Thermal processing and quality retention of pineapple and peach in jars and pouches: Effect of reciprocation agitation and ultrasonic water bath processing

By

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Dedicated to Allah, my family, and friends.

ABSTRACT

Thermal processing is the most widely used method of eliminating pathogenic microorganisms of public health concern and reducing the activity of enzymes and microorganisms that are responsible for their spoilage. However, the type and severity of heat treatment involved during thermal processing also affects the quality and nutritional attributes. This study was carried out to evaluate the retention of quality attributes in fruits after subjecting them to reciprocation agitation thermal processing (RATP) and ultrasonic water bath processing (USWB). The effect of process variables (temperature and reciprocation frequency) on heat penetration behavior of canned pineapple and peach for RATP and pouch-packed pineapple and peach for USWB were evaluated to establish the thermal process times based on a prescheduled lethality criterion. The effects of selected process variables on retention of quality attributes were assessed and compared.

First, the heating behavior of pineapple and peach in 15% sugar solution were evaluated under various modes of retort processing conditions and ultrasonic water bath processing. Heating rate index (f_h), process lethality (F_o) and process time (P_t) were evaluated. Processing times were established to achieve a preset process lethality value of 10 min at 90˚C with a z value of 10˚C. The different products were then processed again to these established process times under the different processing conditions and the retention of product quality were evaluated. Specifically, texture, color and ascorbic acid retention of pineapple and peach were evaluated and compared.

Higher reciprocation frequency resulted in lowering of heating rate index, meaning improving the rate of heat transfer. The necessary processing time also simultaneously decreased with an increase in reciprocation speed. Processing at higher reciprocation frequency and higher temperatures had an improving positive effect on the retention of different quality attributes for both RATP and USWB processes.

This is a first-time study of pineapple and peach fruit processing in glass jars subjected to RATP processing and in retort pouches subjected to USWB processing. The study helped to provide appropriate processing conditions for the maximum retention of quality attributes.

RÉSUMÉ

Le traitement thermique est la méthode la plus largement utilisée pour éliminer les micro-organismes pathogènes préoccupants pour la santé publique, ainsi que pour réduire les activités enzymatiques et les micro-organismes responsables de la détérioration des aliments. D'autre part, le type et la sévérité du traitement thermique pourraient affecter la qualité et les attributs nutritionnels des produits alimentaires. Cette étude a été menée pour étudier la rétention des attributs de qualité dans les fruits soumis à un traitement thermique par agitation réciproque (RATP) et à un traitement par bain d'eau à ultrasons (USWB). L'effet des variables de procédé (température et fréquence de réciproque) sur le comportement de pénétration de la chaleur de l'ananas et de la pêche en conserve pour la RATP, et de l'ananas et de la pêche en sachet pour l'USWB a été évalué pour établir les temps de traitement thermique en fonction d'un critère de létalité préprogrammé. Les effets des variables de processus sélectionnées sur la rétention des attributs de qualité ont, ensuite, été évalués et comparés.

L'étude a été menée pour évaluer d'abord le comportement de traitement thermique de l'ananas et de la pêche dans une solution de sucre à 15 % dans divers modes de conditions de traitement en autoclave et de traitement au bain-marie à ultrasons. En conséquence, l'indice de taux de chauffage (f_h), la létalité du processus (F_o) et le temps de traitement thermique (Pt) ont été évalués. Les temps de traitement ont été établis pour obtenir une valeur de létalité de processus prédéfinie de 10 min à 90 °C avec une valeur z de 10 °C. Les fruits sélectionnés ont ensuite été traités en fonction des temps de traitement établis dans les différentes conditions de traitement, suivi par évaluation de la texture, de la couleur et de la rétention d'acide ascorbique.

Une fréquence de réciproque plus élevée a entraîné une diminution de l'indice de vitesse de chauffage et donc une amélioration de la vitesse de transfert de chaleur. Le temps de traitement nécessaire a également diminué simultanément avec une augmentation de la vitesse de réciproque. Le traitement à une fréquence de réciproque plus élevée et à des températures plus élevées a eu un effet positif amélioré sur la conservation des différents attributs de qualité pour les processus RATP et USWB.

Il s'agit de la première étude sur l'ananas et la pêche emballé en bocaux de verre et traité par la RATP, ainsi que dans des sachets autoclaves par traitement USWB. L'étude pourrait aider à fournir des conditions de traitement appropriées pour la conservation maximale des attributs de qualité.

CONTRIBUTIONS OF AUTHORS

Some parts of this thesis research work have been presented at scientific conferences and manuscripts have been planned for publication. The thesis is written in the manuscript style so that the chapters highlighting the thesis research could be suitably edited for publication.

Husain Dhariwala is the M.Sc. candidate who planned and conducted all the experiments, in consultation with his supervisor, gathered and analyzed the results and drafted the thesis and the manuscripts for scientific presentations and publications.

Dr. Hosahalli S. Ramaswamy is the thesis supervisor, under whose guidance the research was carried out, and who guided and supervised the candidate in planning and conducting the research, as well as in correcting, reviewing, and editing of the thesis and the manuscript drafts for publication.

Dr. Ali Taherian, who is a professional associate with the research team helped in carrying out experiments, initial analysis and first reading of the draft material for prepared for presentation and publication.

LIST OF PUBLICATIONS AND PRESENTATIONS

Parts of this thesis have been prepared as manuscripts for publications in refereed scientific journals:

Dhariwala, Husain and Ramaswamy, H. S., 2023. Heat penetration and process time calculation of pineapple and peach in glass jars and pouches – effect of reciprocating agitation and ultrasonic waves. (draft manuscript prepared for publication)

Dhariwala, Husain and Ramaswamy, H. S., 2023. Reciprocation agitation thermal processing and ultrasonic water bath processing of pineapple (Ananas comosus) and peach (Prunus persica). (draft manuscript prepared for publication)

Parts of this thesis have also been presented at the following scientific conference:

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Chapter 1

Introduction

Thermal processing is widely used to eliminate spoilage and pathogenic microorganisms as well as inactivate enzymes present in the canned food in order to render them safe and shelf stable. The fundamental principle of thermal processing is to transfer the heat from a heating medium to the contents of the specific containers to achieve the degree of heat treatment required. Conduction and convection are the two major mechanisms of heat transfer, which facilitate the heat transfer into or out of the food contained inside. The mixture of liquid and particle products such as soups, fruits in syrup and sauces, will heat by combination of both conduction and convection mechanisms (Ramaswamy and Marcotte, 2006) and can be improved by induced convection through agitation.

