking, purchase intent, appearance, mouthfeel, aftertaste, and freshness, are tightly clustered together, indicating high correlation. UHPH-treated and UT samples are positioned close to the cluster of positive sensory attributes, suggesting these treatments preserve cantaloupe juice's sensory quality. HTST-treated samples are isolated, indicating the lowest consumer acceptance. This suggests that HTST-treated samples performed poorly in preserving the desirable sensory qualities of cantaloupe juice compared to both UHPH and UT samples.

Grapefruit juice: PC 1 explains 90.5% of the variance in the grapefruit juice biplot, while PC 2 accounts for 5.8%. Sensory attributes such as flavor, overall liking, mouthfeel, and freshness are clustered together, indicating high correlation. Appearance is positioned separately, suggesting it contributes differently to consumer perception. UT, UHPH3, and UHPH4 samples are closest to the desirable sensory attribute cluster, suggesting these treatments best preserved grapefruit juice's sensory qualities. UHPH1 and UHPH2, although retaining some positive qualities, did not perform as well as UHPH3, UHPH4, or UT. HTST-treated samples are farthest from the positive attributes, indicating the lowest consumer acceptance.

Summary of findings across all juices: Principal Component Analysis (PCA) provides an effective approach to understanding consumer acceptance of fruit juices. This multivariate method identifies critical drivers of liking and has demonstrated high predictive accuracy in studies on orange, pineapple, and grape juices, where consumer acceptance was closely linked to these parameters (Correa et al., 2014). By correlating sensory attributes with consumer preferences, PCA helps to map the sensory landscape of fruit juices and highlight how different processing methods can affect these attributes.

The main distinction between UHPH1, UHPH2, and UHPH3, UHPH4 treatments lies in the inlet temperature during processing. UHPH1 and UHPH2 were conducted at a lower inlet temperature of 4°C, while UHPH3 and UHPH4 used a higher inlet temperature of 22°C. This temperature difference appears to significantly impact the sensory quality of the fruit juices. In all four fruit juices—watermelon, cantaloupe, blueberry, and grapefruit—UHPH3 and UHPH4 consistently aligned more closely with the UT samples in terms of desirable sensory attributes, such as flavor, freshness, naturalness, and overall liking. These treatments preserved sensory qualities more effectively, suggesting that the higher inlet temperature of 22°C contributes to better retention of fresh-like and natural-like sensory attributes. Conversely, UHPH1 and UHPH2, processed at 4°C, were positioned farther from the positive sensory attribute cluster. Although they still outperformed HTST, these treatments resulted in slightly lower consumer acceptance compared to UHPH3 and UHPH4. This indicates that the lower inlet temperature may not be as effective in preserving the sensory quality of the juices. This study highlights UHPH as a superior alternative to thermal pasteurization, particularly for juices where sensory qualities are key drivers of consumer acceptance and purchase behavior. By better preserving flavor, freshness, and other key sensory attributes, UHPH treatments tend to yield juices with higher consumer liking and stronger purchase intent (Lima & Rosenthal, 2023; Patrignani et al., 2020; Stinco et al., 2020). Moreover, UHPH is advantageous in retaining the nutritional quality of beverages, including the preservation of micro and macro nutrients, which is significant for health-conscious consumers (Patrignani et al., 2019; Szczepańska et al., 2021). These findings suggest that UHPH technology is a promising solution for producing minimally processed, high-quality fruit juices that align with modern consumer preferences (Joly et al., 2022; Velázquez Estrada, 2012).

Comparison of UHPH Treatments at Different Treatment Combinations

Pressure: The effect of pressure on sensory attributes was observed across all fruit juices, with higher pressures (250 and 300 MPa) leading to better preservation of sensory qualities. UHPH-treated samples processed at higher pressures showed more desirable flavor and freshness scores compared to samples treated at lower pressures (200 MPa), though the differences were more pronounced for certain juices, like watermelon and grapefruit.

Flow Rate: Flow rate also influenced sensory attributes, with higher flow rates (1.125–1.5 L/min) resulting in improved overall liking and flavor scores. This trend was especially evident in watermelon and cantaloupe juices, where higher flow rates helped maintain a fresh appearance and natural flavor. Lower flow rates (0.75 L/min) led to slight reductions in sensory scores, though UHPH still outperformed HTST in all cases.

Inlet Temperature: The most significant impact on sensory attributes was observed with changes in inlet temperature. Higher inlet temperatures (22°C) used in UHPH3 and UHPH4 treatments resulted in better flavor preservation, freshness, and naturalness than in lower inlet temperatures (4°C) used in UHPH1 and UHPH2. This effect was consistent across all juices, particularly in watermelon and grapefruit, where UHPH3 and UHPH4 showed superior performance in maintaining sensory quality.

Demographic Analysis

The consumer demographic analysis provided insights into participants' age, education level, juice consumption habits, and purchasing preferences for each fruit juice type. A total of 116 to 126 participants took part in sensory evaluations of watermelon, cantaloupe, blueberry, and grapefruit juices (see Table 2). The majority of participants were between 18 and 65 years old, with about 55% having incomplete higher education. Most consumers reported drinking juice more than 3 to 4 times per month, with taste, price, and ingredients consistently ranked as the top factors influencing purchasing decisions. Over 90% of participants indicated that they read health claims before purchasing fruit juices, which played a significant role in their decision-making.

A clear preference emerged for cold-pressed and high-pressure processed juices, with 73% of participants favoring minimally processed options over heat-treated alternatives. This preference was driven by perceptions of higher nutritional value and a fresher, more natural taste—attributes commonly associated with non-heat processed juices. Interestingly, participants linked the presence of pulp sediment with a more natural and less processed product, further reinforcing the preference for minimally processed juices. The uniformity of these preferences across all participants suggests that the broader market for minimally processed juices is driven by common factors such as health claims, natural processing methods, and taste quality. These trends highlight a growing interest in health-conscious products and natural ingredients, making this an important area for future product development and marketing strategies.

Conclusion

The present study demonstrated the superior effectiveness of UHPH in preserving the sensory attributes of watermelon, cantaloupe, blueberry, and grapefruit juices, offering "fresh-like" and "natural-like" qualities that align with consumer preferences for minimally processed products. UHPH treatments consistently retained better flavor, freshness, naturalness, and overall liking leading to higher consumer acceptance compared to HTST, as confirmed by PCA and penalty analysis. In particular, UHPH3 and UHPH4 treatments performed similarly to UT samples, while HTST-treated juices showed significant reductions in consumer acceptance, especially for watermelon, cantaloupe and grapefruit juices. Meanwhile, blueberry juice showed resilience across both UHPH and HTST treatments, with no significant differences in sensory attributes, suggesting that it is less sensitive to processing. UHPH also achieved a better balance of sweet and sour flavors in grapefruit juice compared to HTST, further underscoring its potential to produce high-quality, fresh-tasting juices.

These findings suggest that UHPH can successfully preserve the desirable sensory attributes of fruit juices, yielding a "fresh-like" sensory quality compared to HTST-treated juices. PCA analysis confirmed a high degree of similarity between UHPH and UT fruit juices, indicating the minimal impact of UHPH on the compounds responsible for sensory quality. This highlights UHPH’s potential for producing minimally processed, natural, fresh-tasting juices, aligning with modern consumer preferences for minimally processed products. Given these results, UHPH is recommended over HTST for producing natural, fresh-tasting juices without compromising safety or quality. In summary, UHPH treatments that use higher inlet temperatures (22°C) combined with higher pressures (250 and 300 MPa) and moderate to high flow rates (1.125 and 1.5 L/min) tend to produce fruit juices with superior sensory qualities, closely mimicking fresh-like and natural characteristics, leading to higher consumer acceptance. Future research should explore the long-term effects of UHPH on juice quality during storage, as well as its impact on consumer acceptance across broader demographic groups.

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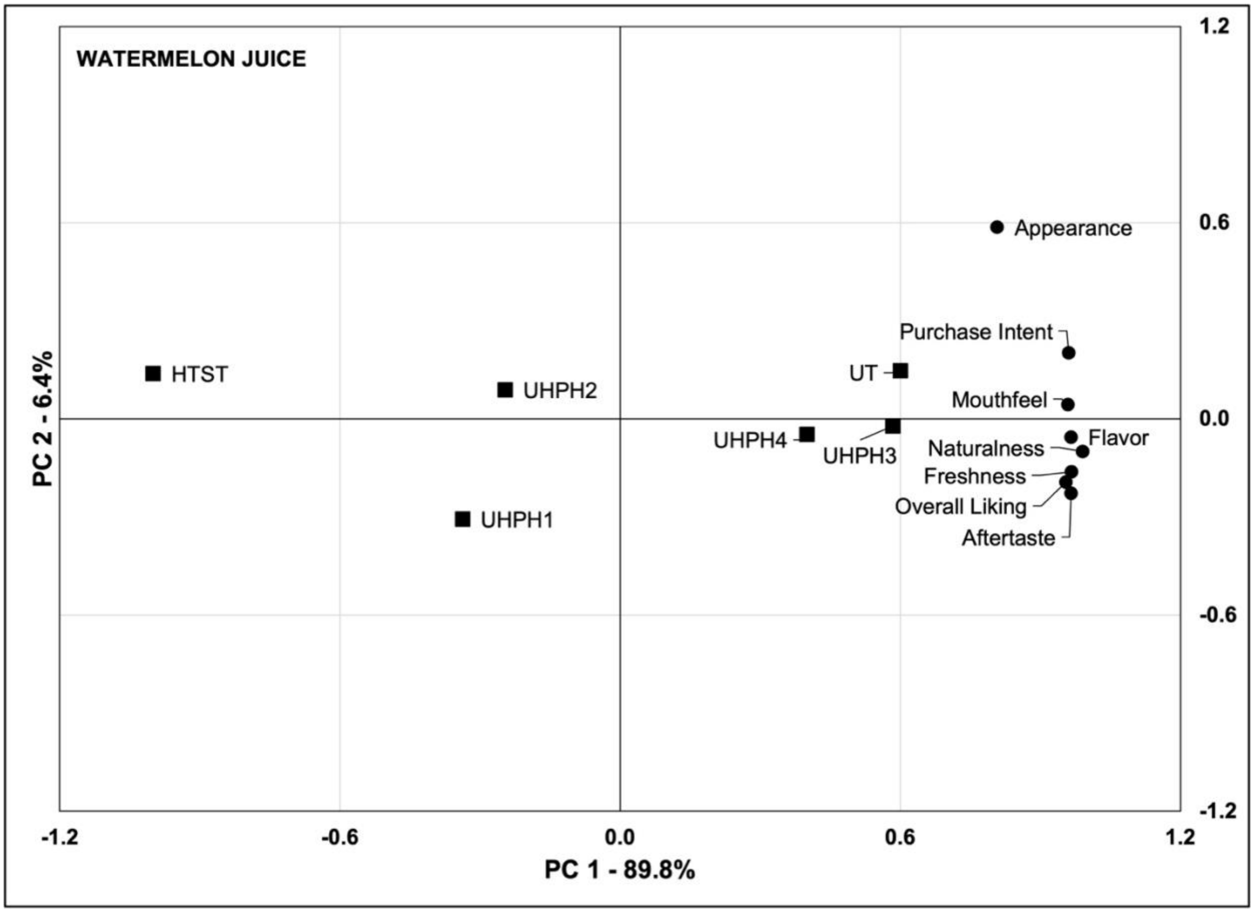


Figure 5.1 Principal Component Analysis (PCA) biplots of sensory attributes of watermelon juice across treatments. Circle points are sensory attributes and square points are treatments. UT, untreated juice; UHPH, ultra-high-pressure homogenization; HTST, thermal pasteurization – high temperature short time.

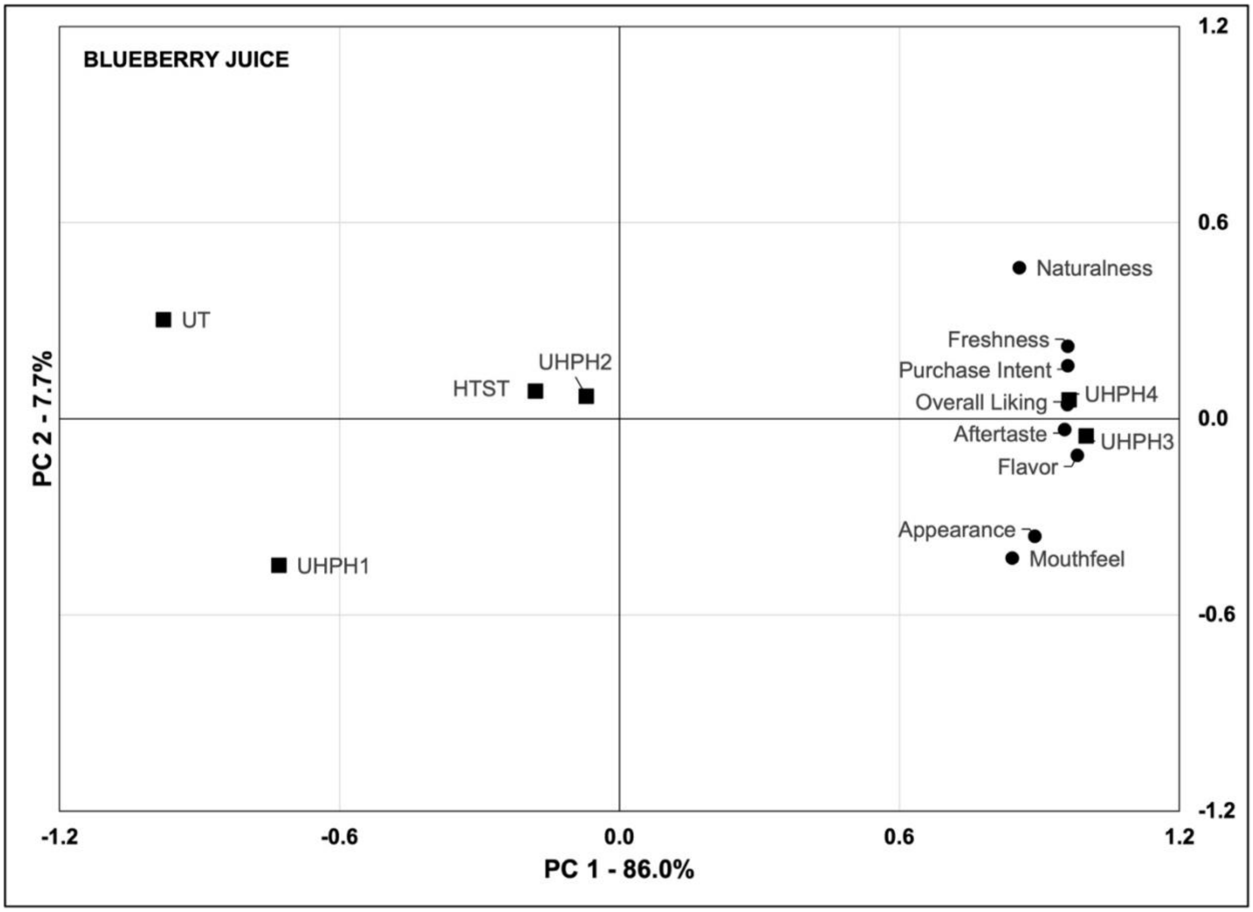


Figure 5.2 Principal Component Analysis (PCA) biplots of sensory attributes of blueberry juice across treatments. Circle points are sensory attributes and square points are treatments. UT, untreated juice; UHPH, ultra-high-pressure homogenization; HTST, thermal pasteurization - high temperature short time.

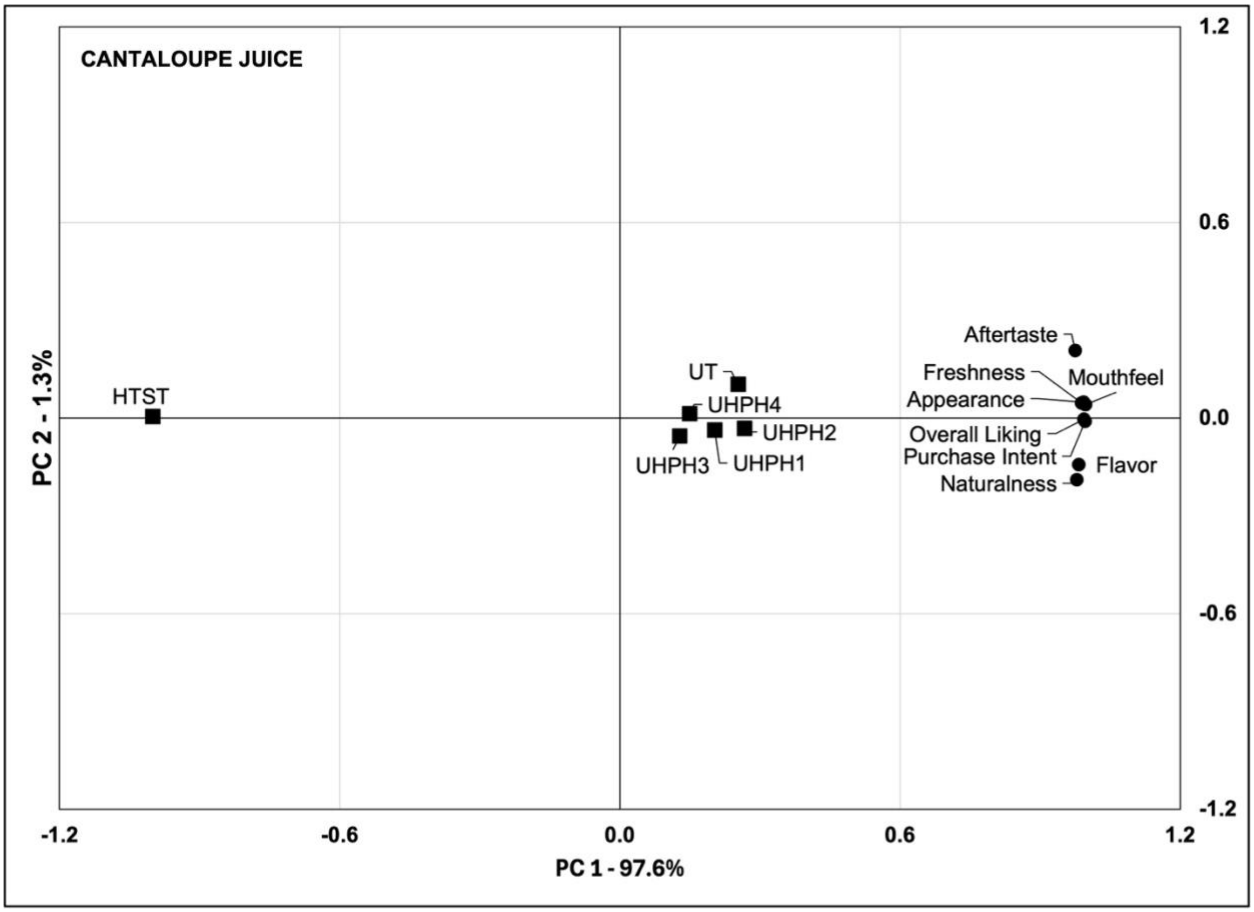


Figure 5.3 Principal Component Analysis (PCA) biplots of sensory attributes of cantaloupe juice across treatments. Circle points are sensory attributes and square points are treatments. UT, untreated juice; UHPH, ultra-high-pressure homogenization; HTST, thermal pasteurization - high temperature short time.

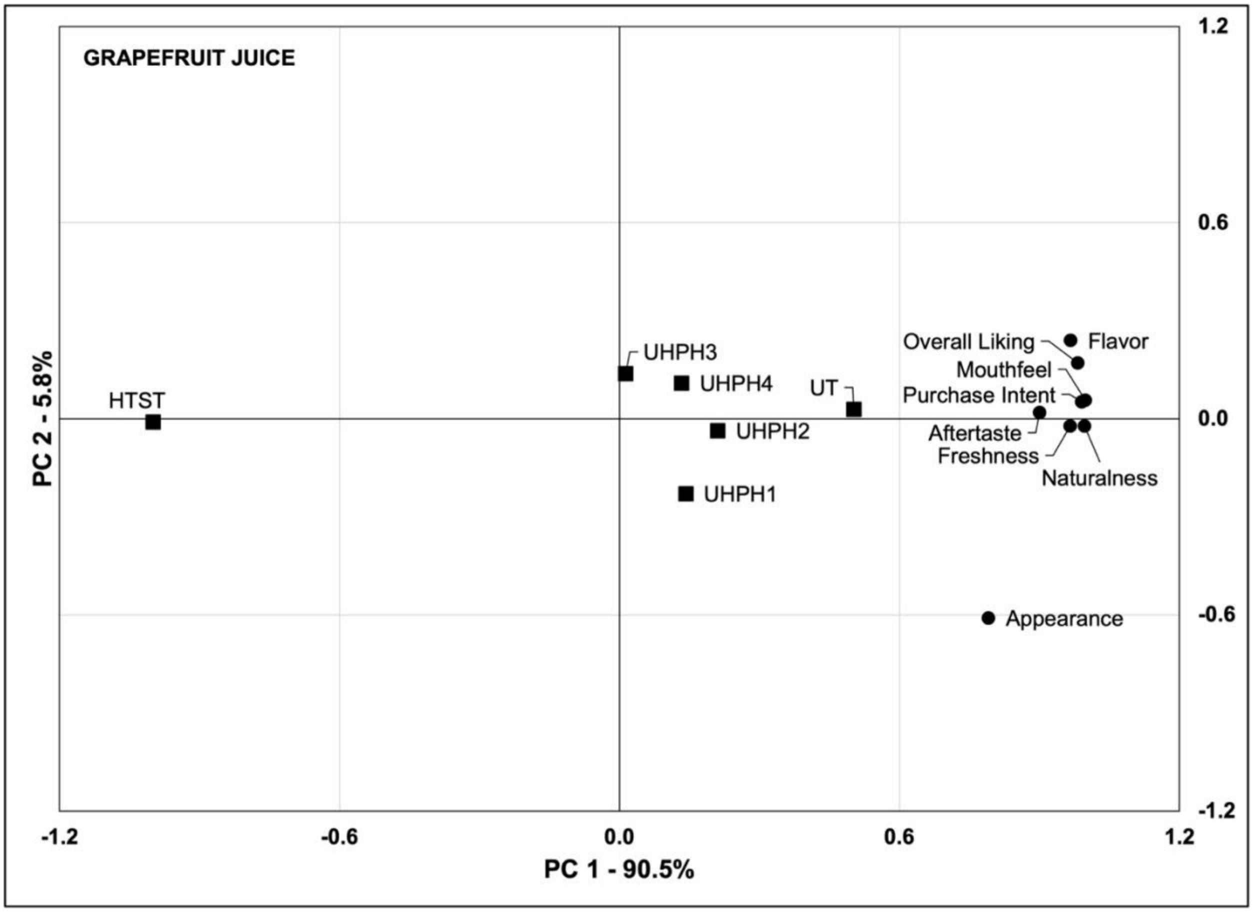


Figure 5.4 Principal Component Analysis (PCA) biplots of sensory attributes of grapefruit juice across treatments. Circle points are sensory attributes and square points are treatments. UT, untreated juice; UHPH, ultra-high-pressure homogenization; HTST, thermal pasteurization - high temperature short time.