In order to get maximum retention of quality of thermally processed products, high temperature short time processes (HTST) have been widely used in food industry as an alternative approach to conventional thermal techniques. The benefits of HTST are due to the different destruction rate of microorganisms and quality attributes (Ramaswamy and Marcotte, 2006). Several researchers have shown that the rate of microbial spore destruction generally is much higher at higher temperatures (z value of ~10 ºC) which also is true for quality parameter destruction (z value of 30 to 35 ºC) (Holdsworth, 1985; Lund, 1977); however, their relative destruction rates differ and drift farther apart at higher temperatures with the destruction rate of microbial spores increasing much more rapidly than that of quality factors (Ramaswamy and Marcotte, 2006).

The influences of different processing variables on heat transfer rate have also been studied by several researchers (Sablani and Ramaswamy, 1995; Meng and Ramaswamy, 2006; Dwivedi and Ramaswamy, 2010; Rattan and Ramaswamy, 2014; You et al, 2016; Singh et al, 2016). All these studies were unanimous in concluding that heat transfer rate during thermal processing was significantly affected by several major processing variables, including the type of retort, retort temperature, the nature of particle, the size of particle, rotational speed, and headspace. The reciprocating agitation cause greater movement of products within the can, which can increase heat transfer rate and thus reduce the processing time. As compared to conventional static agitation, agitation processing in various forms like end-over-end agitation, axial agitation and reciprocating agitation provide a much faster heat transfer rate and a significant reduction in processing time (Singh et al., 2015; Walden et al., 2010; Dwivedi and Ramaswamy, 2010).

Another way of imparting agitation is by the application of ultrasonic waves, these waves while propagating through a medium, generate compressions and rarefaction (decompressions) in the medium particles. These compressions and rarefactions facilitate the increase of heat transfer (Bhargava et al., 2020). When these waves which are generated by a transducer converting electrical pulses into acoustic energy of required intensity are applied in combination with temperature it is called thermo-sonication (Rojas et al., 2021).

However, heat penetration studies on incorporation of reciprocation agitation and ultrasonic waves lack in literature especially for fruits in glass jars and retort pouches. Therefore, this study was aimed to evaluate the effect of reciprocation agitation retort processing (RATP) and ultrasonic water bath processing (USWB) on the heating behavior of pineapple and peach, to compute the heating rate index and finally to establish processing times to accomplish a designated pasteurization process lethality of 10 min at 90˚C ($F_{90^\circ C}$-10min) using the improved numerical integration general method of process calculations. The product texture, color, and ascorbic acid content (quality parameters) as influenced by reciprocation frequency, temperature, and presence or absence of ultrasound were also evaluated and compared.

The general objectives are :

- To evaluate the effect of reciprocation agitation and ultrasonic water bath processing factors on the heating behavior of pineapple and peach, heating rate index and establish the required processing times.

- To investigate the quality retention in pineapple and peach under the reciprocation agitation thermal processing and ultrasonic water bath processing based on the pre-established processing times.

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Chapter 2

Literature Review

1. Microbes and food spoilage

The recent rise in awareness towards healthy lifestyle habits has increased fruit consumption considerably during the recent years (Slavin et al., 2012). The cultivation of fruits has considerably increased too in reaction to this increased demand, a significant portion of which are wasted each year (Skaf et al., 2021). Approximately one-third of all food produced for human consumption in the world is lost or wasted according to FAO. The global volume of total agricultural production is about 6 G tonnes and the wastage is estimated to be is 1.6 G tonnes (FAO, 2021).

Fruits contain various nutrients such as carbohydrates, minerals, vitamins, and proteins which are not only beneficial to humans but also an actual source of nutrients for microorganisms that invade the fruits (Thiyam and Sharma, 2013). Fruits for that reason are highly perishable commodities subjected to spoilage by microorganisms (Qadri et al., 2015). Apart from physical, chemical damages and enzymatic digestion, the most significant spoilage of fruits occurs due to microbial activity. It is initiated when spoilage microorganisms invade the fruit. Microorganisms are simply present almost everywhere along the production chain and they can get into foods from both natural and external sources. Air, soil, water, manure, feces, human handling, animals, dust, harvesting equipment, transportation equipment and processing equipment are all sources for spoilage microorganisms to come from (Burnett et al., 2001). Apart from the nutrients provided by the fruit, these microorganisms depend on many factors such as pH, temperature, water activity and oxygen for their growth and development (Beuchat, 1996).

The water activity of a food product refers to free unbound water available for biochemical reactions. Fruits fall under the category of high moisture foods and provide a complete medium for fungi to grow and multiply as their low pH and nutritional properties with high water activity make them an ideal environment for microbial growth (Gustavo et al., 2003). Temperature is another important factor that modulates the survival and growth of microorganisms (Hoagland et al., 2018). Some microorganisms become inactive at higher and lower temperatures, respectively. With freezing, microorganisms are inactivated and with long-term heating, most microorganisms die. Spore forming microorganisms are resistant to temperature above 100 ˚C (Hamad, 2012). Based on pH, foods are categorized into three groups: (1) high-acid foods (pH < 3.7), (2) acid or medium-acid foods (3.7 < pH < 4.5), and (3) Low-acid foods (pH > 4.5) (Barrett et al, 2004).

Most spoilage microorganisms, particularly bacteria thrive best at near neutral pH (≥ pH 4.5) (Hoagland et al., 2018). Lactic acid bacteria are, however, an exception as they are capable of growth at pH as low as 3.5. Fungi are much less sensitive to pH and can grow over a broad range commonly within pH range 3 - 8. Yeasts under pH conditions as low as 1.5, exhibiting much better tolerance of acidic conditions (Moss, 2008). Yeasts and moulds predominate in low pH foods such as fruits where bacteria cannot grow (Hamad, 2012). Due to their low pH, a large number of microorganisms are restricted to grow on fruits, but fungi still grow on fruits because of their ability to grow under acidic conditions (Montville and Matthews, 2005). All of these factors are carefully considered while attempting to inactivate the microorganisms during a food processing operation.

2. Methods of preservation

Food processing refers to the deliberate transformation of agriculture produce, through numerous unit operations into more palatable, shelf-stable, portable, and useful, value-added products, safe for human consumption (IFIC, 2010). The process of treating and handling food in such a way so as to stop or greatly slow down spoilage and prevent foodborne illness while maintaining nutritional value, texture, and flavour can be called food preservation (Blackburn, 2006). Since ancient times, preserving fruits and their products by applying various techniques like drying, concentration, freezing, fermentation, and chemical preservation by use of vinegar, wine, sugars, and spices have been well known (Barrett et al, 2004). With development in industry, the need to make food more marketable and attractive to potential consumers arose, to achieve that it was put through numerous types of processing, including canning, drying, and juicing often giving the processed food a longer shelf-life.