Table 5.1 Selected UHPH treatment combinations for each fruit juice type (pressures, inlet temperatures, and flow rates) for consumer study.

Sample Code	**Treatment combinations (MPa - L/min - °C)**			
	Watermelon	**Blueberry**	**Cantaloupe**	**Grapefruit**
UHPH 1	250-0.75-4	250-0.75-4	300-0.75-4	300-0.75-4
UHPH 2	250-1.125-4	300-0.75-4	300-1.125-4	300-1.50-4
UHPH 3	200-1.125-22	250-1.125-22	250-1.125-22	250-1.125-22
UHPH 4	250-1.125-22	300-1.50-22	250-0.75-22	300-1.50-22

Table 5.2 Composition of the consumer population in the study.

		18-25	26-35	36-45	46-55	56-65	66 or older	Total
WJ	Female	15	12	15	16	20	13	91
	Male	5	4	6	5	7	4	31
		20	16	21	21	27	17	122
CJ	Female	14	14	12	15	22	8	85
	Male	5	5	4	5	9	3	31
		19	19	16	20	31	11	116
BJ	Female	11	13	16	18	22	12	92
	Male	4	5	6	7	8	4	34
		15	18	22	25	30	16	126
GJ	Female	11	15	15	16	19	8	84
	Male	5	5	5	7	8	4	34
		16	20	20	23	27	12	118

WJ=watermelon juice, CJ=cantaloupe juice, BJ=blueberry juice, GJ=grapefruit juice.

Table 5.3 Sensory attribute (means) scores for each fruit juice across treatments.

Juices	Attributes	UT	UHPH1	UHPH2	UHPH3	UHPH4	HTST	*p* value
WJ	Appearance	7.48 a	6.83 b	7.22 ab	7.36 ab	7.29 ab	7.00 ab	<.05
	Flavor	6.10 a	5.62 ab	5.77 ab	6.20 a	5.89 a	5.05 b	<.001
	Mouthfeel	6.30 a	5.82 ab	5.87 ab	6.07 ab	6.22 ab	5.54 b	<.05
	Aftertaste	5.41 ab	5.19 ab	5.11 ab	5.52 a	5.50 ab	4.77 b	<.05
	Overall Liking	5.74 ab	5.42 ab	5.28 ab	5.87 a	5.92 a	4.97 b	<.01
	Naturalness	5.44 a	4.97 ab	4.97 ab	5.51 a	5.30 a	4.43 b	<.01
	Freshness	5.73 a	5.33 ab	5.18 ab	5.69 a	5.47 ab	4.74 b	<.01
BJ	Appearance	7.19 a	7.32 a	7.32 a	7.40 a	7.42 a	7.34 a	.81
	Flavor	6.12 a	6.21 a	6.26 a	6.56 a	6.52 a	6.24 a	.28
	Mouthfeel	5.99 a	6.14 a	6.14 a	6.27 a	6.24 a	6.02 a	.78
	Aftertaste	5.38 a	5.47 a	5.60 a	5.73 a	5.78 a	5.64 a	.59
	Overall Liking	5.79 a	5.78 a	5.91 a	6.22 a	6.09 a	5.91 a	.40
	Naturalness	5.05 a	4.80 a	5.19 a	5.30 a	5.41 a	5.05 a	.24
	Freshness	5.24 a	5.18 a	5.42 a	5.59 a	5.70 a	5.42 a	.30
CJ	Appearance	7.08 a	7.06 a	6.92 a	6.78 a	6.91 a	5.23 b	<.0001
	Flavor	5.62 a	5.67 a	5.78 a	5.78 a	5.68 a	4.44 b	<.0001
	Mouthfeel	5.87 a	5.79 a	5.88 a	5.76 a	5.82 a	5.05 b	<.01
	Aftertaste	5.47 a	5.24 ab	5.31 a	5.24 ab	5.27 ab	4.59 b	<.05
	Overall Liking	5.62 a	5.48 a	5.68 a	5.53 a	5.48 a	4.42 b	<.0001
	Naturalness	5.10 a	5.26 a	5.29 a	5.17 a	5.07 a	4.26 b	<.01
	Freshness	5.45 a	5.44 a	5.47 a	5.15 a	5.28 a	4.14 b	<.0001
GJ	Appearance	7.00 a	7.11 a	6.95 a	6.71 a	6.80 a	6.56 a	.09
	Flavor	6.11 a	5.55 ab	5.76 a	5.73 a	5.79 a	4.87 b	<.01
	Mouthfeel	6.14 a	5.86 a	5.93 a	5.81 a	5.91 a	5.10 b	<.01
	Aftertaste	4.97 a	5.03 a	4.98 a	4.87 ab	5.20 a	4.22 b	<.01
	Overall Liking	5.85 a	5.34 a	5.49 a	5.40 a	5.57 a	4.52 b	<.001
	Naturalness	5.95 a	5.66 a	5.77 a	5.57 a	5.61 a	4.80 b	<.001
	Freshness	6.17 a	5.91 a	5.93 a	5.93 a	5.70 ab	5.03 b	<.001

Liking attributes were scored on a standard 9-point hedonic scale, 1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely. Fresh-like attributes were scored on a 9-point interval scale, 1 =not at all, 5 =moderate, 9 = extremely.

Sharing the same letters, a or b, within each row denotes absence of significance according to Tukey's HSD test. UT, untreated juice; UHPH, ultra-high-pressure homogenization; HTST, thermal pasteurization - high temperature short time.

Table 5.4 Penalty analysis of all six watermelon juices for watermelon flavor and sweetness/sourness balance.

Sample	**Variable**	**Level**	**Panelists**	**%**	**Overall Liking**	**Mean drops**	**Penalties**	***p*-value**
UHPH1	Watermelon Flavor JAR	Too little	47	39.17%	4.19	2.19		
		JAR	57	47.50%	6.39		1.83	<0.0001
		Too much	16	13.33%	5.63	0.76		
	Sweet/sour Balance JAR	Too little	29	24.17%	3.90	2.53		
		JAR	63	52.50%	6.43		2.11	<0.0001
		Too much	28	23.33%	4.75	1.68		
UHPH2	Watermelon Flavor JAR	Too little	45	37.50%	4.13	1.95		
		JAR	58	48.33%	6.09		1.55	<0.0001
		Too much	17	14.17%	5.59	0.50		
	Sweet/sour Balance JAR	Too little	29	24.17%	4.79	1.33		
		JAR	57	47.50%	6.12		1.60	<0.0001
		Too much	34	28.33%	4.29	1.83		
UHPH3	Watermelon Flavor JAR	Too little	42	35.00%	4.43	2.27		
		JAR	60	50.00%	6.70		1.67	<0.0001
		Too much	18	15.00%	6.44	0.26		
	Sweet/sour Balance JAR	Too little	23	19.17%	5.22	1.32		
		JAR	72	60.00%	6.54		1.69	<0.0001
		Too much	25	20.83%	4.52	2.02		
UHPH4	Watermelon Flavor JAR	Too little	50	41.67%	4.66	2.23		
		JAR	54	45.00%	6.89		1.77	<0.0001
		Too much	16	13.33%	6.56	0.33		
	Sweet/sour Balance JAR	Too little	24	20.00%	4.88	1.71		
		JAR	69	57.50%	6.58		1.56	<0.0001
		Too much	27	22.50%	5.15	1.43		
HTST	Watermelon Flavor JAR	Too little	57	47.50%	4.00	1.93		
		JAR	43	35.83%	5.93		1.49	0.001
		Too much	20	16.67%	5.70	0.23		
	Sweet/sour Balance JAR	Too little	25	20.83%	4.04	1.98		
		JAR	57	47.50%	6.02		1.99	<0.0001
		Too much	38	31.67%	4.03	1.99		
UT	Watermelon Flavor JAR	Too little	40	33.33%	4.75	1.60		
		JAR	62	51.67%	6.35		1.27	0.000
		Too much	18	15.00%	5.83	0.52		
	Sweet/sour Balance JAR	Too little	21	17.50%	4.52	1.91		
		JAR	71	59.17%	6.44		1.70	<0.0001
		Too much	28	23.33%	4.89	1.54		

Table 5.5 Penalty analysis of all six blueberry juices for blueberry flavor and sweetness/sourness balance.

Sample	**Variable**	**Level**	**Panelists**	**%**	**Overall Liking**	**Mean drops**	**Penalties**	***p*-value**
UHPH1	Blueberry Flavor JAR	Too little	47	37.60%	4.43	2.18		
		JAR	58	46.40%	6.60		1.53	<0.0001
		Too much	20	16.00%	6.60	0.00		
	Sweet/sour Balance JAR	Too little	35	28.00%	5.11	1.48		
		JAR	67	53.60%	6.60		1.75	<0.0001
		Too much	23	18.40%	4.43	2.16		
UHPH2	Blueberry Flavor JAR	Too little	47	37.60%	5.00	1.64		
		JAR	58	46.40%	6.64		1.35	<0.0001
		Too much	20	16.00%	5.95	0.69		
	Sweet/sour Balance JAR	Too little	34	27.20%	5.09	1.69		
		JAR	63	50.40%	6.78		1.75	<0.0001
		Too much	28	22.40%	4.96	1.81		
UHPH3	Blueberry Flavor JAR	Too little	39	31.20%	4.87	2.01		
		JAR	69	55.20%	6.88		1.47	<0.0001
		Too much	17	13.60%	6.65	0.24		
	Sweet/sour Balance JAR	Too little	34	27.20%	5.35	1.48		
		JAR	73	58.40%	6.84		1.47	<0.0001
		Too much	18	14.40%	5.39	1.45		
UHPH4	Blueberry Flavor JAR	Too little	44	35.20%	5.14	1.58		
		JAR	59	47.20%	6.71		1.18	0.000
		Too much	22	17.60%	6.32	0.39		
	Sweet/sour Balance JAR	Too little	23	18.40%	5.52	1.22		
		JAR	77	61.60%	6.74		1.70	<0.0001
		Too much	25	20.00%	4.60	2.14		
HTST	Blueberry Flavor JAR	Too little	40	32.00%	4.08	2.97		
		JAR	61	48.80%	7.05		2.22	<0.0001
		Too much	24	19.20%	6.08	0.97		
	Sweet/sour Balance JAR	Too little	16	12.80%	5.81	1.35		
		JAR	55	44.00%	7.16		2.24	<0.0001
		Too much	54	43.20%	4.67	2.50		
UT	Blueberry Flavor JAR	Too little	43	34.40%	4.44	2.24		
		JAR	67	53.60%	6.69		1.93	<0.0001
		Too much	15	12.00%	5.67	1.02		
	Sweet/sour Balance JAR	Too little	28	22.40%	5.25	1.39		
		JAR	67	53.60%	6.64		1.83	<0.0001
		Too much	30	24.00%	4.40	2.24		

Table 5.6 Penalty analysis of all six cantaloupe juices for cantaloupe flavor and sweetness/sourness balance.

Sample	Variable	Level	Panelists	%	Overall Liking	Mean drops	Penalties	*p*-value
UHPH1	Cantaloupe Flavor JAR	Too little	38	33.63%	4.24	1.69		
		JAR	55	48.67%	5.93		1.01	0.006
		Too much	20	17.70%	6.20	-0.27		
	Sweet/sour Balance JAR	Too little	29	25.66%	4.93	1.47		
		JAR	57	50.44%	6.40		2.01	< 0.0001
		Too much	27	23.89%	3.81	2.59		
UHPH2	Cantaloupe Flavor JAR	Too little	42	37.17%	4.40	2.17		
		JAR	52	46.02%	6.58		1.76	< 0.0001
		Too much	19	16.81%	5.74	0.84		
	Sweet/sour Balance JAR	Too little	28	24.78%	5.11	1.32		
		JAR	59	52.21%	6.42		1.66	< 0.0001
		Too much	26	23.01%	4.38	2.04		
UHPH3	Cantaloupe Flavor JAR	Too little	33	29.20%	4.42	1.74		
		JAR	54	47.79%	6.17		1.32	0.000
		Too much	26	23.01%	5.38	0.78		
	Sweet/sour Balance JAR	Too little	24	21.24%	5.04	1.21		
		JAR	59	52.21%	6.25		1.62	< 0.0001
		Too much	30	26.55%	4.30	1.95		
UHPH4	Cantaloupe Flavor JAR	Too little	49	43.36%	4.37	1.79		
		JAR	45	39.82%	6.16		1.21	0.001
		Too much	19	16.81%	6.42	-0.27		
	Sweet/sour Balance JAR	Too little	26	23.01%	4.69	1.50		
		JAR	67	59.29%	6.19		1.89	< 0.0001
		Too much	20	17.70%	3.80	2.39		
HTST	Cantaloupe Flavor JAR	Too little	72	63.72%	3.46	2.54		
		JAR	31	27.43%	6.00		2.33	< 0.0001
		Too much	10	8.85%	5.20	0.80		
	Sweet/sour Balance JAR	Too little	26	23.01%	3.73	2.14		
		JAR	46	40.71%	5.87		2.63	< 0.0001
		Too much	41	36.28%	2.93	2.94		
UT	Cantaloupe Flavor JAR	Too little	41	36.28%	4.32	2.05		
		JAR	52	46.02%	6.37		1.48	< 0.0001
		Too much	20	17.70%	6.05	0.32		
	Sweet/sour Balance JAR	Too little	22	19.47%	4.23	2.14		
		JAR	66	58.41%	6.36		1.92	< 0.0001
		Too much	25	22.12%	4.64	1.72		

Table 5.7 Penalty analysis of all six grapefruit juices for grapefruit flavor and sweetness/sourness balance.

Sample	Variable	Level	Panelists	%	Overall Liking	Mean drops	Penalties	*p*-value
UHPH1	Grapefruit Flavor JAR	Too little	28	23.73%	4.00	2.22		
		JAR	64	54.24%	6.22		1.92	<0.0001
		Too much	26	22.03%	4.62	1.60		
	Sweet/sour Balance JAR	Too little	6	5.08%	4.83	1.93		
		JAR	55	46.61%	6.76		2.67	<0.0001
		Too much	57	48.31%	4.02	2.75		
UHPH2	Grapefruit Flavor JAR	Too little	24	20.34%	3.67	2.57		
		JAR	67	56.78%	6.24		1.73	<0.0001
		Too much	27	22.88%	5.26	0.98		
	Sweet/sour Balance JAR	Too little	8	6.78%	5.25	1.73		
		JAR	49	41.53%	6.98		2.54	<0.0001
		Too much	61	51.69%	4.33	2.65		
UHPH3	Grapefruit Flavor JAR	Too little	27	22.88%	3.93	2.38		
		JAR	65	55.08%	6.31		2.02	<0.0001
		Too much	26	22.03%	4.65	1.65		
	Sweet/sour Balance JAR	Too little	8	6.78%	3.38	3.29		
		JAR	54	45.76%	6.67		2.34	<0.0001
		Too much	56	47.46%	4.46	2.20		
UHPH4	Grapefruit Flavor JAR	Too little	25	21.19%	3.84	2.48		
		JAR	66	55.93%	6.32		1.70	<0.0001
		Too much	27	22.88%	5.33	0.98		
	Sweet/sour Balance JAR	Too little	15	12.71%	4.73	2.17		
		JAR	50	42.37%	6.90		2.31	<0.0001
		Too much	53	44.92%	4.55	2.35		
HTST	Grapefruit Flavor JAR	Too little	47	39.83%	3.45	2.41		
		JAR	50	42.37%	5.86		2.32	<0.0001
		Too much	21	17.80%	3.76	2.10		
	Sweet/sour Balance JAR	Too little	10	8.47%	4.00	2.50		
		JAR	32	27.12%	6.50		2.71	<0.0001
		Too much	76	64.41%	3.76	2.74		
UT	Grapefruit Flavor JAR	Too little	20	16.95%	3.60	2.89		
		JAR	75	63.56%	6.49		1.77	<0.0001
		Too much	23	19.49%	5.70	0.80		
	Sweet/sour Balance JAR	Too little	7	5.93%	4.86	2.11		
		JAR	60	50.85%	6.97		2.28	<0.0001
		Too much	51	43.22%	4.67	2.30		

CHAPTER 6

CONCLUSIONS AND FUTURE RECOMMENDATIONS

This dissertation investigates Ultra High-Pressure Homogenization (UHPH) as an alternative, sustainable processing technology with the potential to achieve safe, high-quality juice that maintained its fresh-like sensory attributes of grapefruit, watermelon, cantaloupe, and blueberry juices, meeting the standards for minimally processed, natural juice products. The findings demonstrate that UHPH effectively inactivates *E. coli* K12 (>5 log CFU/mL) and reduces natural microflora populations without requiring preservatives, making it a valuable alternative to conventional thermal processing methods, such as High-Temperature Short Time (HTST) pasteurization. UHPH-treated juices maintained consistent physicochemical properties, including stable pH, Brix, titratable acidity, particle size distribution (PSD), viscosity, color, and turbidity over a 45-day storage period, demonstrating the technology's ability to preserve juice quality during extended storage. Optimal outcomes were observed at higher pressures (250 and 300 MPa), higher inlet temperatures (22°C), and moderate flow rates, though these parameters varied across different juice types. This indicates the need for further optimization studies to tailor UHPH conditions for each specific juice matrix.

The consumer study revealed that UHPH-treated juices were more highly accepted than thermally pasteurized – high temperature short time (HTST) juices, retaining natural, fresh-like qualities comparable to untreated (UT) samples. Principal Component Analysis (PCA) and Penalty Analysis confirmed UHPH's effectiveness in preserving essential sensory attributes, including flavor, appearance, mouthfeel, and purchase intent, reinforcing its appeal as a high-quality juice processing method. Collectively, these findings establish UHPH as a promising technology for producing fresh, minimally processed juice products that align with consumer demand for natural, high-quality, and safe beverages.

Future Recommendations

1. **Extended Storage Studies**: To further understand UHPH's long-term effectiveness, future studies should extend storage evaluations beyond 45 days, assessing microbial and physicochemical stability. Additionally, examining UHPH's impact on a broader range of microorganisms will support the development of comprehensive safety guidelines for various juice types.
2. **Broadened Scope for Nutrient and Phytochemical Retention**: Research focused on UHPH's effects on nutrient and phytochemical retention, particularly of antioxidants, vitamins, and other bioactive compounds, could enhance the positioning of UHPH-treated juices as health-oriented products for nutrition-conscious consumers.
3. **Industrial-Scale Trials and Economic Feasibility**: Large-scale trials are essential to validate laboratory findings and address potential challenges in scaling up UHPH technology. A cost-benefit analysis, including energy requirements, processing efficiency, and equipment maintenance, would clarify UHPH's economic viability for commercial application.
4. **Optimization Studies**: Given the variations in UHPH effectiveness across different juice matrices, future studies should focus on optimizing treatment parameters, including pressure, temperature, and flow rate, for each juice type to maximize quality and efficiency.
5. **Consumer Education and Market Acceptance**: Educating consumers on the benefits of UHPH-treated products, particularly through targeted marketing, could enhance public

awareness and acceptance. Emphasizing the health, quality, and environmental advantages of non-thermal processing could foster market growth for UHPH-treated juices.

In conclusion, UHPH represents a sustainable and consumer-friendly processing technology for the juice industry, effectively combining microbial inactivation and mild heat treatment in a single, efficient step. This study utilized a stabilizer tube to leverage the natural temperature rise induced by depressurization, maintaining the homogenized juices at elevated temperatures (50°C to 85°C) for 10 to 20 seconds, depending on flow rate. Despite this extended heat exposure, consumer acceptance of UHPH-treated juices remained comparable to untreated samples, while UHPH scored significantly higher than thermally pasteurized juices. These findings underscore UHPH's capacity to deliver high-quality, fresh-like juice products with strong consumer appeal, while providing an integrated solution that minimizes the need for multiple processing steps. By addressing these recommendations in future research and industry applications, UHPH can help set new standards for quality, safety, and sustainability in minimally processed juice products, potentially revolutionizing the fruit juice industry.

APPENDICES

APPENDIX-A

RESIDENCE TIME OF THE FLUID IN THE STABILIZING TUBE

The residence time in the stabilizing tube was calculated according to the method described by Toledo (2007). The residence time is determined by the volume of the stabilizing tube and the volumetric flow rate delivered by the positive displacement pump, using the following formula:

$$Holding\ time = \frac{Volume\ (L)}{Volumetric\ flow\ rate\ (L/min)}$$

To measure the stabilizing tube volume, the tube was filled with fruit juice, with one end closed. The calculated volume of the stabilizing tube was 260 mL. Three different flow rates were tested: 0.75, 1.125, and 1.5 L/min. Based on these flow rates, the corresponding stabilizing times were as follows:

- At 0.75 L/min: 20.8 s
- At 1.125 L/min: 13.87 s
- At 1.5 L/min: 10.4 s

This approach allowed for precise determination of residence times at each flow rate. Stabilizing time at these flow rates were

APPENDIX-B

TEMPERATURE RISE CALCULATIONS AFTER HOMOGENIZATION VALVE IN THE UHPH SYSTEM

The theoretical temperature rise after the homogenization valve can be derived from the first law of thermodynamics and was calculated using Equation 1 (Toledo, 2007; Sivanandan, 2007; Sharma, 2008). This calculation incorporated the specific heat capacity *Cp, (J/kg.°C*) and density, *ρ (kg/m³)* of the tested fruit juices. The inlet temperature (T_{in}) was either 4°C or 22°C, with the inlet pressure *(P_{in}, Pa)* representing the pressure applied, and the outlet pressure (P_{out}) was atmospheric (*101325 Pa*) pressure.

$$T_{out} = T_{in} + \frac{(P_{in} - P_{out})}{\rho C_p} \tag{1}$$

This equation estimates the outlet temperature (T_{out}) after homogenization. However, actual temperature measurements at the exit of the stabilizing tube (post-valve) may differ from these theoretical values due to two opposing factors:

1. Heat Losses: Heat loss occurs through convection to the surroundings and conduction through the connecting pipe to the cooling heat exchanger. These mechanisms reduce the experimental temperature at the exit compared to theoretical predictions.
2. Heat Rise Inside the Stabilizing Tube: Despite heat losses, the temperature within the stabilizing tube may continue to rise due to ongoing cavitation and the dissipation of energy. Cavitation produces localized heating as microbubbles collapse, resulting in a temperature increase during fluid stabilization.

These opposing factors result in a complex thermal profile within the stabilizing tube, where localized heating (from cavitation) and overall cooling (from heat losses) coexist, influencing the final measured outlet temperature.

Table B.1 Theoretical temperature rise calculations in fruit juices after homogenization valve.

P_{in} (Pa)	P_{out} (Pa)	T_{in} (°C)	T_{out} (°C) $=T_{in}+((P_{in}-P_{out})/(\rho*C_p))$	dT (°C) $=T_{out}-T_{in}$
200000000	101325	4	46.07	42.07
250000000	101325	4	56.59	52.59
300000000	101325	4	67.11	63.11
200000000	101325	22	64.07	42.07
250000000	101325	22	74.59	52.59
300000000	101325	22	85.11	63.11

APPENDIX-C

PHYSICOCHEMICAL AND MICROBIOLOGICAL QUALITY OF FRUIT JUICES DURING 45 DAYS OF REFRIGARATED STORAGE

Table C.1 Changes in pH of blueberry juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	3.11 ± 0.26[a]	3.09 ± 0.26	3.10 ± 0.28	3.06 ± 0.28
			1.125	3.02 ± 0.26[a]	2.97 ± 0.29	2.99 ± 0.29	2.98 ± 0.31
			1.50	3.26 ± 0.33[a]	3.18 ± 0.26	3.19 ± 0.27	3.20 ± 0.27
		250	0.75	3.08 ± 0.28[a]	3.03 ± 0.29	3.05 ± 0.26	3.05 ± 0.29
			1.125	3.07 ± 0.25[a]	3.05 ± 0.29	3.04 ± 0.27	3.02 ± 0.27
			1.50	2.98 ± 0.28[a]	2.96 ± 0.30	2.96 ± 0.29	2.96 ± 0.25
		300	0.75	3.05 ± 0.22[a]	3.07 ± 0.25	3.06 ± 0.28	3.04 ± 0.27
			1.125	3.06 ± 0.27[a]	3.06 ± 0.28	3.05 ± 0.29	3.03 ± 0.27
			1.50	2.93 ± 0.23[a]	2.97 ± 0.28	2.95 ± 0.29	3.00 ± 0.29
	22	200	0.75	3.34 ± 0.05[a]	3.33 ± 0.03	3.34 ± 0.02	3.33 ± 0.02
			1.125	3.35 ± 0.02[a]	3.35 ± 0.01	3.36 ± 0.01	3.33 ± 0.02
			1.50	3.35 ± 0.03[a]	3.39 ± 0.03	3.35 ± 0.01	3.38 ± 0.03
		250	0.75	3.33 ± 0.03[a]	3.31 ± 0.01	3.44 ± 0.04	3.41 ± 0.03
			1.125	3.33 ± 0.04[a]	3.32 ± 0.04	3.32 ± 0.03	3.31 ± 0.04
			1.50	3.35 ± 0.02[a]	3.40 ± 0.03	3.32 ± 0.03	3.29 ± 0.01
		300	0.75	3.36 ± 0.05[a]	3.33 ± 0.03	3.32 ± 0.03	3.34 ± 0.04
			1.125	3.32 ± 0.02[a]	3.33 ± 0.03	3.33 ± 0.03	3.33 ± 0.02
			1.50	3.35 ± 0.01[a]	3.33 ± 0.01	3.33 ± 0.02	3.30 ± 0.03
Control	HTST		75 °C/15s	3.02 ± 0.02[a]	3.02 ± 0.02	3.02 ± 0.02	3.03 ± 0.02
			85 °C/15s	3.06 ± 0.01[a]	3.04 ± 0.02	3.02 ± 0.02	3.03 ± 0.01
			95 °C/15s	3.05 ± 0.02[a]	3.03 ± 0.02	3.03 ± 0.02	3.02 ± 0.01
	UT		Untreated	3.23 ± 0.04[a]	3.43 ± 0.01	3.43 ± 0.04	3.45 ± 0.01

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.2 Changes in TSS (°Brix) of blueberry juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (°C)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	9.97 ± 0.12[a]	9.80 ± 0.10	9.87 ± 0.06	9.80 ± 0.10
			1.125	9.96 ± 0.21[a]	9.54 ± 0.16	9.54 ± 0.24	9.44 ± 0.16
			1.5	9.90 ± 0.06[a]	9.77 ± 0.06	9.74 ± 0.06	9.57 ± 0.06
		250	0.75	9.97 ± 0.33[a]	9.64 ± 0.31	9.60 ± 0.27	9.60 ± 0.37
			1.125	9.89 ± 0.18[a]	9.80 ± 0.18	9.74 ± 0.16	9.70 ± 0.18
			1.5	9.94 ± 0.26[a]	9.74 ± 0.26	9.70 ± 0.20	9.67 ± 0.29
		300	0.75	9.90 ± 0.21[a]	9.77 ± 0.16	9.77 ± 0.16	9.74 ± 0.16
			1.125	9.94 ± 0.16[a]	9.80 ± 0.21	9.77 ± 0.12	9.70 ± 0.20
			1.5	9.90 ± 0.21[a]	9.77 ± 0.21	9.74 ± 0.26	9.74 ± 0.26
	22	200	0.75	9.94 ± 0.21[a]	9.84 ± 0.21	9.84 ± 0.26	9.94 ± 0.24
			1.125	9.97 ± 0.42[a]	9.90 ± 0.37	9.90 ± 0.37	9.90 ± 0.37
			1.5	9.97 ± 0.16[a]	9.87 ± 0.16	9.84 ± 0.21	9.80 ± 0.20
		250	0.75	10.00 ± 0.27[a]	10.00 ± 0.27	10.00 ± 0.27	9.94 ± 0.21
			1.125	10.07 ± 0.16[a]	10.10 ± 0.20	10.17 ± 0.16	10.14 ± 0.16
			1.5	9.97 ± 0.21[a]	9.84 ± 0.16	9.80 ± 0.18	9.80 ± 0.18
		300	0.75	10.10 ± 0.20[a]	10.10 ± 0.20	10.07 ± 0.26	10.07 ± 0.16
			1.125	9.97 ± 0.26[a]	10.00 ± 0.31	10.00 ± 0.27	10.00 ± 0.31
			1.5	9.97 ± 0.16[a]	9.94 ± 0.21	9.90 ± 0.18	9.87 ± 0.16
Control	HTST		75 °C/15s	9.90 ± 0.44[a]	9.44 ± 0.38	9.44 ± 0.38	9.40 ± 0.35
			85 °C/15s	9.90 ± 0.18[a]	9.90 ± 0.18	9.87 ± 0.16	9.90 ± 0.18
			95 °C/15s	10.14 ± 0.12[a]	10.07 ± 0.06	10.04 ± 0.12	10.04 ± 0.12
	UT		Untreated	10.60 ± 0.18[a]	10.54 ± 0.06	10.47 ± 0.06	10.14 ± 0.47

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.3 Changes in viscosity of blueberry juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (℃)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	1.48 ± 0.04	1.46 ± 0.01	1.51 ± 0.05	1.49 ± 0.02
			1.125	1.48 ± 0.02	1.48 ± 0.03	1.48 ± 0.03	1.46 ± 0.08
			1.5	1.51 ± 0.05	1.48 ± 0.02	1.47 ± 0.04	1.44 ± 0.04
		250	0.75	1.48 ± 0.03	1.46 ± 0.06	1.46 ± 0.03	1.43 ± 0.06
			1.125	1.50 ± 0.03	1.50 ± 0.07	1.48 ± 0.03	1.47 ± 0.09
			1.5	1.47 ± 0.02	1.42 ± 0.01	1.46 ± 0.02	1.44 ± 0.04
		300	0.75	1.49 ± 0.06	1.49 ± 0.04	1.46 ± 0.02	1.46 ± 0.02
			1.125	1.51 ± 0.04	1.51 ± 0.02	1.51 ± 0.04	1.46 ± 0.06
			1.5	1.46 ± 0.02	1.46 ± 0.03	1.46 ± 0.02	1.42 ± 0.06
	22	200	0.75	1.44 ± 0.01	1.44 ± 0.01	1.43 ± 0.02	1.47 ± 0.07
			1.125	1.41 ± 0.05	1.44 ± 0.04	1.41 ± 0.01	1.40 ± 0.03
			1.5	1.41 ± 0.02	1.40 ± 0.02	1.39 ± 0.01	1.42 ± 0.02
		250	0.75	1.40 ± 0.01	1.46 ± 0.04	1.41 ± 0.04	1.44 ± 0.03
			1.125	1.44 ± 0.05	1.42 ± 0.04	1.43 ± 0.02	1.42 ± 0.03
			1.5	1.39 ± 0.03	1.39 ± 0.03	1.42 ± 0.05	1.38 ± 0.04
		300	0.75	1.42 ± 0.03	1.41 ± 0.04	1.39 ± 0.03	1.40 ± 0.03
			1.125	1.39 ± 0.02	1.37 ± 0.00	1.39 ± 0.02	1.37 ± 0.04
			1.5	1.38 ± 0.02	1.41 ± 0.04	1.38 ± 0.03	1.39 ± 0.03
Control	HTST		75 ℃/15s	1.40 ± 0.03	1.40 ± 0.02	1.40 ± 0.03	1.38 ± 0.02
			85 ℃/15s	1.50 ± 0.02	1.48 ± 0.01	1.49 ± 0.02	1.49 ± 0.02
			95 ℃/15s	1.50 ± 0.02	1.50 ± 0.03	1.50 ± 0.02	1.49 ± 0.02
	UT		Untreated	1.49 ± 0.00	1.45 ± 0.02	1.43 ± 0.00	1.50 ± 0.04

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.4 Changes in titratable acidity (%TA) of blueberry juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (℃)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	0.30 ± 0.10[a]	0.31 ± 0.11	0.31 ± 0.10	0.32 ± 0.12
			1.125	0.32 ± 0.05[a]	0.27 ± 0.09	0.30 ± 0.12	0.31 ± 0.11
			1.5	0.24 ± 0.10[a]	0.25 ± 0.10	0.25 ± 0.18	0.26 ± 0.14
		250	0.75	0.30 ± 0.11[a]	0.29 ± 0.09	0.30 ± 0.10	0.31 ± 0.12
			1.125	0.31 ± 0.10[a]	0.32 ± 0.11	0.32 ± 0.11	0.32 ± 0.10
			1.5	0.29 ± 0.13[a]	0.32 ± 0.07	0.32 ± 0.11	0.32 ± 0.13
		300	0.75	0.31 ± 0.10[a]	0.32 ± 0.11	0.28 ± 0.13	0.31 ± 0.09
			1.125	0.30 ± 0.12[a]	0.30 ± 0.10	0.30 ± 0.12	0.32 ± 0.10
			1.5	0.31 ± 0.11[a]	0.31 ± 0.11	0.32 ± 0.10	0.31 ± 0.11
	22	200	0.75	0.17 ± 0.01[a]	0.17 ± 0.02	0.17 ± 0.02	0.18 ± 0.01
			1.125	0.19 ± 0.02[a]	0.18 ± 0.02	0.18 ± 0.02	0.18 ± 0.02
			1.5	0.18 ± 0.01[a]	0.19 ± 0.01	0.19 ± 0.01	0.18 ± 0.02
		250	0.75	0.18 ± 0.02[a]	0.18 ± 0.01	0.18 ± 0.03	0.19 ± 0.01
			1.125	0.17 ± 0.01[a]	0.18 ± 0.01	0.18 ± 0.02	0.19 ± 0.01
			1.5	0.15 ± 0.05[a]	0.19 ± 0.01	0.19 ± 0.01	0.19 ± 0.01
		300	0.75	0.19 ± 0.02[a]	0.18 ± 0.02	0.18 ± 0.00	0.18 ± 0.02
			1.125	0.19 ± 0.01[a]	0.18 ± 0.01	0.18 ± 0.01	0.18 ± 0.02
			1.5	0.19 ± 0.01[a]	0.18 ± 0.00	0.19 ± 0.02	0.19 ± 0.02
Control	HTST		75 ℃/15s	0.38 ± 0.04[a]	0.41 ± 0.02	0.41 ± 0.04	0.40 ± 0.03
			85 ℃/15s	0.39 ± 0.02[a]	0.42 ± 0.02	0.43 ± 0.01	0.43 ± 0.02
			95 ℃/15s	0.42 ± 0.02[a]	0.43 ± 0.01	0.43 ± 0.04	0.44 ± 0.02
	UT		Untreated	0.18 ± 0.01[a]	0.19 ± 0.01	0.19 ± 0.01	0.2 ± 0.020

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.5 Changes in turbidity of blueberry juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (°C)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	72.07 ± 4.54[a]	49.27 ± 2.99	49.72 ± 1.00	47.51 ± 3.97
			1.125	69.45 ± 3.75[a]	51.60 ± 8.03	52.53 ± 7.98	48.53 ± 7.00
			1.5	71.26 ± 2.91[a]	63.16 ± 0.6	63.23 ± 1.84	60.12 ± 0.90
		250	0.75	69.58 ± 3.80[a]	54.10 ± 3.61	57.29 ± 3.97	54.19 ± 0.28
			1.125	71.84 ± 3.63[a]	53.75 ± 2.19	53.63 ± 5.45	50.29 ± 1.38
			1.5	71.42 ± 4.38[a]	52.57 ± 3.50	53.21 ± 6.49	49.47 ± 2.27
		300	0.75	74.67 ± 7.05[a]	60.01 ± 3.04	61.84 ± 5.03	54.42 ± 0.35
			1.125	71.21 ± 7.49[a]	60.03 ± 2.20	59.68 ± 2.22	53.01 ± 0.80
			1.5	71.71 ± 4.48[a]	60.73 ± 0.41	59.54 ± 2.18	55.92 ± 1.47
	22	200	0.75	73.94 ± 2.34[a]	65.14 ± 0.29	67.19 ± 3.03	60.71 ± 4.14
			1.125	74.02 ± 1.53[a]	68.16 ± 0.73	68.17 ± 1.99	59.60 ± 1.29
			1.5	74.73 ± 2.39[a]	69.07 ± 2.96	71.28 ± 2.59	63.96 ± 4.60
		250	0.75	74.20 ± 2.86[a]	72.08 ± 0.26	71.06 ± 0.73	66.41 ± 5.57
			1.125	74.57 ± 2.57[a]	70.19 ± 1.20	69.44 ± 3.68	61.79 ± 0.95
			1.5	75.68 ± 2.88[a]	68.94 ± 0.52	68.05 ± 0.16	62.83 ± 4.06
		300	0.75	74.57 ± 2.87[a]	75.25 ± 0.01	75.86 ± 0.32	68.70 ± 5.78
			1.125	74.55 ± 0.90[a]	73.80 ± 1.12	71.19 ± 1.62	65.61 ± 6.69
			1.5	73.07 ± 0.99[a]	76.70 ± 2.15	75.11 ± 1.39	67.27 ± 7.00
Control	HTST		75 °C/15s	60.15 ± 0.77[b]	56.65 ± 1.07	56.60 ± 0.92	59.70 ± 4.69
			85 °C/15s	59.62 ± 1.56[b]	57.91 ± 1.43	56.52 ± 2.75	56.45 ± 0.78
			95 °C/15s	57.82 ± 1.47[b]	56.06 ± 0.60	57.94 ± 4.40	56.17 ± 3.40
	UT		Untreated	73.94 ± 4.89[a]	67.06 ± 0.51	61.39 ± 1.69	63.80 ± 2.53

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.6 Changes in color of blueberry juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0						Day 45					
				*L	*a	*b	AE	C*	Hue	*L	*a	*b	AE	C*	Hue
UHPH	4	200	0.75	0.20	1.20	0.34	0.06	1.25	15.82	2.97	6.89	1.34	6.35	7.02	11.01
			1.125	0.67	2.87	0.59	1.69	2.93	11.62	1.53	6.11	1.91	5.27	6.40	17.36
			1.5	0.55	2.86	0.70	1.67	2.94	13.75	1.17	5.52	1.77	4.60	5.80	17.78
		250	0.75	0.49	2.15	0.53	0.95	2.21	13.85	0.51	3.18	0.87	2.01	3.30	15.30
			1.125	0.44	1.77	0.38	0.56	1.81	12.12	0.65	3.76	1.10	2.65	3.92	16.31
			1.5	0.32	1.59	0.42	0.36	1.64	14.80	0.60	3.57	1.03	2.44	3.72	16.09
		300	0.75	0.42	1.68	0.38	0.47	1.72	12.75	0.63	3.65	1.08	2.54	3.81	16.48
			1.125	0.32	1.50	0.32	0.26	1.53	12.04	0.61	3.54	1.02	2.41	3.68	16.07
			1.5	0.29	1.18	0.26	0.14	1.21	12.43	0.51	3.61	0.88	2.43	3.72	13.70
	22	200	0.75	0.50	1.93	0.33	0.73	1.96	9.70	0.96	4.96	1.63	3.99	5.22	18.19
			1.125	0.37	1.81	0.38	0.57	1.85	11.86	0.70	3.76	1.18	2.68	3.94	17.42
			1.5	0.69	2.68	0.53	1.51	2.73	11.19	0.28	1.74	0.48	0.50	1.80	15.42
		250	0.75	0.53	1.77	0.30	0.60	1.80	9.62	0.41	2.44	0.71	1.25	2.54	16.22
			1.125	0.51	1.75	0.33	0.57	1.78	10.68	0.37	2.23	0.64	1.03	2.32	16.01
			1.5	0.42	2.20	0.47	0.97	2.25	12.06	0.38	2.27	0.66	1.07	2.36	16.21
		300	0.75	0.40	1.75	0.32	0.53	1.78	10.36	0.32	1.95	0.55	0.73	2.03	15.75
			1.125	0.34	1.76	0.35	0.52	1.79	11.25	0.42	2.44	0.72	1.26	2.54	16.44
			1.5	0.69	2.36	0.47	1.21	2.41	11.26	0.24	1.55	0.42	0.30	1.61	15.16
Control	HTST		75 °C/15s	0.67	3.34	0.77	2.17	3.43	12.98	0.98	5.07	1.57	4.08	5.31	17.21
			85 °C/15s	0.92	3.35	0.69	2.23	3.42	11.64	1.01	5.07	1.54	4.07	5.30	16.90
			95 °C/15s	0.78	3.29	0.73	2.14	3.37	12.51	0.94	4.75	1.56	3.77	5.00	18.18
	UT		Untreated	0.21	1.26	0.34	0.00	1.31	15.10	0.68	3.55	1.14	2.47	3.73	17.80

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.7 Changes in pH of cantaloupe juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	4.69 ± 0.03^{aA}	4.69 ± 0.01^{aAB}	4.60 ± 0.16^{aA}	4.71 ± 0.02^{aA}
			1.125	4.70 ± 0.02^{aA}	4.72 ± 0.02^{aAB}	4.44 ± 0.10^{bA}	4.59 ± 0.14^{abA}
			1.5	4.72 ± 0.04^{aA}	4.72 ± 0.04^{aAB}	4.68 ± 0.03^{aA}	4.68 ± 0.01^{aA}
		250	0.75	4.68 ± 0.03^{aA}	4.72 ± 0.02^{aAB}	4.65 ± 0.10^{aA}	4.68 ± 0.01^{aA}
			1.125	4.70 ± 0.03^{aA}	4.70 ± 0.03^{aAB}	4.69 ± 0.02^{aA}	4.66 ± 0.05^{aA}
			1.5	4.71 ± 0.03^{aA}	4.71 ± 0.02^{aAB}	4.61 ± 0.12^{aA}	4.54 ± 0.17^{aA}
		300	0.75	4.72 ± 0.01^{aA}	4.70 ± 0.00^{aAB}	4.67 ± 0.01^{bA}	4.69 ± 0.02^{abA}
			1.125	4.70 ± 0.03^{aA}	4.71 ± 0.03^{aAB}	4.72 ± 0.03^{aA}	4.70 ± 0.04^{aA}
			1.5	4.69 ± 0.02^{aA}	4.67 ± 0.03^{aAB}	4.62 ± 0.13^{aA}	4.53 ± 0.16^{aA}
	22	200	0.75	4.73 ± 0.15^{aA}	4.76 ± 0.06^{aA}	4.69 ± 0.03^{aA}	4.74 ± 0.08^{aA}
			1.125	4.62 ± 0.10^{aA}	4.63 ± 0.06^{aB}	4.56 ± 0.02^{aA}	4.61 ± 0.07^{aA}
			1.5	4.70 ± 0.13^{aA}	4.65 ± 0.04^{aAB}	4.59 ± 0.15^{aA}	4.74 ± 0.06^{aA}
		250	0.75	4.59 ± 0.12^{aA}	4.64 ± 0.04^{aAB}	4.50 ± 0.06^{aA}	4.63 ± 0.04^{aA}
			1.125	4.53 ± 0.07^{aA}	4.66 ± 0.03^{bAB}	4.58 ± 0.03^{abA}	4.62 ± 0.02^{abA}
			1.5	4.61 ± 0.11^{aA}	4.64 ± 0.04^{aAB}	4.40 ± 0.34^{aA}	4.60 ± 0.05^{aA}
		300	0.75	4.50 ± 0.03^{aA}	4.59 ± 0.07^{aB}	4.53 ± 0.04^{aA}	4.55 ± 0.09^{aA}
			1.125	4.74 ± 0.17^{aA}	4.76 ± 0.09^{aA}	4.68 ± 0.11^{aA}	4.73 ± 0.07^{aA}
			1.5	4.62 ± 0.05^{aA}	4.60 ± 0.05^{aB}	4.57 ± 0.15^{aA}	4.51 ± 0.14^{aA}
Control	HTST		75 °C/15s	4.70 ± 0.13^{aA}	4.65 ± 0.04^{aAB}	4.70 ± 0.13^{aA}	4.65 ± 0.04^{aA}
			85 °C/15s	4.61 ± 0.11^{aA}	4.64 ± 0.04^{aAB}	4.61 ± 0.11^{aA}	4.64 ± 0.04^{aA}
			95 °C/15s	4.62 ± 0.05^{aA}	4.60 ± 0.04^{aB}	4.62 ± 0.05^{aA}	4.60 ± 0.04^{aA}
	UT		Untreated	4.71 ± 0.11^{aA}	4.71 ± 0.08^{aAB}	4.72 ± 0.16^{aA}	4.72 ± 0.15^{aA}