2.1 Thermal processing

Thermal processing involves heating foods in hermetically sealed containers for a specific time – temperature combination to eliminate the pathogenic, mesophilic and spoilage causing microorganisms.

In the beginning of 19^{th} century, Nicholas Appert, developed a method for heat preservation of food. This method, now popularly known as canning, enabled the French army and navy to prolong the shelf life of its rations (Appert, 1810). The fact that microorganisms are the reason for spoilage was not known when the method was developed by Appert. Louis Pasteur discovered that microorganisms, which can be destroyed at elevated temperatures are the reason for spoilage. The technique of pasteurization, as we know today, is named in his honor, refers to a relatively mild heat treatment intended to destroy pathogenic microorganisms in foods, providing short-term extension of shelf life under refrigerated conditions (Barrett et al, 2004).

1913: the National Canners Associated in USA was formed with Dr W.D. Bigelow as its head. The important techniques that were developed, knowledge that was gathered and shared due to the formation of it during the following years includes :

1917: Bigelow used thermocouples to measure the continuous heating of cans of baked beans.

1920: Bigelow and J.R. Esty showed that spores die off quicker at higher temperatures.

1921: Bigelow showed that death time curves are logarithmic.

1921: Bigelow and P.H. Cathcart described the effect of acidity in lowering the thermal processing requirements.

1922: Esty and K.F. Meyer demonstrated the maximum resistance of Clostridium botulinum spores using moist heat, laying the foundation for the 12D concept.

1923–1927: C. Olin Ball together with Dr Bigelow introduced the direct calculation of processing parameters. In 1927 Ball published the concept of a sterilization value.

1948: C.R. Stumbo introduced the concept of integrating sterilization over the entire can contents. Using Esty and Meyer's data he calculated Z value of 10 and a F_o of 2.78.

1965 C. R Stumbo published his classic textbook entitled "Thermobacteriology in Food Processing" (Stumbo, 1965) .

With high temperature sterilization the possibility of detrimental effects on food was very high and to counter this, food manufacturers and academicians have developed processing technologies to minimize the heat load into a product while still rendering it safe for consumption. One such development was the agitation of containers during a thermal process. Agitation of containers induces forced convection in the product, which facilitates faster heating and cooling of the product (Batmaz and Sandeep, 2015). Researchers have incorporated agitation to improve the rate of heat transfer, which in turn shortens processing times, thus retaining more nutrients and quality attributes of the raw product in the processed food. This helps mitigate the adverse effects on sensory properties, while saving costs by minimizing energy consumption (Ramaswamy and Marcotte, 2005).

During the first decade of the 21st century, rotary modes of agitation involving end-over-end and axial mode of rotation/oscillation had already been established and commercialized (Holdsworth and Simpson, 2016). In more recent years, reciprocating motion of containers, which was first invented around 1938 is being implemented (Gerber, 1938).

Nicolas Appert's first products were packed in glass. Soon after his discovery was published, Peter Durand, a British merchant patented the idea of preserving food using tin cans. The patent (No 3372) was granted on August 25,1810 by King George III of England. In 1888 the double seam was invented by Max Ams. This paved the way for automated can lines to be made (Featherstone, 2012). Developments in the closures for glass, starting with the Mason Jar in 1858 resulted in glass becoming a popular alternate to cans. Improvements in lids, caps and closures that form hermetic seals, are easy to open and reclose, and have tamper evident features such as buttons that “pop” on first opening have helped to make glass a viable alternative (Goldblith, 1972). Developments in other packaging types are more recent and restricted to the past 40 years or so. Pouches are flexible and during processing the flat dimensions result in faster heat penetration, therefore shorter cooking times and better-quality product. The ideal packaging choice depends on the requirements of product type, processing conditions, required shelf-life and target market.

Many of the current developments in thermally processed foods are driven by cost saving and an attempt to reduce the carbon footprint. Ways that these can be done is by light-weighting the packaging, optimizing the processing, and improving the heat transfer into the product either by changing the packing format or shape, or using more efficient forms of heating (Featherstone, 2012).

2.2 Ultrasonic water bath processing

Some food products are thermally sensitive and to prevent them from undergoing physical, chemical, and microbial changes such as modification of flavor, color, and texture on exposure to heat treatment, a need for research and development of innovative and effective alternate technologies arose (Misra et al., 2016). Ultrasound is one of these emerging sustainable technologies.

Sound waves exceeding the audible frequency range i.e., greater than 20 kHz are termed as ‘Ultrasound’. When these waves propagate through a medium, they generate compressions and rarefaction (decompressions) in the medium particles. This, in turn, produces a high amount of energy, due to turbulence, and increase in mass transfer

(Jambrak, 2012). When Ultrasound waves are applied in combination with a thermal treatment it is called thermo-sonication, resulting in a synergistic effect, which further enhances its efficacy (Condón-Abanto et al., 2016). By the virtue of cavitation effects, ultrasound helps to eliminate the ill effects of thermal sterilization like development of off-flavors and deterioration of functional properties of foods (Baboli et al., 2020). The killing of microbes is due to thinning of the cell membrane, production of free radicals, and localized heating (O'donnell et al., 2010). Thermo-sonication can result in a significant reduction of D95 value (Silva F.V, 2015). It also accelerates the sterilization rate of food and thus reduces the intensity and time required for heat treatment and the damage caused. Ultrasound minimizes the loss of flavor, enhances homogeneity, effective savings of energy (Vercet et al., 2002).

3. Thermal process establishment

The presence of vacuum in cans generally prevents the growth of most aerobic microorganisms, and if the storage temperature is kept below 25°C, the heat-resistant thermophiles pose little or no problem. From a public health standpoint, *Clostridium botulinum*, the gram-positive anaerobic pathogen is of concern because it can cause a fatal disease and it can grow in conditions conveniently provided by canned foods. It is the most important microorganism in low-acid (pH > 4.6) foods because of its heat-resistant, spore-forming capabilities., which, if it survives processing, can potentially grow, and produce the deadly toxin botulinum. Destruction of resistant spores in severe heat treatment led to standard commercial sterilization processes being based on successfully killing *Clostridium botulinum* as the worst-case scenario and was called bot cook.

The dividing line at pH 4.6 used to separate acid and low acid foods is based on the ability of *Clostridium botulinum* spores to not grow at pH ≤ 4.6. *Clostridium botulinum* has high thermal resistance but can only produce the neurotoxin in an anaerobic environment under mesophilic conditions. The classification of foods by pH value enables in deciding which thermal treatments could be applied. The pH of food differentiates the severity of the process (sterilization vs. pasteurization). Because *C. botulinum* and most spore formers do not grow or produce toxin at pH <4.5 (acid and medium-acid foods), the thermal processing criterion for these foods is the destruction of heat-resistant vegetative microorganisms or enzymes. Because spore formers generally have high heat resistance, the low-acid foods that support their growth are processed at elevated temperatures (115 to 125 °C). For the acid and medium-acid foods, the process is usually based on the heat-resistant, spoilage-type vegetative bacteria or enzymes that are destroyed easily even at temperatures below 100 °C. This is similar to pasteurization.