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.8 Changes in TSS (°Brix) of cantaloupe juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (°C)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	7.97 ± 0.33^{aA}	7.50 ± 0.11^{abAB}	7.24 ± 0.57^{abAB}	6.84 ± 0.42^{bBC}
			1.125	7.60 ± 0.11^{aABC}	7.57 ± 0.12^{aA}	6.70 ± 0.31^{aB}	7.50 ± 0.18^{bABC}
			1.5	8.00 ± 0.11^{aA}	7.70 ± 0.11^{bA}	7.64 ± 0.16^{bA}	7.34 ± 0.06^{cABC}
		250	0.75	7.74 ± 0.06^{aABC}	7.60 ± 0.18^{aA}	7.30 ± 0.61^{aAB}	7.17 ± 0.66^{aABC}
			1.125	7.50 ± 0.71^{aBC}	6.40 ± 1.18^{aB}	7.67 ± 0.12^{aA}	7.67 ± 0.16^{aAB}
			1.5	7.67 ± 0.06^{aABC}	7.47 ± 0.21^{abAB}	7.40 ± 0.11^{abAB}	7.14 ± 0.21^{bABC}
		300	0.75	7.97 ± 0.12^{aA}	8.00 ± 0.18^{aA}	7.87 ± 0.21^{aA}	7.84 ± 0.26^{aA}
			1.125	7.47 ± 0.12^{aABC}	6.97 ± 0.84^{aAB}	7.10 ± 0.37^{aAB}	6.57 ± 0.16^{aC}
			1.5	7.60 ± 0.21^{aABC}	7.34 ± 0.29^{abAB}	7.07 ± 0.12^{abAB}	6.84 ± 0.46^{bBC}
	22	200	0.75	7.47 ± 0.06^{aABC}	7.07 ± 0.59^{aAB}	7.27 ± 0.12^{aAB}	7.24 ± 0.24^{aABC}
			1.125	7.87 ± 0.21^{aAB}	7.90 ± 0.20^{aA}	7.70 ± 0.44^{aA}	7.50 ± 0.44^{aABC}
			1.5	7.87 ± 0.16^{aAB}	7.94 ± 0.06^{aA}	7.60 ± 0.01^{abA}	7.47 ± 0.26^{bABC}
		250	0.75	7.54 ± 0.06^{aABC}	7.50 ± 0.11^{aAB}	7.47 ± 0.16^{aAB}	7.40 ± 0.18^{aABC}
			1.125	7.64 ± 0.06^{aABC}	7.60 ± 0.11^{aA}	7.54 ± 0.12^{aAB}	7.24 ± 0.16^{bABC}
			1.5	7.50 ± 0.11^{aABC}	7.47 ± 0.16^{aAB}	7.44 ± 0.12^{aAB}	7.24 ± 0.29^{aABC}
		300	0.75	7.77 ± 0.12^{aABC}	7.74 ± 0.26^{aA}	7.77 ± 0.16^{aA}	7.27 ± 0.12^{bABC}
			1.125	7.70 ± 0.10^{aABC}	7.74 ± 0.21^{aA}	7.47 ± 0.16^{aAB}	7.24 ± 0.38^{aABC}
			1.5	7.54 ± 0.12^{aABC}	7.44 ± 0.06^{aAB}	7.14 ± 0.38^{abAB}	6.67 ± 0.21^{bC}
Control	HTST		75 °C/15s	7.15 ± 0.05^{aC}	7.45 ± 0.05^{bAB}	7.45 ± 0.16^{bAB}	7.45 ± 0.05^{bABC}
			85 °C/15s	7.25 ± 0.16^{aBC}	7.50 ± 0.11^{aAB}	7.50 ± 0.11^{aAB}	7.35 ± 0.16^{aABC}
			95 °C/15s	7.20 ± 0.21^{aC}	7.30 ± 0.21^{aAB}	7.45 ± 0.25^{aAB}	7.35 ± 0.06^{aABC}
	UT		Untreated	7.84 ± 0.12^{aAB}	7.87 ± 0.26^{aA}	7.64 ± 0.16^{aA}	6.74 ± 0.61^{bBC}

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.9 Changes in viscosity of cantaloupe juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	1.53 ± 0.03^{a}	1.69 ± 0.03^{a}	2.58 ± 1.51^{aA}	1.53 ± 0.03^{aA}
			1.125	1.41 ± 0.02^{a}	1.44 ± 0.05^{a}	4.12 ± 0.25^{bA}	2.95 ± 1.09^{bA}
			1.5	1.66 ± 0.10^{ab}	1.53 ± 0.03^{a}	1.69 ± 0.03^{bA}	1.69 ± 0.03^{bA}
		250	0.75	1.53 ± 0.03^{a}	1.69 ± 0.03^{a}	2.27 ± 1.48^{aA}	1.45 ± 0.05^{aA}
			1.125	1.66 ± 0.10^{a}	1.53 ± 0.03^{a}	1.69 ± 0.03^{aA}	1.66 ± 0.10^{aA}
			1.5	1.43 ± 0.02^{a}	1.43 ± 0.01^{a}	2.64 ± 2.20^{aA}	2.32 ± 1.66^{aA}
		300	0.75	1.41 ± 0.02^{a}	1.44 ± 0.05^{a}	1.43 ± 0.03^{aA}	1.42 ± 0.03^{aA}
			1.125	1.66 ± 0.10^{a}	1.53 ± 0.03^{a}	1.69 ± 0.03^{aA}	1.66 ± 0.10^{aA}
			1.5	1.41 ± 0.01^{a}	1.42 ± 0.03^{a}	4.25 ± 4.92^{aA}	4.15 ± 4.77^{aA}
	22	200	0.75	1.53 ± 0.03^{a}	1.70 ± 0.04^{b}	1.66 ± 0.04^{bA}	1.72 ± 0.02^{bA}
			1.125	1.43 ± 0.03^{a}	1.46 ± 0.05^{a}	1.42 ± 0.02^{aA}	1.44 ± 0.02^{aA}
			1.5	1.57 ± 0.12^{a}	1.50 ± 0.03^{a}	1.54 ± 0.03^{aA}	1.50 ± 0.05^{aA}
		250	0.75	1.41 ± 0.02^{a}	1.45 ± 0.05^{a}	1.41 ± 0.02^{aA}	1.41 ± 0.04^{aA}
			1.125	1.56 ± 0.01^{a}	1.60 ± 0.09^{ab}	1.69 ± 0.02^{bA}	1.66 ± 0.04^{abA}
			1.5	1.39 ± 0.04^{a}	1.40 ± 0.03^{a}	1.40 ± 0.05^{aA}	1.51 ± 0.13^{aA}
		300	0.75	1.42 ± 0.04^{a}	1.48 ± 0.10^{a}	1.39 ± 0.02^{aA}	1.50 ± 0.02^{aA}
			1.125	1.54 ± 0.04^{a}	1.68 ± 0.07^{b}	1.65 ± 0.06^{abA}	1.69 ± 0.02^{bA}
			1.5	1.46 ± 0.02^{a}	1.53 ± 0.07^{a}	3.93 ± 4.21^{aA}	4.11 ± 4.43^{aA}
Control	HTST		75 °C/15s	1.59 ± 0.05^{a}	1.55 ± 0.02^{a}	1.56 ± 0.02^{aA}	1.54 ± 0.04^{aA}
			85 °C/15s	1.52 ± 0.01^{a}	1.56 ± 0.05^{ab}	1.58 ± 0.01^{bA}	1.56 ± 0.02^{abA}
			95 °C/15s	1.50 ± 0.01^{a}	1.55 ± 0.01^{a}	1.55 ± 0.04^{aA}	1.51 ± 0.04^{aA}
	UT		Untreated	1.60 ± 0.06^{a}	1.57 ± 0.02^{a}	1.53 ± 0.03^{aA}	1.54 ± 0.05^{aA}

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.10 Changes in titratable acidity (%TA) of cantaloupe juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (℃)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	0.24 ± 0.07^{aA}	0.23 ± 0.02^{aAB}	0.29 ± 0.04^{aA}	0.24 ± 0.04^{aA}
			1.125	0.26 ± 0.07^{aA}	0.21 ± 0.04^{aB}	0.37 ± 0.06^{bA}	0.25 ± 0.02^{abA}
			1.5	0.24 ± 0.04^{aA}	0.21 ± 0.02^{aB}	0.24 ± 0.03^{aA}	0.25 ± 0.03^{aA}
		250	0.75	0.23 ± 0.02^{aA}	0.21 ± 0.02^{aB}	0.27 ± 0.08^{aA}	0.25 ± 0.02^{aA}
			1.125	0.24 ± 0.02^{aA}	0.24 ± 0.05^{aAB}	0.24 ± 0.02^{aA}	0.26 ± 0.03^{aA}
			1.5	0.25 ± 0.01^{aA}	0.25 ± 0.02^{aAB}	0.35 ± 0.18^{aA}	0.41 ± 0.25^{aA}
		300	0.75	0.22 ± 0.02^{aA}	0.22 ± 0.01^{aAB}	0.23 ± 0.02^{aA}	0.24 ± 0.03^{aA}
			1.125	0.23 ± 0.01^{aA}	0.24 ± 0.01^{aAB}	0.23 ± 0.03^{aA}	0.25 ± 0.04^{aA}
			1.5	0.25 ± 0.05^{aA}	0.25 ± 0.04^{aAB}	0.40 ± 0.20^{aA}	0.42 ± 0.23^{aA}
	22	200	0.75	0.24 ± 0.01^{aA}	0.22 ± 0.01^{aAB}	0.24 ± 0.01^{bA}	0.24 ± 0.02^{bA}
			1.125	0.23 ± 0.01^{aA}	0.22 ± 0.01^{aAB}	0.23 ± 0.04^{aA}	0.25 ± 0.01^{aA}
			1.5	0.24 ± 0.01^{aA}	0.22 ± 0.01^{aAB}	0.24 ± 0.02^{aA}	0.24 ± 0.02^{aA}
		250	0.75	0.24 ± 0.02^{aA}	0.23 ± 0.03^{aAB}	0.24 ± 0.01^{aA}	0.24 ± 0.02^{aA}
			1.125	0.24 ± 0.01^{aA}	0.23 ± 0.02^{aAB}	0.24 ± 0.03^{aA}	0.24 ± 0.01^{aA}
			1.5	0.24 ± 0.01^{aA}	0.23 ± 0.02^{aAB}	0.23 ± 0.02^{aA}	0.23 ± 0.02^{aA}
		300	0.75	0.24 ± 0.01^{aA}	0.23 ± 0.02^{aAB}	0.24 ± 0.01^{aA}	0.23 ± 0.03^{aA}
			1.125	0.23 ± 0.00^{aA}	0.22 ± 0.01^{aAB}	0.24 ± 0.01^{abA}	0.24 ± 0.02^{bA}
			1.5	0.24 ± 0.01^{aA}	0.23 ± 0.02^{aAB}	0.24 ± 0.01^{aA}	0.24 ± 0.01^{aA}
Control	HTST		75 ℃/15s	0.24 ± 0.01^{aA}	0.26 ± 0.01^{bAB}	0.25 ± 0.01^{abA}	0.25 ± 0.01^{abA}
			85 ℃/15s	0.25 ± 0.02^{aA}	0.25 ± 0.00^{aAB}	0.25 ± 0.01^{aA}	0.26 ± 0.02^{aA}
			95 ℃/15s	0.24 ± 0.01^{aA}	0.24 ± 0.01^{aAB}	0.25 ± 0.00^{aA}	0.24 ± 0.01^{aA}
	UT		Untreated	0.28 ± 0.05^{aA}	0.28 ± 0.05^{aA}	0.30 ± 0.06^{aA}	0.30 ± 0.04^{aA}

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.11 Changes in color of cantaloupe juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0						Day 45					
				*L	*a	*b	AE	C*	Hue	*L	*a	*b	AE	C*	Hue
UHPH	4	200	0.75	47.22	22.10	33.32	5.10	40.02	56.38	47.22	22.10	33.32	5.10	40.02	56.38
			1.125	47.39	22.57	34.71	4.25	41.42	56.91	47.39	22.57	34.71	4.25	41.42	56.91
			1.5	47.24	21.90	34.30	4.38	40.72	57.45	47.24	21.90	34.30	4.38	40.72	57.45
		250	0.75	47.13	22.01	34.53	4.03	40.96	57.45	47.13	22.01	34.53	4.03	40.96	57.45
			1.125	47.09	22.04	34.82	3.78	41.22	57.62	47.09	22.04	34.82	3.78	41.22	57.62
			1.5	47.05	21.79	33.63	4.65	40.07	57.05	47.05	21.79	33.63	4.65	40.07	57.05
		300	0.75	47.61	22.63	33.73	5.12	40.64	56.06	47.61	22.63	33.73	5.12	40.64	56.06
			1.125	47.17	22.61	32.99	5.50	40.02	55.51	47.17	22.61	32.99	5.50	40.02	55.51
			1.5	47.24	22.49	33.73	4.89	40.55	56.29	47.24	22.49	33.73	4.89	40.55	56.29
	22	200	0.75	46.78	22.35	33.65	4.79	40.41	56.41	46.78	22.35	33.65	4.79	40.41	56.41
			1.125	46.22	22.06	32.75	5.39	39.51	56.05	46.22	22.06	32.75	5.39	39.51	56.05
			1.5	46.60	21.90	33.64	4.65	40.16	56.95	46.60	21.90	33.64	4.65	40.16	56.95
		250	0.75	47.40	22.06	32.86	5.75	39.60	56.15	47.40	22.06	32.86	5.75	39.60	56.15
			1.125	46.90	22.83	33.58	5.13	40.63	55.79	46.90	22.83	33.58	5.13	40.63	55.79
			1.5	47.22	22.07	32.46	5.86	39.28	55.77	47.22	22.07	32.46	5.86	39.28	55.77
		300	0.75	47.85	21.76	30.95	7.33	37.87	54.80	47.63	22.21	32.74	5.93	39.62	55.59
			1.125	47.87	21.44	30.57	7.70	37.36	54.92	47.28	22.23	32.72	6.08	39.62	55.47
			1.5	48.05	21.60	30.59	7.73	37.48	54.71	48.58	21.73	31.71	7.29	38.54	55.08
Control	HTST		75 °C/15s	46.08	20.70	33.03	4.99	39.02	57.90	45.99	20.06	34.79	3.19	40.19	59.95
			85 °C/15s	46.22	20.50	32.43	5.57	38.42	57.65	46.44	19.74	32.77	5.32	38.33	58.67
			95 °C/15s	46.87	20.26	32.38	5.73	38.25	57.91	45.08	20.02	35.09	2.97	40.43	60.28
	UT		Untreated	45.07	20.53	37.62	0.00	42.85	61.37	42.50	22.59	41.17	5.70	46.96	61.26

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature;

Table C.12 Changes in turbidity of cantaloupe juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (°C)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	69.06 ± 10.44^{aA}	52.07 ± 23.04^{aA}	5.18 ± 1.55^{a}	34.68 ± 24.72^{a}
			1.125	57.97 ± 15.15^{aAB}	42.04 ± 26.86^{aA}	6.94 ± 1.83^{a}	7.19 ± 1.90^{a}
			1.5	58.76 ± 14.80^{aAB}	37.71 ± 49.24^{aA}	9.93 ± 1.62^{a}	19.19 ± 12.72^{a}
		250	0.75	69.2 ± 10.48^{aA}	47.04 ± 43.50^{aA}	22.61 ± 6.23^{a}	21.21 ± 11.22^{a}
			1.125	73.35 ± 9.93^{aA}	64.75 ± 13.64^{aA}	5.33 ± 1.60^{a}	32.44 ± 22.40^{b}
			1.5	71.59 ± 8.84^{aA}	57.15 ± 17.47^{aA}	19.5 ± 5.51^{ab}	30.24 ± 18.06^{b}
		300	0.75	75.07 ± 10.72^{aA}	70.33 ± 12.24^{aA}	51.64 ± 14.53^{a}	59.72 ± 6.39^{a}
			1.125	71.87 ± 10.73^{aA}	71.91 ± 12.36^{aA}	50.97 ± 14.17^{a}	63.32 ± 0.23^{a}
			1.5	74.01 ± 10.90^{aA}	61.49 ± 43.6^{aA}	4.36 ± 1.36^{a}	8.58 ± 3.10^{a}
	22	200	0.75	73.2 ± 9.96^{aA}	70.33 ± 8.59^{aA}	28.58 ± 8.17^{a}	35.18 ± 28.13^{b}
			1.125	75.02 ± 6.06^{aA}	68.17 ± 9.15^{aA}	38.68 ± 10.99^{a}	43.40 ± 13.22^{a}
			1.5	65.77 ± 8.36^{aA}	44.49 ± 28.91^{abA}	17.83 ± 1.88^{b}	42.35 ± 18.10^{a}
		250	0.75	75.02 ± 9.96^{aA}	74.94 ± 8.59^{aA}	50.97 ± 8.17^{a}	64.88 ± 28.13^{a}
			1.125	72.2 ± 6.06^{aA}	71.82 ± 9.15^{aA}	52.69 ± 10.99^{a}	68.76 ± 13.22^{a}
			1.5	76.38 ± 8.36^{aA}	74.25 ± 28.91^{aA}	66.24 ± 1.88^{a}	36.08 ± 18.10^{a}
		300	0.75	76.06 ± 7.85^{aA}	75.61 ± 8.11^{abA}	57.6 ± 15.59^{ab}	69.72 ± 2.10^{b}
			1.125	73.68 ± 10.92^{aA}	73.82 ± 10.82^{aA}	55.79 ± 15.61^{b}	70.00 ± 1.56^{ab}
			1.5	75.32 ± 8.74^{aA}	76.12 ± 11.32^{aA}	61.39 ± 17.66^{a}	72.09 ± 2.27^{a}
Control	HTST		75 °C/15s	45.41 ± 15.33^{abAB}	50.27 ± 16.35^{aA}	39.32 ± 13.06^{a}	30.31 ± 3.52^{a}
			85 °C/15s	46.38 ± 10.95^{abAB}	50.96 ± 16.83^{aA}	42.53 ± 13.82^{a}	42.96 ± 7.44^{a}
			95 °C/15s	46.87 ± 14.06^{abAB}	48.39 ± 13.94^{aA}	43.3 ± 13.63^{a}	21.72 ± 4.17^{a}
	UT		Untreated	26.95 ± 24.62^{bB}	26.31 ± 26.9^{abA}	10.74 ± 3.64^{b}	13.43 ± 0.61^{ab}

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.13 Changes in pH of watermelon juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (°C)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	4.65 ± 0.07[a]	4.66 ± 0.09	5.17 ± 0.44	5.20 ± 0.58
			1.125	4.66 ± 0.09[a]	4.71 ± 0.05	5.27 ± 0.63	4.90 ± 0.69
			1.5	4.74 ± 0.11[a]	4.69 ± 0.05	5.28 ± 0.26	4.83 ± 0.69
		250	0.75	4.58 ± 0.07[a]	4.69 ± 0.12	5.28 ± 0.38	5.05 ± 0.53
			1.125	4.74 ± 0.14[a]	4.68 ± 0.08	5.21 ± 0.10	5.41 ± 0.34
			1.5	4.67 ± 0.07[a]	4.69 ± 0.09	5.55 ± 0.37	5.38 ± 0.29
		300	0.75	4.72 ± 0.07[a]	4.70 ± 0.07	5.28 ± 0.29	5.25 ± 0.59
			1.125	4.70 ± 0.04[a]	4.70 ± 0.13	5.37 ± 0.34	5.36 ± 0.27
			1.5	4.72 ± 0.08[a]	4.71 ± 0.10	5.41 ± 0.17	5.03 ± 0.19
	22	200	0.75	4.56 ± 0.06[a]	4.54 ± 0.01	4.50 ± 0.01	4.52 ± 0.04
			1.125	4.50 ± 0.05[a]	4.54 ± 0.01	4.49 ± 0.04	4.59 ± 0.03
			1.5	4.52 ± 0.06[a]	4.53 ± 0.01	4.50 ± 0.01	4.68 ± 0.22
		250	0.75	4.59 ± 0.04[a]	4.54 ± 0.01	4.50 ± 0.01	4.54 ± 0.02
			1.125	4.49 ± 0.04[a]	4.56 ± 0.02	4.49 ± 0.02	4.51 ± 0.02
			1.5	4.50 ± 0.05[a]	4.54 ± 0.01	4.57 ± 0.07	4.72 ± 0.17
		300	0.75	4.55 ± 0.07[a]	4.55 ± 0.01	4.49 ± 0.01	4.53 ± 0.02
			1.125	4.49 ± 0.04[a]	4.57 ± 0.03	4.94 ± 0.44	4.52 ± 0.04
			1.5	4.51 ± 0.05[a]	4.57 ± 0.01	4.70 ± 0.25	4.78 ± 0.29
Control	HTST		75 °C/15s	4.47 ± 0.05[a]	4.54 ± 0.01	4.64 ± 0.15	4.53 ± 0.05
			85 °C/15s	4.50 ± 0.05[a]	4.61 ± 0.11	4.68 ± 0.41	4.45 ± 0.11
			95 °C/15s	4.47 ± 0.06[a]	4.59 ± 0.08	4.94 ± 0.38	5.00 ± 0.38
	UT		Untreated	4.58 ± 0.03	5.13 ± 0.06	4.52 ± 0.66	4.16 ± 0.06

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.14 Changes in turbidity of watermelon juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	11.04 ± 0.52[b]	11.04 ± 0.55	10.19 ± 0.52	10.18 ± 0.54
			1.125	11.44 ± 0.57[b]	11.43 ± 0.53	5.10 ± 0.57	5.09 ± 0.52
			1.5	8.53 ± 0.51[b]	8.53 ± 0.57	5.91 ± 0.51	5.90 ± 0.56
		250	0.75	11.76 ± 0.51[b]	11.75 ± 0.57	5.97 ± 0.51	5.96 ± 0.56
			1.125	9.22 ± 0.54[b]	9.22 ± 0.53	7.79 ± 0.54	7.78 ± 0.52
			1.5	10.00 ± 0.59[b]	10.00 ± 0.51	8.56 ± 0.59	8.55 ± 0.50
		300	0.75	10.72 ± 0.51[b]	10.72 ± 0.54	10.06 ± 0.51	10.05 ± 0.53
			1.125	9.07 ± 0.58[b]	9.06 ± 0.51	5.94 ± 0.58	5.93 ± 0.50
			1.5	8.39 ± 0.51[b]	8.39 ± 0.55	12.02 ± 0.51	12.01 ± 0.54
	22	200	0.75	10.30 ± 0.58[b]	10.29 ± 0.58	13.36 ± 0.58	13.35 ± 0.57
			1.125	10.89 ± 0.51[b]	10.89 ± 0.51	10.15 ± 0.51	10.14 ± 0.50
			1.5	14.12 ± 0.53[b]	14.11 ± 0.56	11.78 ± 0.53	11.77 ± 0.55
		250	0.75	14.49 ± 0.52[b]	14.49 ± 0.52	16.07 ± 0.52	16.06 ± 0.51
			1.125	11.32 ± 0.56[b]	11.32 ± 0.51	9.81 ± 0.56	9.80 ± 0.50
			1.5	16.08 ± 0.51[b]	16.07 ± 0.51	16.43 ± 0.51	16.42 ± 0.50
		300	0.75	14.34 ± 0.54[b]	14.34 ± 0.53	12.44 ± 0.54	12.43 ± 0.52
			1.125	11.80 ± 0.51[b]	11.80 ± 0.54	13.01 ± 0.51	13.00 ± 0.53
			1.5	11.31 ± 0.53[b]	11.30 ± 0.51	11.89 ± 0.53	11.88 ± 0.50
Control	HTST		75 °C/15s	18.96 ± 0.54[a]	18.95 ± 0.54	15.60 ± 0.54	15.59 ± 0.53
			85 °C/15s	23.04 ± 0.51[a]	23.04 ± 0.53	21.89 ± 0.51	21.88 ± 0.52
			95 °C/15s	25.51 ± 0.51[a]	25.51 ± 0.51	25.03 ± 0.51	25.02 ± 0.50
	UT		Untreated	18.86 ± 0.51[a]	18.85 ± 0.56	23.32 ± 0.51	23.31 ± 0.55

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.15 Changes in TSS (°Brix) of watermelon juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (℃)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	8.80 ± 0.40[a]	8.77 ± 0.33	8.74 ± 0.61	9.04 ± 0.59
			1.125	8.74 ± 0.67[a]	8.97 ± 0.47	8.60 ± 0.52	8.54 ± 0.33
			1.5	8.97 ± 0.69[a]	9.20 ± 0.50	9.17 ± 0.67	8.70 ± 0.70
		250	0.75	8.50 ± 0.37[a]	8.70 ± 0.30	8.57 ± 0.42	8.30 ± 0.18
			1.125	8.64 ± 0.57[a]	8.67 ± 0.58	8.77 ± 0.52	8.57 ± 0.24
			1.5	9.00 ± 0.10[a]	9.30 ± 0.53	8.87 ± 0.61	8.77 ± 0.57
		300	0.75	8.80 ± 0.27[a]	8.87 ± 0.26	8.87 ± 0.16	8.60 ± 0.27
			1.125	8.90 ± 0.18[a]	8.67 ± 0.29	8.67 ± 0.21	8.57 ± 0.33
			1.5	9.10 ± 0.20[a]	8.94 ± 0.26	8.90 ± 0.21	8.70 ± 0.30
	22	200	0.75	9.04 ± 0.29[a]	8.80 ± 0.18	8.64 ± 0.93	8.34 ± 0.42
			1.125	8.54 ± 0.51[a]	8.67 ± 0.31	8.27 ± 0.21	8.74 ± 0.38
			1.5	8.87 ± 0.41[a]	8.50 ± 0.27	8.37 ± 0.41	8.40 ± 0.18
		250	0.75	8.70 ± 0.11[a]	8.94 ± 0.56	8.60 ± 0.21	8.50 ± 0.37
			1.125	8.57 ± 0.56[a]	8.87 ± 0.16	8.47 ± 0.46	8.50 ± 0.53
			1.5	8.60 ± 0.44[a]	8.74 ± 0.42	8.50 ± 0.46	8.54 ± 0.76
		300	0.75	9.00 ± 0.20[a]	9.04 ± 0.77	8.50 ± 0.31	8.50 ± 0.27
			1.125	8.90 ± 0.31[a]	8.77 ± 0.50	8.47 ± 0.41	8.37 ± 0.36
			1.5	8.80 ± 0.21[a]	8.70 ± 0.21	8.37 ± 0.36	8.44 ± 0.38
Control	HTST		75 ℃/15s	8.64 ± 0.48[a]	8.77 ± 0.82	8.47 ± 0.47	8.50 ± 0.27
			85 ℃/15s	8.54 ± 0.31[a]	8.74 ± 0.42	8.60 ± 0.80	8.34 ± 0.21
			95 ℃/15s	8.47 ± 0.21[a]	8.60 ± 0.40	8.57 ± 0.41	8.40 ± 0.18
	UT		Untreated	8.70 ± 0.44[a]	8.24 ± 0.29	8.24 ± 0.33	7.20 ± 0.21

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.16 Changes in titratable acidity (%TA) of watermelon juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	0.36 ± 0.03[a]	0.35 ± 0.03	0.30 ± 0.07	0.30 ± 0.10
			1.125	0.34 ± 0.02[a]	0.34 ± 0.02	0.27 ± 0.03	0.40 ± 0.13
			1.5	0.32 ± 0.08[a]	0.40 ± 0.11	0.25 ± 0.05	0.35 ± 0.10
		250	0.75	0.36 ± 0.04[a]	0.37 ± 0.02	0.27 ± 0.05	0.35 ± 0.01
			1.125	0.30 ± 0.04[a]	0.30 ± 0.05	0.26 ± 0.05	0.26 ± 0.12
			1.5	0.32 ± 0.05[a]	0.23 ± 0.08	0.15 ± 0.05	0.18 ± 0.08
		300	0.75	0.30 ± 0.04[a]	0.33 ± 0.01	0.27 ± 0.07	0.27 ± 0.11
			1.125	0.32 ± 0.07[a]	0.30 ± 0.06	0.26 ± 0.05	0.28 ± 0.11
			1.5	0.18 ± 0.03[a]	0.19 ± 0.04	0.13 ± 0.03	0.20 ± 0.07
	22	200	0.75	0.21 ± 0.11[a]	0.18 ± 0.01	0.19 ± 0.05	0.19 ± 0.08
			1.125	0.16 ± 0.07[a]	0.22 ± 0.02	0.17 ± 0.01	0.19 ± 0.06
			1.5	0.17 ± 0.07[a]	0.19 ± 0.00	0.18 ± 0.07	0.17 ± 0.01
		250	0.75	0.18 ± 0.10[a]	0.19 ± 0.05	0.19 ± 0.06	0.19 ± 0.03
			1.125	0.17 ± 0.10[a]	0.19 ± 0.03	0.19 ± 0.06	0.19 ± 0.07
			1.5	0.16 ± 0.07[a]	0.18 ± 0.01	0.19 ± 0.05	0.19 ± 0.10
		300	0.75	0.19 ± 0.10[a]	0.19 ± 0.07	0.19 ± 0.03	0.18 ± 0.06
			1.125	0.18 ± 0.09[a]	0.19 ± 0.03	0.18 ± 0.03	0.19 ± 0.03
			1.5	0.16 ± 0.07[a]	0.19 ± 0.02	0.14 ± 0.02	0.14 ± 0.01
Control	HTST		75 °C/15s	0.24 ± 0.01[a]	0.20 ± 0.01	0.17 ± 0.02	0.19 ± 0.00
			85 °C/15s	0.22 ± 0.04[a]	0.18 ± 0.03	0.18 ± 0.06	0.19 ± 0.04
			95 °C/15s	0.24 ± 0.01[a]	0.18 ± 0.03	0.17 ± 0.05	0.15 ± 0.06
	UT		Untreated	0.29 ± 0.01[a]	0.31 ± 0.01	0.92 ± 0.50	1.47 ± 0.12

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.17 Changes in viscosity of watermelon juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (°C)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	1.55 ± 0.06	1.49 ± 0.06	1.58 ± 0.03	1.48 ± 0.03
			1.125	1.55 ± 0.01	1.67 ± 0.03	1.64 ± 0.08	1.56 ± 0.04
			1.5	1.77 ± 0.08	1.63 ± 0.02	1.61 ± 0.03	1.53 ± 0.05
		250	0.75	1.54 ± 0.07	1.65 ± 0.06	1.60 ± 0.08	1.56 ± 0.02
			1.125	1.70 ± 0.01	1.62 ± 0.03	1.57 ± 0.03	1.66 ± 0.05
			1.5	1.64 ± 0.06	1.51 ± 0.07	1.54 ± 0.03	1.59 ± 0.05
		300	0.75	1.51 ± 0.01	1.53 ± 0.02	1.54 ± 0.03	1.68 ± 0.05
			1.125	1.69 ± 0.02	1.78 ± 0.05	1.62 ± 0.10	1.82 ± 0.28
			1.5	1.56 ± 0.17	1.51 ± 0.05	1.58 ± 0.02	1.64 ± 0.02
	22	200	0.75	1.43 ± 0.02	1.56 ± 0.12	1.48 ± 0.01	1.45 ± 0.05
			1.125	1.45 ± 0.04	1.43 ± 0.02	1.46 ± 0.02	1.70 ± 0.22
			1.5	1.49 ± 0.07	1.43 ± 0.03	1.46 ± 0.02	1.45 ± 0.03
		250	0.75	1.41 ± 0.01	1.44 ± 0.02	1.46 ± 0.02	1.43 ± 0.06
			1.125	1.48 ± 0.07	1.46 ± 0.04	1.46 ± 0.02	1.45 ± 0.04
			1.5	1.47 ± 0.05	1.45 ± 0.03	1.51 ± 0.02	1.45 ± 0.04
		300	0.75	1.38 ± 0.02	1.56 ± 0.11	1.45 ± 0.03	1.43 ± 0.04
			1.125	1.48 ± 0.07	1.45 ± 0.01	1.47 ± 0.01	1.71 ± 0.26
			1.5	1.48 ± 0.05	1.44 ± 0.01	1.44 ± 0.05	1.45 ± 0.03
Control	HTST		75 °C/15s	1.50 ± 0.07	1.46 ± 0.03	1.46 ± 0.03	1.48 ± 0.07
			85 °C/15s	1.51 ± 0.06	1.46 ± 0.02	1.5 ± 0.010	1.49 ± 0.07
			95 °C/15s	1.53 ± 0.07	1.47 ± 0.03	1.54 ± 0.08	1.51 ± 0.06
	UT		Untreated	1.44 ± 0.01	1.56 ± 0.04	1.77 ± 0.44	1.73 ± 0.14

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.18 Changes in pH of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	3.39 ± 0.18[a]	3.35 ± 0.06	3.32 ± 0.05	3.15 ± 0.07
			1.125	3.23 ± 0.12[a]	3.31 ± 0.08	3.24 ± 0.03	3.16 ± 0.12
			1.5	3.27 ± 0.15[a]	3.32 ± 0.05	3.31 ± 0.07	3.19 ± 0.07
		250	0.75	3.29 ± 0.08[a]	3.34 ± 0.06	3.20 ± 0.11	3.11 ± 0.12
			1.125	3.41 ± 0.27[a]	3.33 ± 0.08	3.25 ± 0.10	3.13 ± 0.13
			1.5	3.27 ± 0.11[a]	3.31 ± 0.09	3.24 ± 0.02	3.15 ± 0.04
		300	0.75	3.32 ± 0.07[a]	3.38 ± 0.08	3.29 ± 0.04	3.18 ± 0.11
			1.125	3.37 ± 0.24[a]	3.31 ± 0.01	3.28 ± 0.04	3.17 ± 0.12
			1.5	3.28 ± 0.17[a]	3.35 ± 0.13	3.26 ± 0.05	3.20 ± 0.14
	22	200	0.75	3.20 ± 0.16[a]	3.25 ± 0.14	3.14 ± 0.06	3.09 ± 0.08
			1.125	3.20 ± 0.10[a]	3.25 ± 0.15	3.26 ± 0.06	3.08 ± 0.07
			1.5	3.18 ± 0.11[a]	3.18 ± 0.09	3.21 ± 0.10	3.09 ± 0.07
		250	0.75	3.16 ± 0.08[a]	3.16 ± 0.06	3.21 ± 0.09	3.09 ± 0.06
			1.125	3.18 ± 0.06[a]	3.15 ± 0.05	3.17 ± 0.05	3.01 ± 0.05
			1.5	3.17 ± 0.13[a]	3.15 ± 0.06	3.20 ± 0.10	3.10 ± 0.08
		300	0.75	3.20 ± 0.09[a]	3.16 ± 0.02	3.18 ± 0.04	3.09 ± 0.08
			1.125	3.14 ± 0.10[a]	3.15 ± 0.05	3.21 ± 0.09	3.09 ± 0.04
			1.5	3.20 ± 0.12[a]	3.13 ± 0.06	3.23 ± 0.10	3.04 ± 0.09
Control	HTST		75 °C/15s	3.16 ± 0.10[a]	3.19 ± 0.13	3.17 ± 0.11	3.07 ± 0.15
			85 °C/15s	3.21 ± 0.12[a]	3.20 ± 0.10	3.12 ± 0.03	3.04 ± 0.13
			95 °C/15s	3.17 ± 0.07[a]	3.19 ± 0.11	3.12 ± 0.11	3.05 ± 0.14
	UT		Untreated	3.02 ± 0.14[a]	3.15 ± 0.07	3.06 ± 0.03	3.09 ± 0.08

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.19 Changes in TSS (°Brix) of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	10.83 ± 0.40[a]	10.20 ± 0.61	10.33 ± 0.40	9.53 ± 1.62
			1.125	10.50 ± 0.72[a]	11.13 ± 0.58	11.53 ± 0.68	10.87 ± 0.45
			1.5	10.87 ± 0.67[a]	10.43 ± 0.55	10.77 ± 0.49	10.53 ± 0.70
		250	0.75	10.60 ± 1.05[a]	10.70 ± 0.56	10.73 ± 0.06	10.60 ± 0.35
			1.125	10.37 ± 0.90[a]	11.27 ± 0.35	11.03 ± 0.31	11.17 ± 0.31
			1.5	11.20 ± 0.46[a]	11.00 ± 0.53	10.97 ± 0.67	11.00 ± 0.69
		300	0.75	10.53 ± 0.83[a]	10.67 ± 0.86	11.17 ± 0.21	10.80 ± 0.36
			1.125	11.30 ± 0.20[a]	10.97 ± 0.45	10.93 ± 0.25	11.03 ± 0.35
			1.5	10.97 ± 0.21[a]	10.87 ± 0.50	11.10 ± 0.72	11.00 ± 0.36
	22	200	0.75	9.47 ± 0.90[a]	9.17 ± 0.81	9.53 ± 1.01	9.20 ± 0.61
			1.125	9.83 ± 0.67[a]	9.67 ± 0.47	9.67 ± 0.12	9.47 ± 0.64
			1.5	9.90 ± 0.44[a]	9.60 ± 0.35	9.13 ± 1.45	9.47 ± 0.47
		250	0.75	10.07 ± 0.55[a]	9.73 ± 0.59	9.70 ± 0.66	9.50 ± 0.61
			1.125	9.97 ± 0.57[a]	9.77 ± 0.55	9.80 ± 0.79	9.57 ± 0.55
			1.5	10.03 ± 0.67[a]	9.73 ± 0.59	9.70 ± 0.95	9.57 ± 0.72
		300	0.75	9.73 ± 0.75[a]	9.73 ± 0.51	9.87 ± 0.38	9.50 ± 0.70
			1.125	9.93 ± 0.59[a]	9.70 ± 0.53	9.87 ± 1.17	9.60 ± 0.70
			1.5	10.10 ± 0.70[a]	9.73 ± 0.67	9.77 ± 0.93	9.43 ± 0.68
Control	HTST		75 °C/15s	9.83 ± 0.59[a]	9.60 ± 0.46	9.53 ± 0.68	9.63 ± 0.65
			85 °C/15s	9.93 ± 0.49[a]	9.77 ± 0.47	9.60 ± 0.89	9.53 ± 0.78
			95 °C/15s	9.97 ± 0.64[a]	9.67 ± 0.72	9.73 ± 0.76	9.77 ± 1.33
	UT		Untreated	10.33 ± 0.55	9.30 ± 1.04	9.70 ± 0.75	10.33 ± 0.25

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.20 Changes in viscosity of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	2.02 ± 0.10[a]	1.86 ± 0.13	1.93 ± 0.04	1.73 ± 0.09
			1.125	1.98 ± 0.09[a]	2.03 ± 0.05	2.11 ± 0.15	1.71 ± 0.10
			1.5	2.04 ± 0.01[a]	1.77 ± 0.13	1.93 ± 0.16	1.79 ± 0.20
		250	0.75	2.05 ± 0.06[a]	2.09 ± 0.12	2.05 ± 0.18	1.86 ± 0.25
			1.125	2.02 ± 0.05[a]	2.08 ± 0.15	2.00 ± 0.17	1.81 ± 0.09
			1.5	2.08 ± 0.10[a]	1.93 ± 0.15	1.95 ± 0.10	1.97 ± 0.25
		300	0.75	1.97 ± 0.07[a]	2.12 ± 0.19	2.03 ± 0.07	1.83 ± 0.20
			1.125	2.05 ± 0.09[a]	2.10 ± 0.12	2.02 ± 0.08	1.81 ± 0.06
			1.5	2.08 ± 0.11[a]	2.05 ± 0.28	2.13 ± 0.06	1.95 ± 0.04
	22	200	0.75	1.91 ± 0.04[a]	1.88 ± 0.12	1.89 ± 0.17	1.66 ± 0.05
			1.125	1.95 ± 0.06[a]	1.85 ± 0.14	1.88 ± 0.08	1.68 ± 0.05
			1.5	1.93 ± 0.08[a]	1.77 ± 0.02	1.79 ± 0.04	1.73 ± 0.13
		250	0.75	1.96 ± 0.12[a]	1.76 ± 0.02	1.79 ± 0.13	1.70 ± 0.11
			1.125	1.91 ± 0.05[a]	1.78 ± 0.02	1.73 ± 0.02	1.82 ± 0.08
			1.5	1.91 ± 0.05[a]	1.75 ± 0.03	1.81 ± 0.12	1.73 ± 0.14
		300	0.75	1.94 ± 0.04[a]	1.71 ± 0.04	1.82 ± 0.05	1.65 ± 0.05
			1.125	1.92 ± 0.02[a]	1.73 ± 0.01	1.70 ± 0.01	1.73 ± 0.12
			1.5	1.86 ± 0.06[a]	1.75 ± 0.09	1.71 ± 0.17	1.65 ± 0.14
Control	HTST		75 °C/15s	2.28 ± 0.59[a]	2.20 ± 0.32	2.20 ± 0.58	2.08 ± 0.40
			85 °C/15s	2.23 ± 0.53[a]	2.14 ± 0.26	2.10 ± 0.48	1.81 ± 0.05
			95 °C/15s	2.19 ± 0.48[a]	2.07 ± 0.21	2.09 ± 0.43	2.03 ± 0.27
	UT		Untreated	2.05 ± 0.11	1.73 ± 0.06	1.78 ± 0.17	1.61 ± 0.03

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.21 Changes in titratable acidity (%TA) of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	0.94 ± 0.05[a]	0.94 ± 0.16	0.95 ± 0.18	0.92 ± 0.11
			1.125	0.93 ± 0.22[a]	0.95 ± 0.14	0.93 ± 0.16	0.96 ± 0.15
			1.5	0.96 ± 0.16[a]	0.94 ± 0.16	0.97 ± 0.16	0.98 ± 0.16
		250	0.75	0.97 ± 0.04[a]	0.87 ± 0.09	0.90 ± 0.09	0.89 ± 0.10
			1.125	0.94 ± 0.10[a]	0.92 ± 0.13	0.90 ± 0.08	0.95 ± 0.12
			1.5	0.95 ± 0.19[a]	0.91 ± 0.13	0.91 ± 0.12	0.97 ± 0.19
		300	0.75	0.96 ± 0.15[a]	0.91 ± 0.11	0.91 ± 0.11	0.93 ± 0.15
			1.125	0.97 ± 0.13[a]	0.77 ± 0.21	0.90 ± 0.09	0.90 ± 0.12
			1.5	0.96 ± 0.16[a]	0.91 ± 0.09	0.88 ± 0.11	0.87 ± 0.07
	22	200	0.75	0.96 ± 0.07[a]	0.91 ± 0.03	0.92 ± 0.03	0.95 ± 0.03
			1.125	0.98 ± 0.02[a]	0.96 ± 0.03	0.96 ± 0.02	0.96 ± 0.00
			1.5	0.99 ± 0.01[a]	0.93 ± 0.05	0.93 ± 0.02	0.98 ± 0.05
		250	0.75	0.94 ± 0.03[a]	0.94 ± 0.02	0.95 ± 0.02	0.99 ± 0.04
			1.125	0.99 ± 0.04[a]	0.94 ± 0.03	0.97 ± 0.03	0.96 ± 0.01
			1.5	1.02 ± 0.04[a]	0.98 ± 0.01	0.96 ± 0.01	0.96 ± 0.01
		300	0.75	1.03 ± 0.03[a]	0.93 ± 0.03	0.97 ± 0.01	0.94 ± 0.03
			1.125	1.02 ± 0.06[a]	0.95 ± 0.01	0.97 ± 0.03	0.97 ± 0.02
			1.5	0.99 ± 0.04[a]	0.95 ± 0.05	0.95 ± 0.01	0.99 ± 0.03
Control	HTST		75 °C/15s	1.01 ± 0.08[a]	0.90 ± 0.05	0.96 ± 0.02	0.95 ± 0.03
			85 °C/15s	0.99 ± 0.05[a]	0.82 ± 0.20	0.96 ± 0.00	0.96 ± 0.03
			95 °C/15s	0.98 ± 0.09[a]	0.96 ± 0.04	0.98 ± 0.02	0.98 ± 0.06
	UT		Untreated	1.25 ± 0.06[a]	1.28 ± 0.11	1.27 ± 0.09	1.31 ± 0.11