Establishing a thermal processing schedule consists of an appropriate heating time at a specified temperature, the thermal destruction rate of the test microorganism or enzyme must be determined under the conditions that normally prevail in the container. In addition, the temperature dependence of the microbial destruction rate or enzyme inactivation rate must be known in order to integrate the destruction or inactivation effect through the temperature profile, mainly due to the come-up time (CUT) required to achieve processing temperatures.

The microbial destruction rate is defined as a decimal reduction time (D value) which is the heating time in minutes at a given temperature required to result in one decimal reduction (or 90% destruction) in the surviving microbial population. The D value of a particular microorganism or enzyme is strongly dependent on the processing temperature. Increased heating temperatures yield lower D values. A thermal resistance curve with logarithm of D values plotted against temperature would yield a temperature sensitivity indicator, Z value, which is defined as the temperature range that results in a 10-fold change in D values.

The General Method for calculating scheduled process times was originally described by Bigelow et al. in 1920, but contributions by Ball in 1928 and O.T Schulz and F. C. W Olson in 1940 resulted in a much improved General Method. M. Patashnik published his improvements in 1953, which are the most widely used today (Park, 1996; Patashnik, 1953).

The effectiveness of the thermal process in killing microorganisms in a food product may be denoted by the F value or the lethality. The lethality or sterilizing value of a thermal process is a measure of the effectiveness of the heat treatment. In order to compare the relative sterilizing capacities of different heat processes, a unit of lethality has been established as the equivalent heating of 1 min at a reference temperature such as 250°F for sterilization or 180 °F for pasteurization.

In thermal processes which involve a food product passing through a time–temperature profile, the lethal effects at each time–temperature combination may be integrated using the following equation:

$$F_o = \int 10^{(T - T_o)/Z}\, dt$$

where,

T = Product temperature

T_o = Processing temperature

Z = temperature range where D-value passes through one log cycle.

The resulting combined lethality is known as the process lethality and may be represented by the symbol F_o. In the case of acid foods such as fruits, the criterion for the adequacy of the process is based more specifically on the reduction in the number of spoilage-causing bacteria and the inactivation of the most heat-resistant enzymes present.

The two objectives of thermal process calculations are

(1) to estimate how much destruction a given process will accomplish and

(2) to arrive at an appropriate process time required to accomplish the desired level of destruction.

4. Quality retention and progress in thermal processing

Texture, color, taste, smell, and flavor are some of the quality attributes of fruits. The composite of such various characteristics that can fulfill needs and wants of consumers and determine their acceptability of products can be described as Quality

(Kramer and Twigg, 1968). Quality attributes of fruits are negatively affected by thermal processing. The main goal previously with thermal processing was to achieve shelf-stability and assure safety but with improvement in technology the demands of consumers have increased (Awuah et al., 2007). The chemical reactions and changes to the nutritional and sensory attributes, such as texture and color which are triggered by heat treatments are not accepted welcomingly by consumers anymore.

During thermal processing, the texture value would be reduced, and the products would become soft. Texture is usually regarded as the overall indicator of quality for some particular food products (Hutchings and Lillford, 1988). Texture changes in thermal processing can be attributed to cellular degradation, breakdown of cell wall and pectin structure resulting from enzymatic and non-enzymatic reactions (Anthon et al., 2005; Greve et al., 1994). In research, the characterization of texture can be described by various parameters which include hardness, chewiness, gumminess, springiness, skin strength and elasticity. A texture Analyzer is used to measure these properties (Srilakshmi, 2020). During a Texture Profile Analysis (TPA), test samples are compressed twice using a texture analyzer to provide insight into how samples behave when chewed. The TPA test was often called the “two bite test” because the texture analyzer mimics the mouth's biting action (Texture technologies, 2020). Hardness is defined as the peak force that occurs during the first compression. The sensory meaning of hardness is the maximum force required to compress a food between the molar teeth (Szczesniak, 2002). Chewiness is the measure of the energy required to chew a solid food to the point adequate for swallowing (Peleg, 2019). Springiness in TPA is related to the height that the food recovers during the time that elapses during the end of first bite and the start of the second bite. If springiness is high, it requires more mastication energy in the mouth (Rahman and Al-Mahrouqi, 2009).

A penetration test destructively measures firmness by registering the force required for a cylindrical probe (generally from 2mm – 8mm in diameter), to penetrate the fruit’s flesh to a chosen distance and is frequently used for testing firmness of a wide variety of fruits. This type of test primarily assesses skin strength/toughness and elasticity of the underlying flesh. Skin strength assesses the firmness of the flesh. Elasticity is the tendency of an object to return to its original shape after deformation. It is not synonymous with the instrumental TPA “springiness.” (Peleg, 2019).

The color of a product is more visible and is an early indicator that aids consumers in acceptability (Pathare et al., 2013). Heat treatment would degrade or change the naturally occurring pigments in foods, affecting, or completely changing them. The CIE L*a*b* color space devised in 1976 provides a more uniform color difference in relation to human perception of differences. The parameter a* takes positive values for reddish colours and negative values for the greenish ones, whereas b* takes positive values for yellowish colours and negative values for the bluish ones. L* is an approximate measurement of luminosity, which is the property according to which each colour can be considered as equivalent to a member of the greyscale, between black and white (Granato and Masson, 2010). Colorimeters give measurements that can be correlated with human eye–brain perception and give tristimulus (L, a and b) values directly (HunterLab, 1995).

Vitamins, organic acids, and antioxidant compounds are also sensitive to heat Conventional (still) thermal processing may jeopardize a food’s nutrient content and organoleptic properties due to the severe heat treatment required to render a food microbiologically safe (Singh et al, 2016). Sensory and nutritional qualities of food like antioxidant and vitamin content may be better pre-served with improvement in heat transfer and optimization. Ascorbic acid (also known as vitamin C) is an antioxidant that is necessary for humans and its deficiency can cause a disease called scurvy, which may cause symptoms such as muscle weakness, tooth loss, rash, tiredness, and joint pain (Chin and Ima-Nirwana, 2018). Therefore, this vitamin should be consumed daily because it is needed to maintain the health of blood vessels, skin, teeth, bone, and cartilage. Also, it is essential in anti-allergic treatments, strengthens the immune system and prevents flus and infections (Sorice et al., 2014; Krzyczmonik et al., 2017).There are numerous methods for the determination of vitamin C in a variety of natural samples, biological fluids, and pharmaceutical formulations. The preparation method and methods for the determination of vitamin C are spectrophotometric methods and nonspectrophotometric methods (Arya and Mahajan, 1997). The most common vitamin C sources, which assures around 90% of the necessary amount for the human diet, is represented by fruits mainly citrus fruits and the juice obtained from them (Cojocaru et al., 2010). There are numerous methods which are used for the quantitative determination of vitamin C, such as the titrimetric–iodometric method (Bekele and Geleta, 2016), the 2,6 dichloro indophenol method (Shreshtha et al., 2016), the voltametric methods (Pisoschi et al., 2008; Pisoschi et al., 2011), the spectrophotometric method (Al-Majidi and Al-Qubury, 2016), and the chromatographic method (Trani et al., 2012).

5. Agitation thermal processing

Within the first decade of the 21st century, rotary modes of agitation involving end-over-end and axial mode of rotation/oscillation had already been established (Holdsworth and Simpson, 2016). Clifcorn et al. first suggested the use of rotation to increase heat transfer to canned foods by placing cans with their symmetrical axis along the plane of rotation, often called the end-over-end mode (Clifcorn et al., 1950). Axial mode is another possible orientation, wherein the product is placed with its symmetrical axis perpendicularly to the plane of rotation (Dwivedi and Ramaswamy, 2010). Due to the centrifugal forces contributing to clump formation after certain speeds of rotation, the heat transfer reduces for end over end and axial mode of agitation (Ramaswamy and Sablani, 1997). The biaxial mode of agitation was recently developed to overcome this problem (Dwivedi and Ramaswamy, 2010). Implementing reciprocating motion of containers has comparatively been a recent development but due to the introduction of Shaka and Gentle motion retort it has gained extensive attention (Gerber, 1938).

Several studies have attempted to find the optimal agitation frequency for reciprocating agitation. One research study indicated that RATP can be effective to obtain tomato puree with a brighter red color (closer to fresh) was obtained during RATP at 3 Hz reciprocation frequency. It also concluded that a very high reciprocation frequency (>3 Hz) is not necessarily needed, and significant quality improvement can be obtained at lower frequencies (∼2 Hz) (Singh et al., 2017). One study indicated that processing banana puree while reciprocating agitation was employed, resulted in reduced processing times along with improved quality in comparison to still processing (Batmaz and Sandeep, 2015). One study on processing white sauce concluded that the reciprocating agitation process reduced process time by better than 20-fold compared with static, and better than 10-fold compared with rotary while processing. The sauce resultant from the reciprocating agitation method was still white, virtually indistinguishable from the unprocessed product, compared with the rotary retorted samples which were noticeably brown, and the static, which was an even darker brown, especially against the walls of the can (Walden and Emanuel, 2010). One study concluded that high reciprocation frequency and operating temperature significantly reduced the required process times for thermal processing of potatoes and radish. Overall high-temperature–frequency combination resulted in better retention of texture, color and antioxidant activity and had relatively lower leaching of solids to the can liquid (You et al., 2016). Another study concluded that higher reciprocation frequency and temperatures not only significantly reduced the required process times for thermal processing of green beans but was also very effective in reducing the total color change. RA-TP resulted in a greener product with a higher chlorophyll and antioxidant activity retention but also texture breakage of green beans in many scenarios with higher amount of solids and turbidity in liquid. For canned products containing soft particulates which might be susceptible to damage under rapid agitation, operating at lower frequencies, would be preferable and more advantageous to preserve the overall quality of food product (Singh et al., 2016). One study concluded that reciprocal agitation thermal processing of canned shrimp resulted in superior product compared with static retort processing, improved process parameters, and potential energy savings (Dixon et al., 2020). The available studies in literature involve liquids or particle in fluid type of foods. Even in the studies involving particle in fluid type of foods, vegetables are the major contributors. The influence of reciprocation agitation thermal processing (RATP) on fruits as particle in fluid type of foods is very limited in literature.

6. Ultrasound Processing

Ultrasound technology is one of the emerging nonthermal technologies. Power ultrasound is generally used in food processing. The frequency is between 20 and 100 kHz, and the mechanism of ultrasound action is mainly related to its cavitation effect. The cavitation effect refers to the periodic, alternating stretching and compression of the liquid medium molecules as the ultrasound propagates through the medium. It is generally believed that the inactivation of microorganisms by ultrasound is mainly due to cavitation, mechanical, thermal, and chemical effects (Chen et al., 2020). The "cavitation" effect of ultrasound waves in solution produced high temperature and high pressure, and the high-speed alternating temperature and pressure directly damages the cell wall or cell membrane of bacteria, promotes decomposition of water molecules, generates free radical reaction, and the generated free radicals with strong oxidative properties break the DNA of microbial cells and inactivate enzymes to kill the bacteria (Wu et al., 2015). When ultrasound is combined with mild heat treatment it is known as thermosonication (Abid et al., 2014). Evelyn and Silva studied the effect of ultrasound on the heat inactivation of Clostridium perfringens spores in beef slurry. Their results showed that ultrasound treatment reduced the D95 value from 20.2 min to 9.8 min, doubling the thermal inactivation rate of spores in beef slurry (Silva, 2015). Cichoski et al. has shown that ultrasound-assisted pasteurization can inhibit the growth of psychrotrophic and lactic bacteria, reduce lipid oxidation, improve the pasteurization effect of packaged sausages, and thus extend the shelf life of products without changing their physical and chemical properties (Cichoski et al., 2015). A study showed that high-power ultrasound (40 W, 30 kHz) improved the microbial inactivation of fresh-cut coconut by high-pressure carbon dioxide, while also reducing temperature and pressure, and the total acidity and pH of fresh-cut coconuts did not change during storage (4 weeks) (Ferrentino et al., 2015). Ultrasound assisted pasteurization was found to be very effective against E. coli, Listeria monocytogenes and Pseudomonas fluorescens with no ill effect on casein or total protein content of the milk pasteurized (Cameron et al., 2009). Ultrasound minimizes the loss of flavor, enhances homogeneity, effective savings of energy (Vercet et al., 2002). The results of one study indicated the usefulness of thermosonication for apple juice processing at low temperature, for enhanced inactivation of enzymes and microorganisms. Fresh apple juice was thermosonicated using ultrasound in-bath (25 kHz, 30 min, 0.06Wcm 3) and ultrasound with-probe sonicator (20 kHz, 5 and 10 min, 0.30Wcm 3) at 20, 40 and 60 ˚C for inactivation of enzymes and microflora. The highest inactivation of enzymes was obtained in ultrasound with-probe at 60 ˚C for 10 min, and the microbial population was completely inactivated at 60˚C (Abid et al., 2014). The simultaneous application of ultrasound and mild heat in fruit juice processing industry has the greatest potential and numerous benefits of juice quality preservation and safe processing. The cavitation effects of ultrasound give improvement in terms of the enzyme's inactivation and microbial destruction. For a shorter processing time, it can be categorised as minimal processing for freshness and health purposes (Abdullah and Chin, 2014). The available studies in literature involve liquid type of foods. The influence of thermo-sonication on fruits as particle in fluid type of foods is very limited in literature.