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.22 Changes in turbidity of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (°C)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	70.24 ± 2.91[a]	47.35 ± 23.07	45.31 ± 24.01	16.67 ± 2.62
			1.125	67.91 ± 1.40[a]	70.92 ± 1.33	35.78 ± 18.50	14.55 ± 0.77
			1.5	67.59 ± 1.92[a]	47.68 ± 27.24	19.37 ± 1.20	19.45 ± 5.49
		250	0.75	70.60 ± 1.98[a]	73.92 ± 3.32	42.65 ± 31.03	39.81 ± 31.21
			1.125	70.48 ± 5.55[a]	76.20 ± 0.76	40.87 ± 27.97	38.26 ± 29.37
			1.5	68.51 ± 3.52[a]	74.74 ± 3.23	39.56 ± 30.42	35.80 ± 25.05
		300	0.75	71.89 ± 2.76[a]	75.03 ± 0.83	73.07 ± 3.91	30.25 ± 18.30
			1.125	70.00 ± 3.63[a]	73.02 ± 2.02	39.82 ± 28.87	15.96 ± 3.66
			1.5	70.10 ± 2.72[a]	73.08 ± 5.24	71.99 ± 3.54	70.94 ± 7.45
	22	200	0.75	64.89 ± 2.09[a]	68.90 ± 2.23	51.21 ± 14.56	66.13 ± 0.28
			1.125	65.06 ± 4.66[a]	67.36 ± 0.56	70.86 ± 4.89	68.95 ± 1.07
			1.5	69.50 ± 4.72[a]	66.42 ± 1.32	69.08 ± 0.17	68.27 ± 0.55
		250	0.75	65.02 ± 1.98[a]	72.32 ± 0.22	68.75 ± 0.19	70.13 ± 0.98
			1.125	67.34 ± 1.55[a]	68.94 ± 0.87	71.63 ± 3.20	72.61 ± 1.85
			1.5	69.53 ± 0.65[a]	68.25 ± 1.95	70.29 ± 0.32	67.34 ± 1.72
		300	0.75	63.75 ± 2.90[a]	65.65 ± 0.18	68.17 ± 1.27	53.43 ± 9.94
			1.125	66.97 ± 2.17[a]	68.36 ± 1.89	66.77 ± 1.75	71.22 ± 0.71
			1.5	69.46 ± 0.69[a]	68.68 ± 0.12	69.11 ± 1.30	70.19 ± 0.39
Control	HTST		75 °C/15s	43.19 ± 18.02[b]	33.46 ± 7.48	30.37 ± 5.78	30.49 ± 6.16
			85 °C/15s	43.96 ± 18.04[b]	34.65 ± 8.98	31.51 ± 5.12	30.81 ± 5.73
			95 °C/15s	44.64 ± 18.75[b]	32.61 ± 3.75	34.91 ± 3.69	38.90 ± 5.33
	UT		Untreated	43.53 ± 6.09[b]	39.41 ± 1.56	19.6 ± 10.42	11.82 ± 0.34

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.23 Changes in color (L*) of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (°C)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	50.08 ± 0.73	48.35 ± 1.99	47.24 ± 1.43	46.74 ± 0.78
			1.125	50.20 ± 0.46	49.94 ± 0.02	47.44 ± 1.20	46.38 ± 0.84
			1.5	50.00 ± 0.45	47.88 ± 1.59	43.89 ± 4.21	46.96 ± 0.67
		250	0.75	50.82 ± 0.85	51.30 ± 0.31	48.17 ± 1.75	48.04 ± 1.56
			1.125	50.78 ± 0.85	50.02 ± 0.12	48.41 ± 1.48	47.30 ± 0.38
			1.5	50.47 ± 0.33	49.98 ± 0.94	47.63 ± 0.62	47.07 ± 0.80
		300	0.75	50.07 ± 0.48	50.22 ± 0.29	48.72 ± 0.52	47.34 ± 1.14
			1.125	50.67 ± 0.69	50.37 ± 0.29	48.27 ± 1.32	47.42 ± 0.60
			1.5	50.60 ± 0.50	50.17 ± 0.38	48.99 ± 0.48	48.10 ± 0.68
	22	200	0.75	47.29 ± 1.94	47.84 ± 1.93	44.17 ± 1.77	44.50 ± 2.02
			1.125	47.57 ± 1.97	46.79 ± 2.28	44.35 ± 2.41	44.18 ± 2.83
			1.5	48.63 ± 2.08	47.76 ± 2.81	44.26 ± 2.73	44.70 ± 3.23
		250	0.75	47.41 ± 2.09	47.32 ± 2.26	44.05 ± 2.70	44.88 ± 2.47
			1.125	48.14 ± 1.38	47.19 ± 1.68	44.74 ± 2.44	45.07 ± 2.63
			1.5	47.54 ± 1.41	47.38 ± 1.86	44.53 ± 2.53	44.88 ± 2.52
		300	0.75	47.32 ± 1.92	47.38 ± 1.35	44.79 ± 2.38	45.87 ± 4.61
			1.125	47.56 ± 1.33	45.71 ± 1.53	45.44 ± 2.13	45.25 ± 2.72
			1.5	48.17 ± 1.34	47.75 ± 1.40	45.20 ± 1.86	44.68 ± 2.21
Control	HTST		75 °C/15s	45.28 ± 1.85	42.75 ± 3.46	42.46 ± 2.56	42.66 ± 2.14
			85 °C/15s	45.07 ± 2.33	43.65 ± 3.50	42.79 ± 2.30	43.13 ± 2.48
			95 °C/15s	44.14 ± 1.31	42.54 ± 2.70	42.33 ± 2.21	42.43 ± 1.96
	UT		Untreated	45.26 ± 2.60	40.73 ± 2.13	39.08 ± 2.34	38.98 ± 2.71

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.24 Changes in color (a*) of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	9.62 ± 2.04	11.13 ± 1.81	13.16 ± 1.35	13.42 ± 1.67
			1.125	8.96 ± 1.89	9.77 ± 1.35	12.18 ± 0.41	13.66 ± 1.51
			1.5	9.42 ± 1.69	12.16 ± 2.57	12.88 ± 1.68	14.03 ± 1.37
		250	0.75	9.73 ± 1.79	9.96 ± 1.63	12.32 ± 1.17	12.34 ± 1.62
			1.125	9.12 ± 1.88	9.61 ± 1.18	12.01 ± 1.44	12.68 ± 1.62
			1.5	9.59 ± 1.28	10.07 ± 1.81	13.15 ± 1.91	13.14 ± 2.12
		300	0.75	10.13 ± 2.28	10.2 ± 1.58	12.17 ± 0.57	13.33 ± 0.84
			1.125	10.10 ± 1.32	10.15 ± 1.42	12.50 ± 1.03	12.75 ± 1.32
			1.5	9.93 ± 1.55	10.08 ± 1.74	12.15 ± 0.94	12.42 ± 1.64
	22	200	0.75	14.72 ± 3.26	14.58 ± 2.92	18.59 ± 3.32	18.58 ± 3.00
			1.125	14.72 ± 3.10	14.93 ± 2.63	18.62 ± 3.73	18.72 ± 3.11
			1.5	14.19 ± 2.81	13.70 ± 4.29	18.80 ± 4.08	18.29 ± 3.76
		250	0.75	14.99 ± 3.53	15.06 ± 3.45	18.62 ± 3.83	18.78 ± 4.08
			1.125	15.22 ± 3.19	14.85 ± 3.37	18.58 ± 3.51	18.42 ± 3.85
			1.5	14.60 ± 3.11	14.29 ± 2.60	18.38 ± 3.72	18.21 ± 3.59
		300	0.75	15.7 ± 3.40	15.36 ± 3.35	18.79 ± 3.54	18.36 ± 4.09
			1.125	15.03 ± 3.12	14.57 ± 3.99	18.46 ± 3.48	18.44 ± 3.48
			1.5	15.27 ± 3.40	15.16 ± 3.49	18.61 ± 3.64	18.93 ± 2.84
Control	HTST		75 °C/15s	15.64 ± 3.74	18.32 ± 6.04	19.20 ± 4.09	19.09 ± 3.87
			85 °C/15s	15.85 ± 3.09	18.02 ± 5.25	18.87 ± 3.56	18.53 ± 3.19
			95 °C/15s	16.94 ± 3.34	18.20 ± 5.19	19.19 ± 3.91	19.03 ± 3.71
	UT		Untreated	18.60 ± 2.72	23.19 ± 2.94	24.58 ± 2.88	25.23 ± 2.22

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.25 Changes in color (b*) of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	**T_{in} (°C)**	**P (MPa)**	**FR (L/min)**	**Day 0**	**Day 15**	**Day 30**	**Day 45**
UHPH	4	200	0.75	28.02 ± 1.24	27.28 ± 1.15	26.63 ± 1.13	27.47 ± 1.43
			1.125	28.20 ± 0.80	28.29 ± 0.59	27.94 ± 1.33	29.22 ± 4.20
			1.5	28.09 ± 0.60	28.13 ± 2.82	26.82 ± 1.72	33.96 ± 0.99
		250	0.75	27.81 ± 2.02	28.46 ± 3.00	28.17 ± 0.91	28.46 ± 3.25
			1.125	26.74 ± 2.27	26.65 ± 1.94	27.03 ± 1.22	29.38 ± 4.83
			1.5	27.09 ± 1.83	27.99 ± 1.90	27.43 ± 1.91	30.87 ± 3.79
		300	0.75	27.06 ± 1.89	26.54 ± 1.94	25.58 ± 1.56	28.19 ± 5.67
			1.125	27.19 ± 2.28	27.22 ± 2.43	27.07 ± 0.32	30.45 ± 4.45
			1.5	26.92 ± 1.85	27.05 ± 2.58	26.12 ± 2.51	25.24 ± 2.40
	22	200	0.75	28.42 ± 1.37	29.13 ± 0.34	27.98 ± 4.06	28.36 ± 3.60
			1.125	28.63 ± 1.75	28.76 ± 1.97	26.53 ± 2.09	28.68 ± 5.29
			1.5	28.32 ± 2.03	29.35 ± 1.04	26.46 ± 1.73	26.89 ± 1.72
		250	0.75	27.70 ± 1.71	28.40 ± 2.12	25.77 ± 2.74	25.9 ± 1.48
			1.125	27.68 ± 0.87	28.02 ± 1.28	25.27 ± 2.27	26.06 ± 3.20
			1.5	27.97 ± 0.74	28.02 ± 2.08	24.85 ± 2.08	25.46 ± 1.61
		300	0.75	27.82 ± 1.79	28.53 ± 0.67	25.95 ± 2.93	25.07 ± 1.30
			1.125	27.38 ± 0.95	27.62 ± 0.19	25.42 ± 2.40	25.81 ± 2.29
			1.5	27.99 ± 0.68	28.73 ± 0.62	25.72 ± 2.00	26.61 ± 4.03
Control	HTST		75 °C/15s	31.63 ± 0.33	29.10 ± 2.60	27.00 ± 3.72	29.44 ± 0.60
			85 °C/15s	31.65 ± 0.72	30.14 ± 3.07	29.98 ± 0.45	29.47 ± 1.10
			95 °C/15s	31.53 ± 0.70	29.93 ± 2.01	30.42 ± 0.88	30.50 ± 1.02
	UT		Untreated	31.38 ± 1.11	30.48 ± 1.25	31.45 ± 3.39	32.40 ± 2.25

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.26 Changes in total color difference (TCD) of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	10.83 ± 2.33	9.76 ± 4.15	8.22 ± 2.71	7.44 ± 1.52
			1.125	11.44 ± 2.33	10.60 ± 3.05	8.23 ± 2.45	7.09 ± 3.43
			1.5	11.01 ± 3.40	8.19 ± 2.12	8.44 ± 3.04	6.00 ± 3.01
		250	0.75	11.12 ± 2.49	11.13 ± 2.92	7.91 ± 3.04	8.31 ± 1.99
			1.125	11.96 ± 2.89	11.29 ± 3.22	8.82 ± 2.77	8.39 ± 1.33
			1.5	11.34 ± 3.31	10.49 ± 2.62	7.57 ± 0.66	6.70 ± 0.88
		300	0.75	10.79 ± 3.00	10.96 ± 2.96	9.52 ± 3.10	8.35 ± 3.45
			1.125	10.97 ± 3.21	10.80 ± 3.54	8.22 ± 2.77	7.78 ± 3.49
			1.5	11.20 ± 2.98	10.83 ± 3.25	9.36 ± 3.11	9.32 ± 3.34
	22	200	0.75	7.01 ± 4.05	6.12 ± 5.05	6.87 ± 2.09	6.51 ± 1.80
			1.125	6.98 ± 4.03	6.52 ± 3.64	7.58 ± 2.83	7.29 ± 2.61
			1.5	7.25 ± 4.11	7.49 ± 5.87	7.90 ± 1.85	7.65 ± 2.76
		250	0.75	7.38 ± 4.01	7.10 ± 4.13	8.26 ± 2.69	8.11 ± 2.46
			1.125	7.07 ± 4.02	6.95 ± 4.20	8.44 ± 2.04	8.24 ± 2.00
			1.5	6.81 ± 4.37	7.41 ± 3.48	8.86 ± 1.60	8.30 ± 2.52
		300	0.75	7.02 ± 3.62	6.10 ± 4.32	7.97 ± 2.64	9.77 ± 2.83
			1.125	7.07 ± 3.97	6.73 ± 4.35	8.25 ± 2.19	8.27 ± 1.93
			1.5	6.76 ± 4.40	6.58 ± 4.38	7.95 ± 1.56	7.45 ± 2.05
Control	HTST		75 °C/15s	6.17 ± 3.55	8.42 ± 3.94	7.90 ± 5.34	6.44 ± 3.81
			85 °C/15s	6.45 ± 2.60	7.63 ± 3.12	6.15 ± 3.72	5.90 ± 4.25
			95 °C/15s	6.12 ± 2.06	7.34 ± 4.47	6.46 ± 4.25	6.24 ± 4.14
	UT		Untreated	0.00 ± 0.00	6.55 ± 0.13	8.86 ± 0.25	9.32 ± 0.61

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.27 Changes in color (Hue°) of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	71.04 ± 4.14	67.92 ± 2.49	63.70 ± 2.92	63.96 ± 3.47
			1.125	72.36 ± 3.94	70.96 ± 2.67	66.43 ± 1.03	64.58 ± 5.93
			1.5	71.48 ± 3.33	66.48 ± 6.17	64.31 ± 4.07	67.58 ± 1.65
		250	0.75	70.68 ± 3.73	70.72 ± 2.28	66.42 ± 1.31	66.41 ± 4.23
			1.125	71.16 ± 3.68	70.16 ± 2.14	66.11 ± 1.65	66.39 ± 4.28
			1.5	70.52 ± 2.18	70.30 ± 2.34	64.48 ± 1.86	67.01 ± 1.00
		300	0.75	69.49 ± 4.38	68.98 ± 2.94	64.52 ± 2.02	64.24 ± 4.55
			1.125	69.57 ± 2.99	69.53 ± 2.74	65.24 ± 1.69	66.89 ± 5.46
			1.5	69.70 ± 3.57	69.54 ± 3.28	64.99 ± 1.91	63.72 ± 4.01
	22	200	0.75	62.66 ± 6.30	63.52 ± 4.88	56.13 ± 8.27	56.57 ± 7.32
			1.125	62.79 ± 6.16	62.50 ± 5.65	55.00 ± 7.41	56.39 ± 8.75
			1.5	63.32 ± 6.00	65.11 ± 7.69	54.74 ± 7.70	55.87 ± 7.22
		250	0.75	61.61 ± 7.02	62.04 ± 7.03	54.15 ± 8.21	54.23 ± 7.49
			1.125	61.29 ± 5.88	62.16 ± 6.30	53.70 ± 7.59	54.66 ± 8.82
			1.5	62.53 ± 5.62	62.91 ± 5.79	53.60 ± 7.85	54.54 ± 7.09
		300	0.75	60.57 ± 6.83	61.83 ± 5.82	54.03 ± 7.99	54.01 ± 7.41
			1.125	61.33 ± 5.74	62.46 ± 6.59	54.03 ± 7.63	54.47 ± 7.42
			1.5	61.52 ± 5.98	62.31 ± 6.00	54.18 ± 7.42	54.30 ± 7.89
Control	HTST		75 °C/15s	63.87 ± 5.46	57.98 ± 10.84	54.50 ± 9.18	57.22 ± 5.82
			85 °C/15s	63.50 ± 4.79	59.14 ± 9.62	57.98 ± 5.25	57.93 ± 5.37
			95 °C/15s	61.91 ± 4.53	58.85 ± 8.95	57.94 ± 5.72	58.20 ± 5.53
	UT		Untreated	59.43 ± 3.80	52.81 ± 4.11	51.93 ± 5.21	52.07 ± 4.02

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.28 Changes in color (C*) of grapefruit juice treated by UHPH and HTST during storage at 4 °C.

Tt	T_{in} (°C)	P (MPa)	FR (L/min)	Day 0	Day 15	Day 30	Day 45
UHPH	4	200	0.75	29.68 ± 1.00	29.48 ± 1.73	29.73 ± 0.91	30.61 ± 1.17
			1.125	29.63 ± 0.25	29.96 ± 0.46	30.49 ± 1.28	32.37 ± 3.07
			1.5	29.66 ± 0.49	30.76 ± 2.00	29.80 ± 1.17	36.75 ± 1.31
		250	0.75	29.51 ± 1.86	30.17 ± 3.20	30.75 ± 1.30	31.07 ± 2.83
			1.125	28.29 ± 2.29	28.34 ± 2.00	29.59 ± 1.68	32.06 ± 4.47
			1.5	28.76 ± 1.93	29.76 ± 2.32	30.43 ± 2.52	33.55 ± 4.30
		300	0.75	28.95 ± 1.93	28.46 ± 2.01	28.34 ± 1.33	31.25 ± 5.14
			1.125	29.03 ± 2.13	29.08 ± 2.43	29.83 ± 0.62	33.10 ± 3.51
			1.5	28.73 ± 1.59	28.90 ± 2.60	28.82 ± 2.50	28.18 ± 2.09
	22	200	0.75	32.14 ± 0.24	32.65 ± 1.01	33.83 ± 1.76	34.10 ± 1.61
			1.125	32.32 ± 0.79	32.51 ± 0.64	32.59 ± 0.80	34.53 ± 2.95
			1.5	31.80 ± 0.88	32.59 ± 0.82	32.65 ± 0.85	32.69 ± 0.57
		250	0.75	31.65 ± 0.58	32.31 ± 0.83	32.01 ± 1.15	32.17 ± 1.20
			1.125	31.70 ± 0.69	31.83 ± 0.95	31.55 ± 0.21	32.16 ± 0.61
			1.5	31.65 ± 0.85	31.56 ± 0.93	31.10 ± 0.41	31.46 ± 0.73
		300	0.75	32.10 ± 0.33	32.51 ± 0.98	32.25 ± 0.95	31.24 ± 1.59
			1.125	31.34 ± 0.99	31.36 ± 1.86	31.60 ± 0.43	31.90 ± 0.56
			1.5	32.00 ± 1.04	32.60 ± 1.06	31.93 ± 0.60	32.87 ± 1.82
Control	HTST		75 °C/15s	35.39 ± 1.73	34.79 ± 0.76	33.41 ± 1.69	35.20 ± 1.70
			85 °C/15s	35.48 ± 1.21	35.44 ± 1.33	35.52 ± 1.61	34.91 ± 0.87
			95 °C/15s	35.87 ± 1.89	35.32 ± 0.96	36.08 ± 1.83	36.06 ± 1.72
	UT		Untreated	36.53 ± 1.70	38.37 ± 1.66	40.02 ± 2.62	41.13 ± 1.28

The data are provided as mean value ± standard deviation (n = 3). FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.29.a Processing parameters and temperature rise after homogenization valve.

Treatments		T_{in} (°C)	P_{in} (MPa)	P_{out} (MPa)	FL (L/min)	dT (°C)	T_{out} (°C)	Residence Time (s)
UHPH		4	200	0.10	0.75	40.00 ± 2.00	50.00 ± 2.00	20.00 ± 1.00
				0.10	1.12	40.00 ± 2.00	52.00 ± 2.00	14.00 ± 1.00
				0.10	1.50	40.00 ± 2.00	54.00 ± 2.00	10.00 ± 1.00
			250	0.10	0.75	50.00 ± 2.50	60.00 ± 2.00	20.00 ± 1.00
				0.10	1.12	50.00 ± 2.50	62.00 ± 2.00	14.00 ± 1.00
				0.10	1.50	50.00 ± 2.50	64.00 ± 2.00	10.00 ± 1.00
			300	0.10	0.75	60.00 ± 3.00	70.00 ± 2.00	20.00 ± 1.00
				0.10	1.12	60.00 ± 3.00	72.00 ± 2.00	14.00 ± 1.00
				0.10	1.50	60.00 ± 3.00	74.00 ± 2.00	10.00 ± 1.00
		22	200	0.10	0.75	40.00 ± 2.00	60.00 ± 2.00	20.00 ± 1.00
				0.10	1.12	40.00 ± 2.00	62.00 ± 2.00	14.00 ± 1.00
				0.10	1.50	40.00 ± 2.00	64.00 ± 2.00	10.00 ± 1.00
			250	0.10	0.75	50.00 ± 2.50	70.00 ± 2.00	20.00 ± 1.00
				0.10	1.12	50.00 ± 2.50	72.00 ± 2.00	14.00 ± 1.00
				0.10	1.50	50.00 ± 2.50	74.00 ± 2.00	10.00 ± 1.00
			300	0.10	0.75	60.00 ± 3.00	80.00 ± 2.00	20.00 ± 1.00
				0.10	1.12	60.00 ± 3.00	82.00 ± 2.00	15.00 ± 1.00
				0.10	1.50	60.00 ± 3.00	84.00 ± 2.00	10.00 ± 1.00
Control	HTST	75	–	–	0.50	–	75.00 ± 2.00	15.00 ± 1.00
		85	–	–	0.50	–	85.00 ± 2.00	14.00 ± 1.00
		95	–	–	0.50	–	95.00 ± 2.00	15.00 ± 1.00
	UT		Untreated			–	–	–

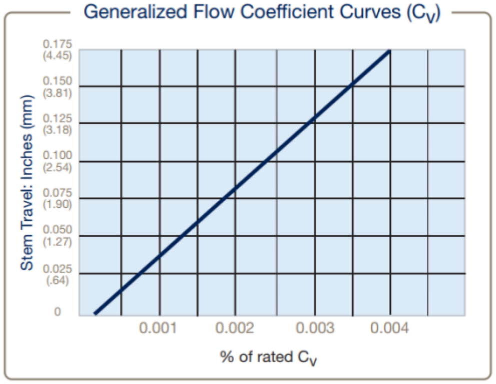
FR, flow rate; P, pressure; T_{in}, inlet temperature

Table C.29.b Theoretical processing parameters and flow behavior.

P (MPa)	FR (L/min)	Cv	Diameter (mm)	Velocity (m/s)	Reynolds Number
200	0.75	0.00149	0.46	45.64	21029
	1.125	0.00224	0.67	54.90	36824
	1.50	0.00298	0.87	61.68	53907
250	0.75	0.00133	0.43	50.45	21650
	1.125	0.00200	0.63	60.55	38427
	1.50	0.00267	0.83	68.08	56435
300	0.75	0.00122	0.41	54.30	22118
	1.125	0.00183	0.60	65.48	39582
	1.50	0.00245	0.79	73.63	58283

FR, flow rate; P, pressure; Cv, flow coefficient

According to the company manual (MicroMetering - VRMM needle valve):
Fully open orifice diameter: 1.57 mm at maximum stem travel.
Nearly closed orifice diameter: 0.15 mm at minimal stem travel.



MicroMetering (VRMM) Series Flow Curve

Table C.29.c Theoretical processing parameters.

Inlet Temp (°C)	**P (MPa)**	**FL (L/min)**	**Shear Rate (s^{-1})**	**Shear Stress (Pa)**	**Cavitation Potential**	**Temp Rise (°C)**	**Reynolds Number**
4	200	0.75	645,394	1012.28	High	40	21029
		1.125	567,567	890.09	High	40	36824
		1.5	505,747	793.95	Moderate	40	53907
	250	0.75	714,286	1120.14	Very High	50	21650
		1.125	627,451	983.88	High	50	38427
		1.5	559,701	878.73	Moderate	50	56435
	300	0.75	778,947	1222.99	Very High	60	22118
		1.125	684,932	1072.11	High	60	39582
		1.5	609,756	956.37	Moderate	60	58283
22	200	0.75	645,394	619.57	Moderate	40	21029
		1.125	567,567	544.93	Moderate	40	36824
		1.5	505,747	486.61	Low	40	53907
	250	0.75	714,286	685.71	High	50	21650
		1.125	627,451	603.36	Moderate	50	38427
		1.5	559,701	539.71	Low	50	56435
	300	0.75	778,947	745.96	High	60	22118
		1.125	684,932	659.54	Moderate	60	39582
		1.5	609,756	586.83	Low	60	58283

FR, flow rate; P, pressure

Table C.30 Microbicidal effects of UHPH and HTST on total aerobic plate count (APC) and yeast and mold (Y/M) in watermelon juice during 45 days of storage at 4 ºC.

Treatments		**Tin (°C)**	**P (MPa)**	**FR (L/min)**	**APC (log CFU/mL)**				**Y/M (log CFU/mL)**			
					Day0	**Day15**	**Day30**	**Day45**	**Day0**	**Day15**	**Day30**	**Day45**
UHPH		4	200	0.75	1.16 ± 0.12	3.84 ± 0.51	4.69 ± 0.09	5.60 ± 0.05	ND	3.42 ± 0.95	4.20 ± 1.06	5.17 ± 0.48
				1.12	1.80 ± 0.21	3.62 ± 0.16	4.80 ± 0.20	5.97 ± 0.20	ND	2.52 ± 0.98	3.76 ± 0.28	5.14 ± 0.79
				1.50	1.16 ± 0.15	3.32 ± 0.17	4.88 ± 0.09	3.12 ± 0.48	ND	2.49 ± 0.29	3.83 ± 0.16	2.23 ± 0.20
			250	0.75	ND	ND	ND	ND	ND	ND	ND	ND
				1.12	ND	ND	ND	ND	ND	ND	ND	ND
				1.50	1.40 ± 0.17	4.05 ± 0.69	5.07 ± 0.38	5.65 ± 0.38	ND	3.51 ± 0.42	4.59 ± 0.36	5.37 ± 0.05
			300	0.75	1.38 ± 0.52	3.89 ± 0.21	4.77 ± 0.14	5.83 ± 0.13	ND	2.21 ± 0.62	3.68 ± 0.90	5.31 ± 0.17
				1.12	1.43 ± 0.23	1.24 ± 0.12	1.12 ± 0.10	1.10 ± 0.17	ND	ND	ND	ND
				1.50	1.28 ± 0.17	1.89 ± 0.66	3.96 ± 0.86	ND	ND	1.21 ± 0.64	3.37 ± 0.49	ND
		22	200	0.75	1.23 ± 0.68	1.10 ± 0.17	1.26 ± 0.24	ND	ND	ND	ND	ND
				1.12	ND	1.57 ± 0.38	ND	4.93 ± 0.24	ND	ND	ND	4.04 ± 0.08
				1.50	1.29 ± 0.11	1.03 ± 0.18	1.26 ± 0.24	1.43 ± 0.51	ND	ND	ND	ND
			250	0.75	1.29 ± 0.36	1.36 ± 0.10	3.86 ± 0.21	4.24 ± 0.21	ND	ND	2.04 ± 0.24	4.04 ± 0.79
				1.12	1.12 ± 0.10	1.39 ± 0.09	ND	ND	ND	ND	ND	ND
				1.50	1.45 ± 0.39	1.29 ± 0.66	1.26 ± 0.24	5.95 ± 0.22	ND	ND	ND	4.28 ± 0.09
			300	0.75	1.45 ± 0.63	ND	ND	ND	ND	ND	ND	ND
				1.12	1.45 ± 0.78	1.10 ± 0.17	1.26 ± 0.24	1.16 ± 0.15	ND	ND	ND	ND
				1.50	1.35 ± 0.16	4.27 ± 0.21	5.16 ± 0.49	5.76 ± 0.46	ND	3.03 ± 0.30	4.63 ± 0.65	4.77 ± 0.27
Control	**HTST**	75 °C/15s			2.63 ± 0.05	2.59 ± 0.08	3.88 ± 0.10	4.66 ± 0.12	ND	1.65 ± 0.87	3.67 ± 0.84	4.42 ± 1.04
		85 °C/15s			2.05 ± 0.03	1.95 ± 0.11	3.05 ± 0.12	4.12 ± 0.13	ND	1.71 ± 0.67	2.99 ± 065	3.76 ± 1.18
		95 °C/15s			1.86 ± 0.43	1.68 ± 0.52	2.78 ± 0.20	3.88 ± 0.10	ND	1.30 ± 0.84	2.59 ± 0.54	3.41 ± 0.21
	UT	Untreated			4.23 ± 0.24	4.84 ± 0.58	4.46 ± 0.68	4.08 ± 1.10	3.32 ± 0.54	4.23 ± 0.41	4.31 ± 0.65	4.69 ± 0.93

The data are provided as mean value ± standard deviation (n = 3). Values with different letters, lowercase in row or uppercase in column (day 0), are different ($p < 0.05$). ND, not detectable (<1 Log CFU/mL)

Table C.31 Microbicidal effects of UHPH and HTST on total aerobic plate count (APC) and yeast and mold (Y/M) in blueberry juice during 45 days of storage at 4 ºC.

Treatments		Tin (℃)	P (MPa)	FR (L/min)	APC (log CFU/mL)				Y/M (log CFU/mL)			
					Day 0	Day 15	Day 30	Day 45	Day 0	Day 15	Day 30	Day 45
UHPH		4	200	0.75	1.16 ± 0.25	ND	1.81 ± 0.73	ND	ND	ND	0.75 ± 1.29	ND
				1.12	ND	ND	1.29 ± 1.07	2.92 ± 1.78	ND	ND	2.17 ± 0.43	3.94 ± 1.87
				1.50	1.07 ± 0.95	1.22 ± 1.54	2.73 ± 1.76	2.83 ± 0.67	ND	1.26 ± 1.14	3.27 ± 0.34	4.51 ± 1.00
			250	0.75	1.13 ± 0.26	ND	1.40 ± 0.75	ND	ND	ND	0.91 ± 1.58	ND
				1.12	ND	ND	ND	ND	ND	ND	ND	1.36 ± 2.36
				1.50	ND	ND	1.14 ± 1.03	ND	ND	ND	0.73 ± 1.27	1.10 ± 1.91
			300	0.75	ND	ND	ND	ND	ND	ND	ND	ND
				1.12	ND	ND	ND	ND	ND	ND	ND	ND
				1.50	ND	ND	ND	ND	ND	ND	ND	ND
		22	200	0.75	ND	ND	ND	ND	ND	ND	1.01 ± 1.75	ND
				1.12	ND	ND	1.10 ± 0.96	ND	ND	ND	1.35 ± 1.77	ND
				1.50	ND	ND	1.14 ± 0.28	ND	ND	ND	1.13 ± 1.96	ND
			250	0.75	ND	ND	ND	ND	ND	ND	ND	ND
				1.12	ND	ND	ND	ND	ND	ND	ND	ND
				1.50	ND	ND	ND	ND	ND	ND	ND	ND
			300	0.75	ND	ND	ND	ND	ND	ND	ND	ND
				1.12	ND	ND	ND	ND	ND	ND	ND	ND
				1.50	ND	ND	ND	ND	ND	ND	ND	ND
Control	HTST	75 ℃/15s			1.70 ± 0.20	1.78 ± 0.68	1.43 ± 0.11	1.61 ± 0.59	ND	ND	ND	ND
		85 ℃/15s			1.35 ± 0.33	1.25 ± 0.33	1.09 ± 0.09	1.22 ± 0.19	ND	ND	ND	ND
		95 ℃/15s			ND	ND	ND	ND	ND	ND	ND	ND
	UT	Untreated			1.75 ± 0.51	1.81 ± 1.57	3.15 ± 0.81	3.79 ± 0.54	1.62 ± 1.41	4.67 ± 0.58	4.09 ± 0.68	4.15 ± 0.67

The data are provided as mean value ± standard deviation (n = 3). Values with different letters, lowercase in row or uppercase in column (day 0), are different ($p < 0.05$). ND, not detectable (<1 Log CFU/mL)

Table C.32 Microbicidal effects of UHPH and HTST on total aerobic plate count (APC) and yeast and mold (Y/M) in cantaloupe juice during 45 days of storage at 4 ºC.

Treatments		Tin (°C)	P (MPa)	FR (L/min)	APC (log CFU/mL)				Y/M (log CFU/mL)			
					Day 0	Day 15	Day 30	Day 45	Day 0	Day 15	Day 30	Day 45
UHPH		4	200	0.75	1.30 ± 0.28	1.89 ± 0.15	2.15 ± 0.74	3.00 ± 0.58	1.70 ± 0.12	2.08 ± 0.13	3.47 ± 0.36	5.08 ± 0.18
				1.12	1.60 ± 0.35	3.10 ± 0.10	3.95 ± 0.29	4.30 ± 0.17	1.77 ± 0.35	2.23 ± 0.60	3.23 ± 0.46	5.10 ± 0.15
				1.50	1.78 ± 0.44	2.90 ± 0.23	4.28 ± 0.41	5.19 ± 0.26	1.15 ± 0.80	2.12 ± 0.22	4.04 ± 0.26	5.30 ± 0.20
			250	0.75	1.70 ± 0.47	2.57 ± 0.33	3.42 ± 0.14	3.47 ± 0.21	1.28 ± 0.25	2.39 ± 0.12	3.84 ± 0.17	3.95 ± 0.57
				1.12	ND	ND	1.02 ± 0.06	1.30 ± 0.12	ND	ND	ND	ND
				1.50	ND	ND	1.30 ± 0.16	2.00 ± 0.40	ND	ND	2.39 ± 0.20	3.65 ± 0.36
			300	0.75	ND	ND	ND	1.40 ± 0.32	ND	ND	ND	1.18 ± 0.20
				1.12	ND	ND	ND	1.15 ± 0.08	ND	ND	ND	ND
				1.50	ND	2.38 ± 0.11	3.03 ± 0.14	3.90 ± 0.10	ND	2.12 ± 0.05	2.68 ± 0.31	3.39 ± 0.30
		22	200	0.75	ND	ND	1.00 ± 0.10	1.94 ± 0.26	ND	ND	ND	ND
				1.12	1.00 ± 0.10	1.30 ± 0.55	2.30 ± 1.08	4.50 ± 0.45	ND	1.00 ± 0.25	3.31 ± 0.47	4.35 ± 0.23
				1.50	1.17 ± 0.54	1.55 ± 0.68	3.07 ± 0.88	3.50 ± 0.25	1.28 ± 0.21	1.60 ± 0.33	3.05 ± 0.35	3.30 ± 0.30
			250	0.75	ND	ND	1.00 ± 0.00	2.20 ± 0.08	ND	ND	ND	2.00 ± 0.02
				1.12	1.00 ± 0.00	1.18 ± 0.10	1.47 ± 0.35	2.65 ± 0.58	ND	ND	ND	ND
				1.50	1.40 ± 0.11	2.00 ± 0.67	3.68 ± 0.57	5.30 ± 0.62	ND	2.10 ± 0.20	4.77 ± 0.33	5.60 ± 0.10
			300	0.75	ND	ND	ND	1.00 ± 0.10	ND	ND	ND	ND
				1.12	ND	ND	ND	1.00 ± 0.10	ND	ND	ND	ND
				1.50	ND	ND	1.40 ± 0.10	1.54 ± 0.34	ND	ND	ND	ND
Control	HTST	75 °C/15s			ND	ND	1.00 ± 0.00	1.70 ± 0.20	ND	ND	2.94 ± 0.24	4.30 ± 0.15
		85 °C/15s			ND	ND	ND	ND	ND	ND	ND	ND
		95 °C/15s			ND	ND	ND	ND	ND	ND	ND	ND
	UT	Untreated			3.95 ± 1.20	4.20 ± 0.78	5.68 ± 0.66	6.50 ± 1.10	3.44 ± 0.77	4.10 ± 0.45	5.12 ± 0.65	6.00 ± 0.20

The data are provided as mean value ± standard deviation (n = 3). Values with different letters, lowercase in row or uppercase in column (day 0), are different ($p < 0.05$). ND, not detectable (<1 Log CFU/mL)

Table C.34 Microbicidal effects of UHPH and HTST on total aerobic plate count (APC) and yeast and mold (Y/M) in grapefruit juice during 45 days of storage at 4 ºC.

Treatments		Tin (℃)	P (MPa)	FR (L/min)	APC (log CFU/mL)				Y/M (log CFU/mL)			
					Day 0	Day 15	Day 30	Day 45	Day 0	Day 15	Day 30	Day 45
UHPH		4	200	0.75	ND	1.06 ± 0.39	2.64 ± 1.27	3.42 ± 0.33	ND	1.85 ± 1.53	4.14 ± 0.31	4.68 ± 0.28
				1.12	ND	ND	2.70 ± 0.72	3.80 ± 0.12	ND	ND	3.61 ± 0.68	4.83 ± 0.10
				1.50	1.15 ± 0.70	1.93 ± 0.88	3.78 ± 0.35	3.73 ± 0.38	ND	3.40 ± 0.18	4.43 ± 0.32	4.82 ± 0.15
			250	0.75	ND	ND	1.43 ± 1.10	2.27 ± 1.05	ND	ND	1.82 ± 1.17	2.76 ± 1.20
				1.12	ND	ND	ND	2.49 ± 1.41	ND	ND	3.36 ± 0.95	4.12 ± 0.88
				1.50	ND	ND	1.62 ± 1.41	1.74 ± 1.33	ND	1.76 ± 1.06	3.98 ± 0.44	3.46 ± 2.13
			300	0.75	ND	ND	1.60 ± 1.31	1.75 ± 1.60	ND	ND	2.95 ± 1.00	1.96 ± 1.92
				1.12	ND	ND	3.16 ± 0.68	3.37 ± 0.05	ND	ND	3.09 ± 0.79	4.68 ± 0.05
				1.50	ND	ND	1.52 ± 1.26	ND	ND	ND	1.63 ± 1.42	2.06 ± 2.08
		22	200	0.75	ND	ND	1.98 ± 0.39	2.63 ± 1.52	ND	1.36 ± 0.38	3.24 ± 1.79	4.16 ± 1.12
				1.12	ND	ND	2.16 ± 1.35	2.70 ± 1.53	ND	1.40 ± 0.40	2.90 ± 1.57	4.88 ± 0.02
				1.50	ND	ND	ND	2.83 ± 0.62	ND	1.02 ± 0.18	3.37 ± 1.99	4.23 ± 0.91
			250	0.75	ND	ND	3.04 ± 0.68	3.47 ± 0.29	ND	ND	4.40 ± 0.24	4.88 ± 0.01
				1.12	ND	ND	2.53 ±0.48	ND	ND	1.02 ± 0.18	3.65 ± 0.12	3.00 ± 2.01
				1.50	ND	ND	ND	2.44 ± 1.40	ND	ND	3.96 ± 0.67	4.90 ± 0.00
			300	0.75	ND	ND	2.95 ± 0.44	3.73 ± 0.20	ND	ND	4.25 ± 0.12	4.42 ± 0.72
				1.12	ND	ND	1.62 ± 0.51	3.12 ± 0.29	ND	ND	4.46 ± 0.17	3.60 ± 0.97
				1.50	ND	ND	1.67 ± 0.82	1.14 ± 0.25	ND	ND	3.35 ± 0.09	3.13 ± 2.11
Control	HTST	75 ℃/15s			ND	ND	ND	ND	ND	ND	ND	ND
		85 ℃/15s			ND	ND	ND	ND	ND	ND	ND	ND
		95 ℃/15s			ND	ND	ND	ND	ND	ND	ND	ND
	UT	Untreated			ND	2.00 ± 0.21	3.01 ± 0.52	3.6 ± 0.26	ND	3.43 ± 0.19	4.15 ± 0.13	4.07 ± 0.80

The data are provided as mean value ± standard deviation (n = 3). Values with different letters, lowercase in row or uppercase in column (day 0), are different ($p < 0.05$). ND, not detectable (<1 Log CFU/mL)

APPENDIX-D
SCHEMATIC DIAGRAM OF UHPH AND HTST SYSTEMS

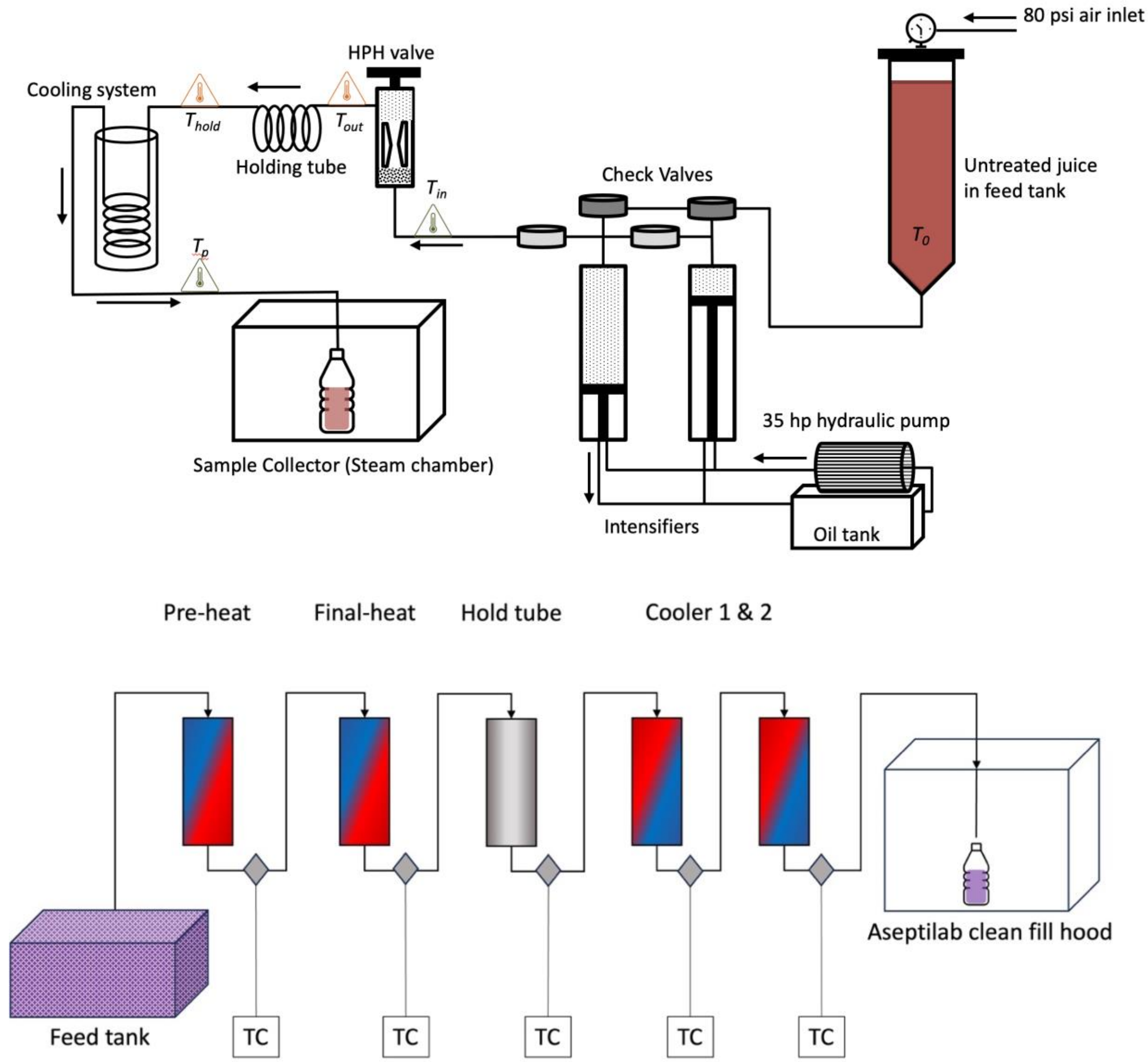


Figure D.1 Schematic representation of UHPH system (top), and HTST (bottom).