7. Importance of pineapple and peach

Pineapple (*Ananas comosus*, family Bromeliaceae) is a tropical fruit grown in the tropical and sub-tropical regions. Pineapple is the third most important tropical fruit crop, after bananas and mangoes. It's grown on large scale in India, Philippines, Thailand, China, Brazil, Mexico, and South Africa. Production for pineapples is the highest in Costa Rica (12.2%), followed by the Philippines (9.8%), and Brazil (9.5%). Production for pineapples worldwide has been on a steady upward trend, with a total of 27.92 million MT in production volume in 2018. The fruit is grown the most in Latin America (Costa Rica), Asia, and West Africa where it may be then exported fresh, or in processed form (FAO, 2019).

Popular varieties of pineapples have changed over time, as the Smooth Cayenne used to be one of the most grown as it was mainly processed as canned pineapples but was replaced by the MD2 pineapple variety in a matter of decades, as it is sweet in taste, has a long shelf life, and is consistent in size. The MD2 is also more superior in terms of transportation, where it is resistant to browning due to its low acid levels. With all these factors considered, the majority of the pineapples grown today are of the MD2 and the Smooth Cayenne variety (Campos et al., 2020).

Pineapple composition has been investigated mainly in the edible portion. Pineapple contains 81.2 to 86.2% moisture, and 13-19% total solids, of which sucrose, glucose and fructose are the main components. Carbohydrates represent up to 85% of total solids whereas fiber makes up for 2-3%. Of the organic acids, citric acid is the most abundant in it. The pulp has very low ash content, nitrogenous compounds, and lipids (0.1%). From 25-30% of nitrogenous compounds are true proteins. Out of this proportion, 80% has proteolytic activity due to a protease known as bromelain. Fresh pineapple contains minerals as Calcium, Chlorine, Potassium, Phosphorus and Sodium (Dull, 1971). Several essential minerals exist in pineapples, including manganese, a trace mineral instrumental to the formation of bone, as well as the creation and activation of certain enzymes. Pineapples also include copper, another trace mineral. It assists in the absorption of iron and regulates blood pressure and heart rate (Debnath et al., 2012). Pineapple is also a source of bromelain, used as a meat-tenderizing enzyme, and high-quality fiber. The U.S. National Library of Medicine lists bromelain as a proteolytic digestive enzyme. When taken with meals, bromelain aids in the digestion of proteins, working to break proteins down into amino acids (Chaudhary et al., 2019).

Pineapple is not an easy to eat, out of hand fruit. The pineapple does not lend itself well to freezing, as it tends to develop off flavors and whole fruit cannot be maintained for long period of time. Pineapple cultivation is quite time intensive. The fruit needs between 14 to 18 months before it reaches full maturity and is ready to harvest (Chaudhary et al., 2019). For these reasons, pineapple is processed for preparation of various products to enhance the effective utilization of the fruit. Canning pineapple is one way to prolong the shelf life of pineapple and is consumed throughout the world. Pineapple is largely consumed around the world as canned fruit in form of slices, chunks and cubes, pineapple juice, pineapple chips and pineapple puree.

Because of its hard shell, mucilaginous texture, and numerous seeds, it is not popular as a fresh fruit. Nearly 80 per cent of pineapple production found in the market is in processed form, out of which 48 per cent is used for single or concentrated juice and 30 per cent for canned fruits in the world (Ali et al., 2020). Processed pineapples are consumed worldwide and processing industries are trying out or using new technologies to retain the nutritional quality of the pineapple fruit. This is to meet the demand of consumers who want healthy, nutritious, and natural products with high organoleptic qualities.

Peach (*Prunus Persica*) belongs to the family Rosaceae and the subfamily Amygdyloideae and is consumed extensively worldwide. Peaches are members of the genus Prunus that includes apricots, plums, cherries, almonds, and nectarines (Giovannini et al., 2014). Peach has an important place in human nutrition, and can be used as fresh, dried or processed fruit (Zhao et al., 2015). It is deciduous tree up to 10m in height or evergreen trees and shrubs naturally distributed throughout temperate regions, originally from Asia or Southern Europe (Gaur, 1999). Melting and rubbery are two types of flesh texture of its (Zheng et al., 2014). They are also consumed as well as processed into juices and sliced or dried product (Hummer and Janick, 2009). The mesocarp surrounds a shell (the pit or stone) of hardened endocarp with a seed inside and due to this, Prunus species are also referred to as “stone fruit”. Based on the type of attachment of flesh to the stone there are two types of peaches, freestone – the pit is relatively free of the flesh – or clingstone – the pit follows to the flesh. It is one of the most variable species of fruit, with the largest number of commercial cultivars, assuming different shapes, sizes, flesh (red, white or yellow flesh), types of skin, the seed, among other variable aspects regarding this popular fruit, representing a diverse international germplasm (Forcada et al., 2014).

Prunus persica is commonly cultivated in West Asia, Europe, Himalayas and India up to an altitude of 1000 ft (Aziz and Rahman, 2012). Prunus has nearly 200 species cultivated for their edible fruits and seeds (Aziz and Rahman, 2012), China is the centre of origin for peach and was domesticated there 4-5000 years ago (Zhao et al., 2015). In the 16th century, it was established in Mexico and in the 18th century Spanish missionaries introduced the peach to California, which turned out to be the most important production area after China and Italy. The main world producing countries of stone fruit include China, USA, Italy, Spain and Turkey (Vicente et al., 2011). As the largest producer of peach fruits in the world, China (11.9 million metric tons, 2013 FAO data) currently has approximately more than 3000 peach cultivars (FAO, 2021).