APPENDIX-E
JUICE EXTRACTION STEPS

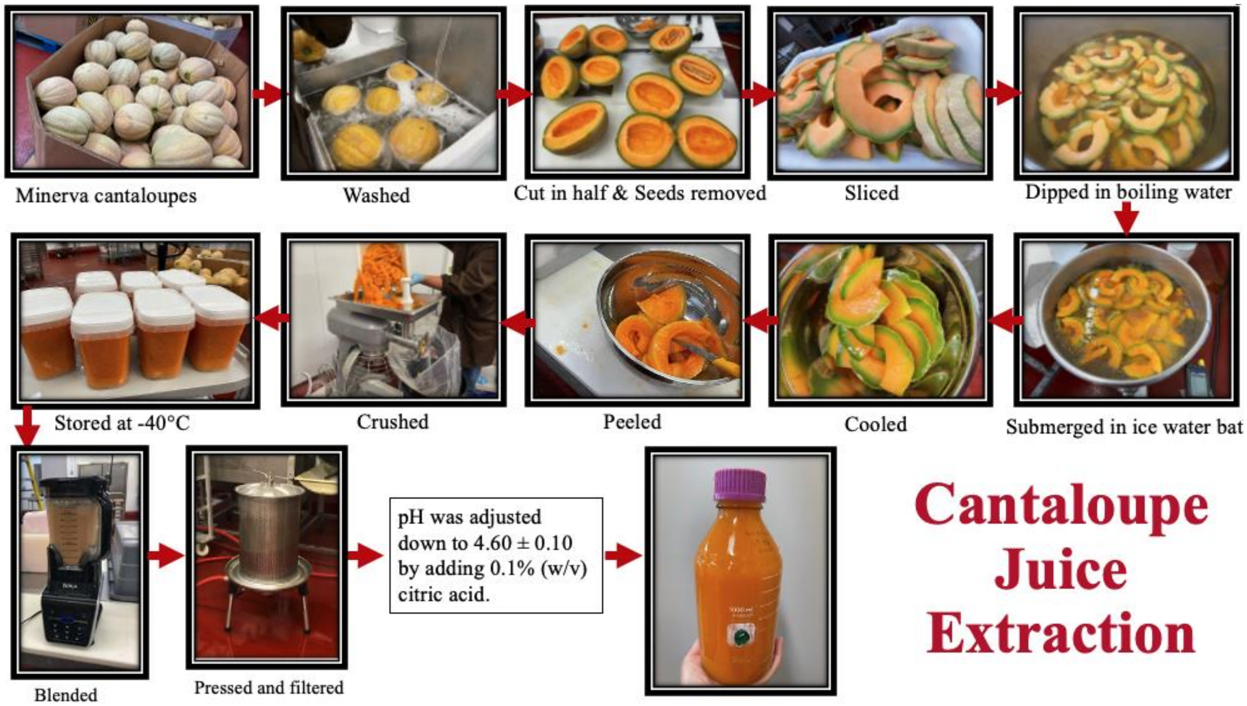


Figure E.1 Cantaloupe juice extraction.

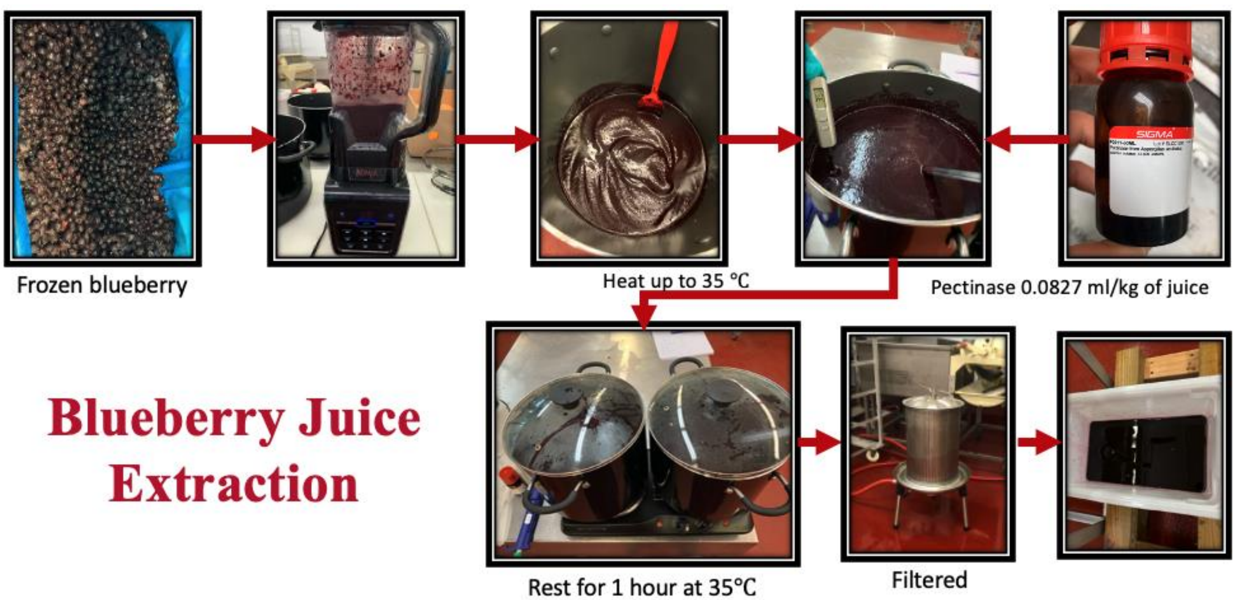


Figure E.2 Blueberry juice extraction.

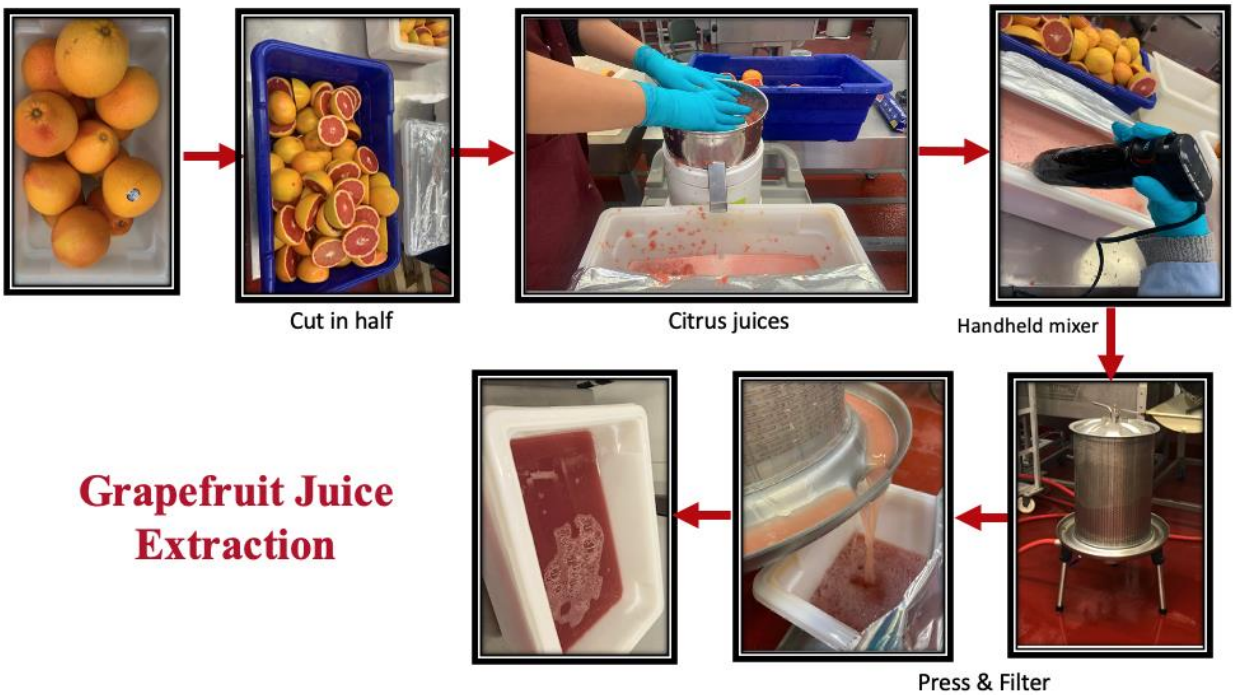


Figure E.3 Grapefruit juice extraction.

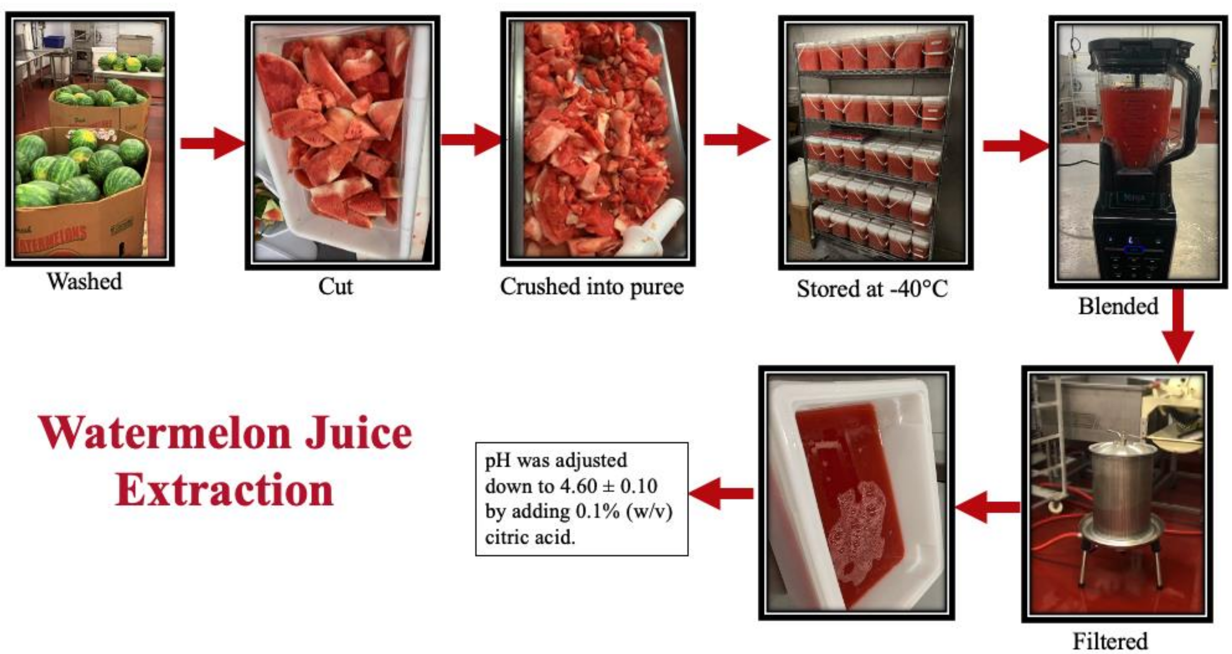


Figure E.4 Watermelon juice extraction.

APPENDIX-F
FLOW DIAGRAMS FOR EACH CHAPTER

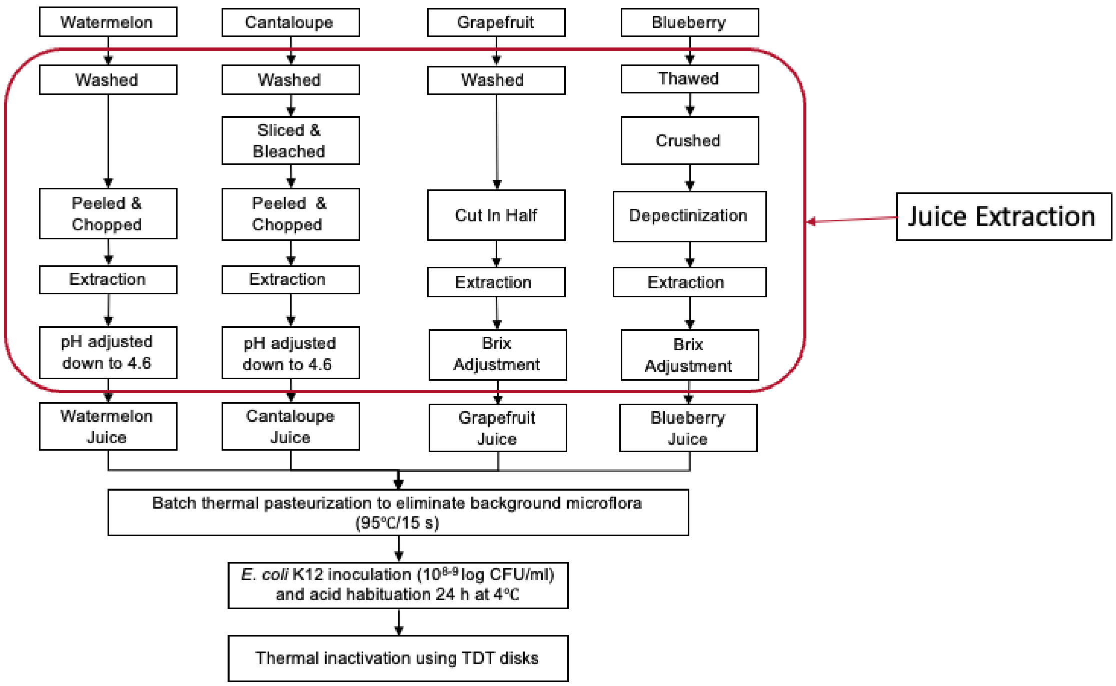


Figure F.1 Summary flow diagram for Chapter 3.

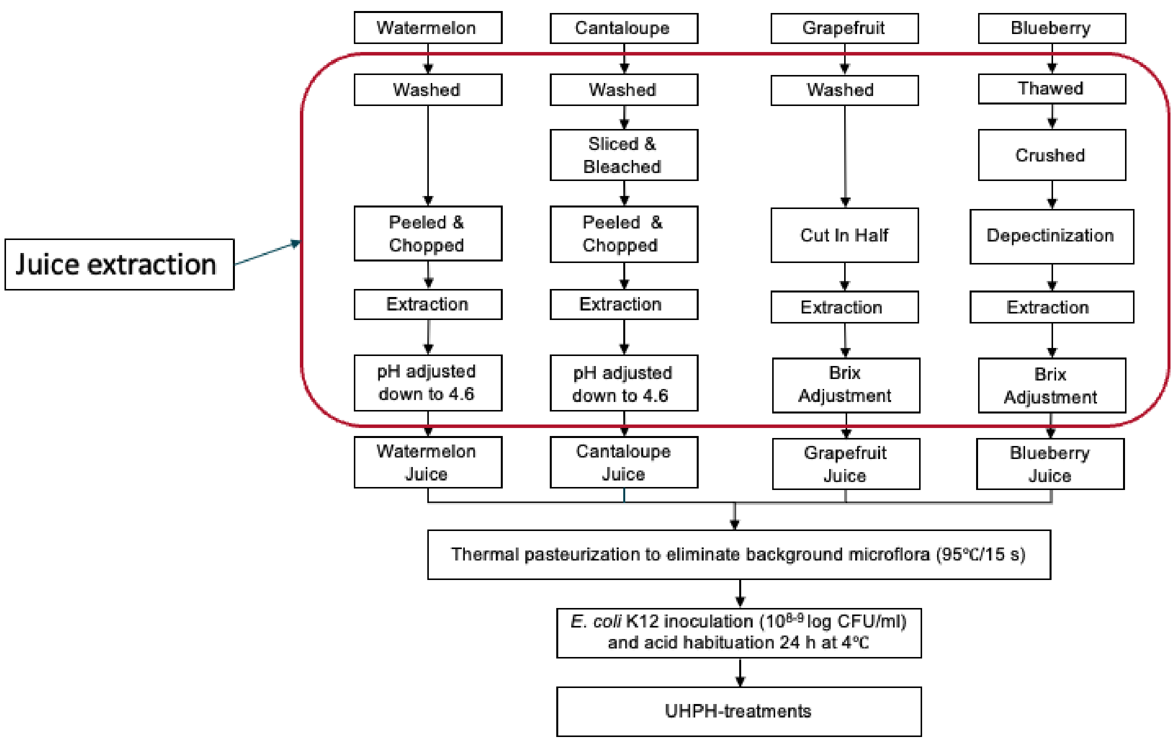


Figure F.2 Summary flow diagram for Chapter 4, Part 1.

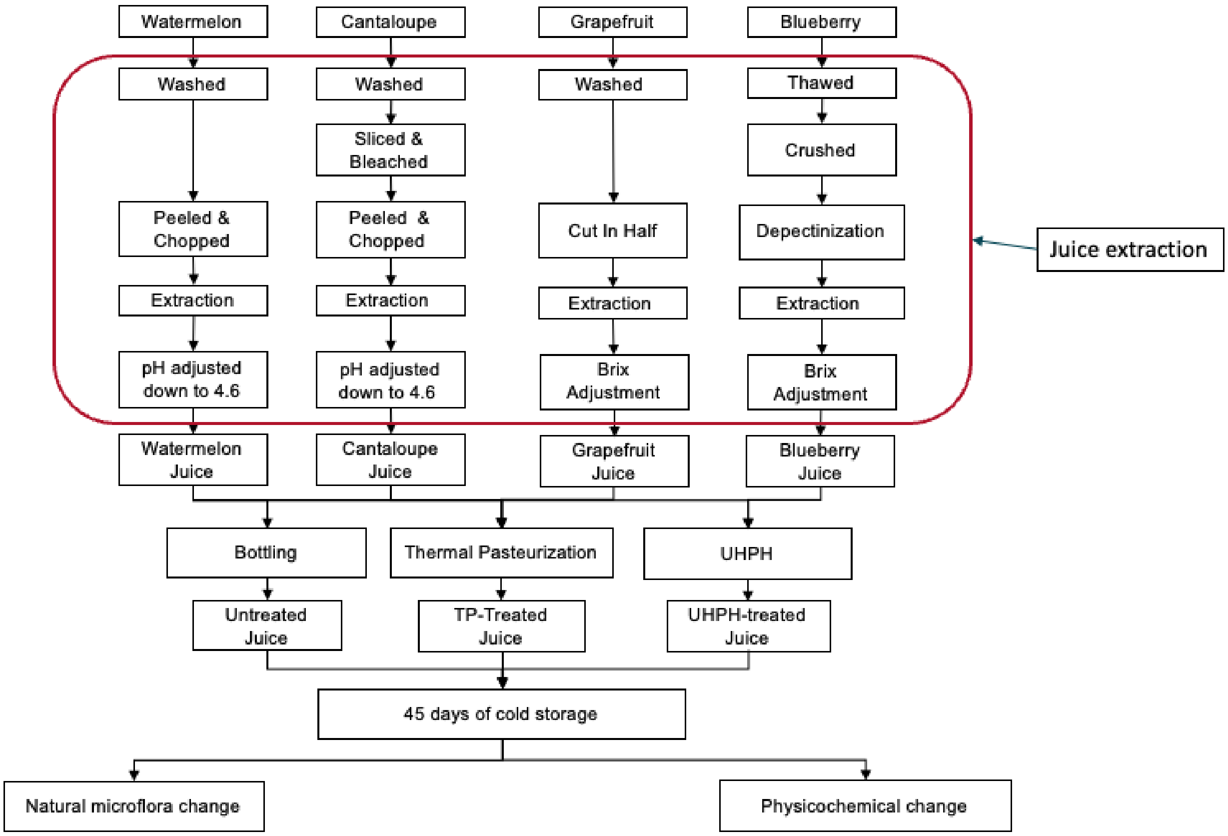


Figure F.3 Summary flow diagram for Chapter 4, Part 2.

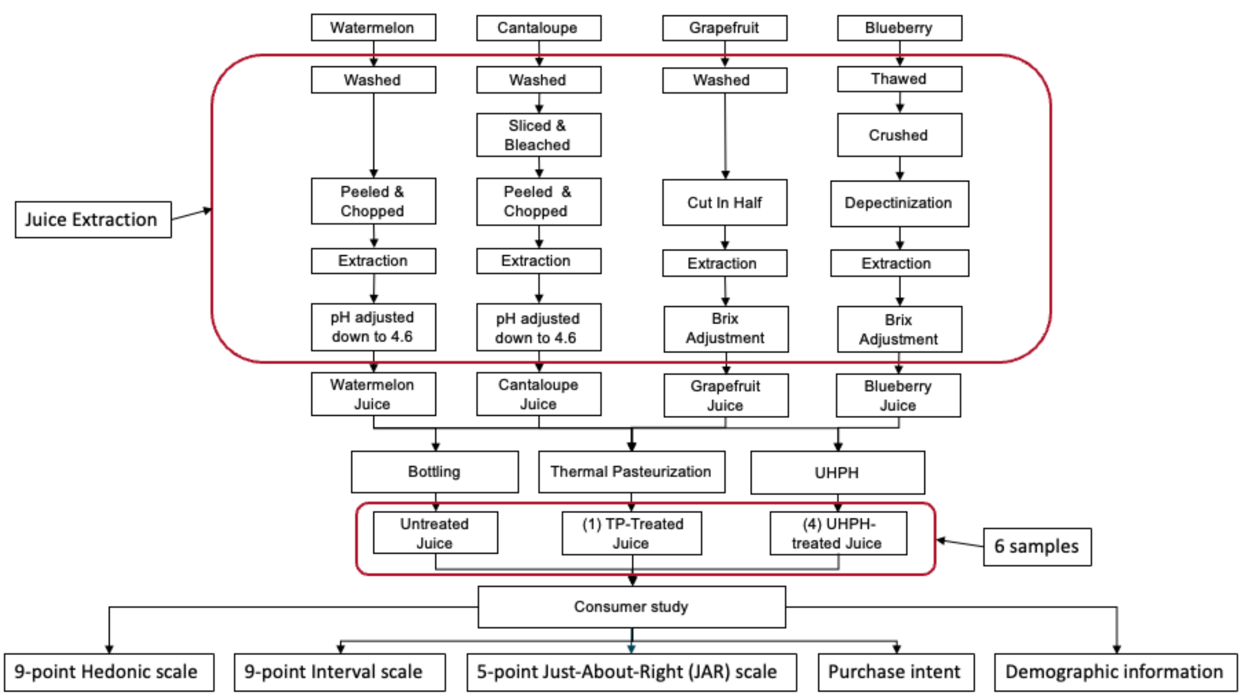


Figure F.4 Summary flow diagram for Chapter 5.