This fruit is considerably rich in antioxidants, being an important source of vitamins A, B and C, carotenoids, and phenolic compounds like chlorogenic and neochlorogenic acids, catechin, epicatechin, cyanidin and quercetin derivatives. The peach is a very nutritious fruit, it is rich in both macro and micro-nutrients (Alina et al., 2015; Manzoor et al., 2012). It is low in fat and contains a lot of water (approximately 88.87 g per 100 g of fruit) (USDA, 2021). It has a considerably low amount of sugars and organic acids like malic acid, citric acid and folic acid. Organic acids represent only 4% of the peach's nutrient content, making carbohydrates the main macronutrients (Ribas-Agustí et al., 2017). The main sugars present in peach are sucrose, fructose, sorbitol and glucose. The main organic acids in peach are malic and citric acids. As for micronutrients, the peach is rich in minerals like potassium, phosphorous, calcium and magnesium; and B-complex vitamins are the main group of vitamins. Sugar/acid ratio is assessed by the SCC (Brix.) and Titratable acidity. Brix values in peach may vary from 9.2 to 19.83 (Scordino et al., 2012). TA values have been found to be between 0.13% and 1.16% (Scordino et al., 2012).

Canned peaches are available all year round. However, fresh peaches used for canning are harvested and processed during certain times in the year. The top global exporters of canned peaches are Greece, China, Spain, Chile, and South Africa. Spain is one of the two largest producers of canned peaches in the European Union, along with Greece (CBI, 2020). Quality of canned fruits is seriously compromised by the loss of their flesh firmness during pasteurization (Ribas-Agustí et al., 2017).

Pineapple and peach, two different kinds of fruits, are selected in this study to be processed as canned fruits using glass jars and pouches in reciprocating agitation thermal processing and ultrasonic water bath processing respectively. The study was aimed to optimize the processing parameters for reciprocal agitation thermal processing (RATP) and ultrasonic water bath processing (USWB) to attain minimum processing time along with minimum product disintegration and maximize product quality retention in pineapple and peach.

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PREFACE TO CHAPTER 3

Thermal processing is recognized as a successful method for food preservation for more than two centuries resulting in safe and shelf stable products. However, texture and color degradation as well as nutrition loss are major disadvantages during thermal processing. Fortunately, the destruction rate of quality attributes is not in the same order of magnitude as that of microorganisms. The study was carried out for evaluating heat penetration behavior of pineapple and peach in glass jars under reciprocating agitation thermal processing and in pouches while under ultrasonic water bath processing in order to establish the appropriate processing schedule.

Based on this study, the following manuscript has been prepared for publication.

Dhariwala, Husain and Ramaswamy, H. S., 2023. Heat penetration and process time calculation of pineapple and peach in glass jars and pouches – effect of reciprocating agitation and ultrasonic waves (draft manuscript prepared for publication)

Chapter 3

Heat penetration data gathering and process establishment for pineapple and peach while under reciprocation agitation thermal processing and ultrasonic water bath processing

3.1 Abstract

The study was carried out for evaluating heat penetration behavior for pineapple and peach in glass jars under reciprocating agitation thermal processing and in pouches while under ultrasonic water bath processing in order to establish the appropriate processing schedule. Pineapple wedges and peach slices were separately filled into glass jars for RATP and pouches for USWB with a light sugar syrup. The fruits were processed at different reciprocating frequencies of 0 Hz, 1Hz, 1.5 & 2 Hz at 90 ˚C, 95 ˚C and 100 ˚C in the pilot-scale reciprocating agitation retort. For ultrasonic water bath processing the runs were conducted at 90 ˚C, 95 ˚C and 98 ˚C while in the presence and absence of ultrasonic waves. The heat penetration parameters for the particle were obtained from the temperature-time data gathered during processing. Heating rate index (f_h) and processing time (Pt) for establishing the target lethality of ($F_{90^\circ C}$ -10 min) were calculated. It was observed that imparting agitation by the means of reciprocation agitation or ultrasonic waves results in reduced process time. For RATP, imparting agitation also resulted in lowering the value of f_h.

3.2 Introduction

Thermal processing is widely used to destroy spoilage and pathogenic microorganisms as well as inactivate enzymes present in the canned food in order to render them safe and shelf stable. The fundamental principle of thermal processing is to transfer the heat from a heating medium to the contents of the container to achieve the degree of heat treatment required. Conduction and convection are the two major mechanisms of heat transfer, which involve the heat transfer into or out of the food contained inside. In conduction heat transfer mechanism, the heat transfer occurs through solids or viscous stationary fluids, while convection mechanism takes place in liquid foods by using the movement of fluids. The mixture of liquid and particle products such as soups, fruits in syrup and sauces, will heat by combination of both conduction and convection mechanisms (Ahmed and Shivhare, 2006; Ramaswamy and Marcotte, 2006) and can be improved by induced convection through agitation.

In order to get maximum retention of quality of thermally processed products, high temperature short time processes (HTST) have been used to heat processing of vegetables in food industry as an alternative approach to conventional thermal techniques. The benefits of HTST are due to the different destruction rate of microorganisms and quality attributes (Ramaswamy and Marcotte, 2006). Several researchers have shown that the rate of microbial destruction generally is much higher at higher temperatures (z value of 10 to 15 ºC) which are also true for quality destruction (z value of 30 to 35 ºC) (Holdsworth, 1985; Lund, 1977); however, their relative destruction rates differ and drift farther apart at higher temperatures with the destruction rate of microbial spores increasing much more rapidly than that of quality factors (Ramaswamy and Marcotte, 2006).

There are several published reports on heating behaviors of foods in rotary retorts (Berry et al., 1979; Berry and Kohnhorst, 1985). The influences of different processing variables on heat transfer rate have also been studied by several researchers (Dwivedi and Ramaswamy, 2010a,b; Meng and Ramaswamy, 2006, 2007a,b; Rattan and Ramaswamy, 2014; Sablani and Ramaswamy, 1995, 1996). All these studies are unanimous in concluding that heat transfer rate during thermal processing is significantly affected by several major processing variables, including the type of retort, retort temperature, the nature of particle, the size of particle, rotational speed, and headspace.

Anantheswaran and Rao (1985) reported that the agitation of container contributes to a rapid heat transfer rate. Therefore, the processing time can be reduced, and the quality attributes of foods will have a better retention. Agitation processing can be achieved by novel reciprocating agitation and three types of traditional rotations which includes fixed axial rotation, end-over-end rotation, and free axial rotation. Container agitation in retort has many advantages over still retort. Foods heated in container agitation have rapid heat penetration rate, even in particulate or viscous products (Ramaswamy et al., 1993). The reciprocating agitation is the new method that exploits the reciprocal agitation in addition to gravity. The reciprocal forces cause greater movement of products within the can, which can increase heat transfer rate and thus reduce the processing time. As compared to conventional static agitation, reciprocating agitation provides a faster heat transfer rate and a significant reduction in processing time (Singh et al., 2015; Walden et al., 2010).

Another way of imparting agitation is by the application of ultrasonic waves, these waves while propagating through a medium, generate compressions and rarefaction (decompressions) in the medium particles. These compressions and rarefactions facilitate the increase of heat transfer (N. Bhargava et al., 2020). When ultrasonic waves are applied in combination with temperature it is called thermo sonication. Ultrasonic waves are generated by a transducer which converts electrical pulses into acoustic energy of required intensity (Rojas et al., 2021).

This study aimed to evaluate the effect of reciprocation agitation processing and ultrasonic water bath processing on the heating behavior of pineapple and peach, to compute the heating rate index and finally to establish processing times to accomplish a designated process lethality using the improved general method of process calculations.

3.3 Materials and methods

Raw materials

Pineapple and peach were purchased from the local market and then stored at 4 ºC. Pineapple was sliced in 1.5 cm thickness using an industrial grade slicer. The core was removed from the slices, and it was cut into wedges of length 2 cm using a sharp knife. Peaches were rinsed and for peeling they were treated according to Yaniga (2007) with slight modifications. The peaches were immersed in a tub containing hot NaOH solution (0.50 mol/L, 90 °C) for 120 s. After peeling, peaches were washed in tap water at ambient temperature to cool them down (Wang et al., 2018). After removal of the skin, the peaches were cut into slices of 1 cm thickness using a sharp knife. The prepared fruit were weighed into batches of 250 grams and filled in glass jars and pouches to process in the retort and the ultrasonic water bath respectively. They were filled with hot, light sugar syrup (15% w/v) keeping 15mm headspace in the jars. Thermocouples were fixed in the geometrical centers of the jar and the pouch, the pineapple wedges and peach slices were filled and one piece was attached to this thermocouple in order to obtain temperature-time data at different combinations of processing temperature and frequency of processing. The thermocouple was secured in place using a toothpick and string.

Retort

A pilot scale, single cage, and vertical static retort (Loveless Manufacturing Co., Tulsa, OK) was modified for reciprocation agitation thermal processing. The reciprocating retort is based on converting a static retort to a reciprocation agitation device. The internal diameter and depth of this steam retort are 62 cm and 100 cm, respectively. The mechanism of reciprocating is a drive method using a crank and slider that drives a basket back and forth through a drive shaft entering the retort. Steam is used as the heating medium while cold water is used as the cooling medium. The come-up time to reach operating temperature was approximately 2 to 3 minutes depending on the load and target temperature. There are three major parts in the modified retort, and it includes the reciprocating cage, a crank and slider, and a magnet motor (Singh et al., 2015). The crank and slider assembly have a steel rotating shaft and a crank. In order to move the jars in a reciprocating fashion, the crank had to be attached to rotating shaft. Thus, the pivoted end of the crank moves circularly through the rotating shaft, while the reciprocating cage moves linearly through the constricted end of the crank. The magnetic motor determined the reciprocating speed by a voltage controller. The speed can be read through a hand-held tachometer and therefore can be adjusted to the required speed. Rotating shaft is moving circularly once, while the reciprocating cage is moving linearly once.

Ultrasound bath

A digital ultrasound cleaner (Model – TH-SPQXJ-40A, made in China) of 10 L capacity with ultrasonic frequency of 28/40 Hz, ultrasonic power of 240W and heating power of 500W was used for ultrasonic water bath processing. The chamber used to hold the sample had dimensions of 53cm * 32cm * 22cm. An additional heating coil was used to supplement the heater supplied with the ultrasound cleaner to reach the required processing temperatures and maintain them. The ultrasonic waves were employed in full wave mode when required.

Heat penetration data gathering

Temperature data of the sample in jar and pouch along with retort and the ultrasonic water bath was gathered during processing in order to obtain the temperature-time profiles. The junction of flexible copper-constantan thermocouple wires (diameter = 0.0762 mm, Omega Engineering Corp, Stamford, CT, USA) were placed at the approximately geometrical center of sample in the jar, the pouch, the retort, and the ultrasonic water bath in order to monitor temperature of sample and heating medium, respectively. The male connectors of thermocouples were connected to the female connectors fixed in agitation retort. The thermocouple signals were recorded by data logger unit (HP34970A, Hewlett Packard, Loveland, CO, USA) at regular intervals of five seconds.

The heat penetration tests were carried out at different reciprocating frequencies of 0 Hz, 1Hz, 1.5Hz & 2 Hz at 90˚C, 95˚C and 100˚C for both pineapple and peach. For ultrasonic water bath processing the runs were conducted at 90˚C, 95˚C and 98˚C while in the presence and absence of ultrasonic waves. After thermal processing, the cans and retort were cooled to 30 ºC by cold water immediately. After ultrasonic water bath processing the pouches were cooled by submerging in a tub of cold water immediately. The heat penetration tests were done in duplicates and the time temperature data gathered were used to calculate the processing time and F_h of the processes.

Using the time temperature data gathered, a heat penetration curve was generated for each combination. It is a semi-logarithmic plot of temperature difference (heating medium minus jar contents). The heating rate index (F_h) can be obtained from this curve. The negative reciprocal of the heat penetration curve is the heat rate index. In other words, the heating rate index is the time required for the straight-line portion of heating curve to pass one log cycle. Low F_h value means high heat transfer rate.

In thermal processing, processing time refers to the time that product is required to be heated in the retort in order to achieve a selected lethality. In this study, processing time is calculated to achieve a process lethality F_{90C} -10 min. The improved general method suggested by Ball (1923) is based on a hypothetical thermal destruction curve or reference TDT curve of the test microorganism with a F_o value of 1 min at the reference temperature. The z value is conventionally taken as 18˚F for sterilization and 10˚F for pasteurization.

The lethal rate or L value at any temperature may be calculated using the following equation:

$$L = 10 \wedge ^{(T - T0)/z.}$$

The L value is the number of minutes at T_o equivalent to 1 min at temperature T. z value, which is defined as the temperature range that results in a 10-fold change in D values. The time–temperature data from the heat penetration test are integrated with respect to the L values via a numerical integration approach to facilitate computer calculation of the area under the curve. This represents the accumulated lethality or process lethality (F_o) as shown by the following equation:

$$\text{Process lethality} = F_o = \int L*dt.$$

Briefly, the sum of the lethal effects of the entire process (heating and cooling) is expressed as the number of minutes at a reference temperature.

Statistical Analysis

A one-way ANOVA was carried out using graph pad prism software, $P < 0.05$ was considered as statistically significant to confirm the significance of the results.

3.4 Results and discussions

In this study, the processing time is calculated to achieve a process lethality of F_{90C} - 10 min while carrying out reciprocal agitation thermal processing (RATP). Table 3.1 and 3.2, show the time to achieve the set lethality at different combinations of processing temperatures and reciprocating frequency for pineapple and peach in glass jars respectively.

Table 3.1. Time to achieve $F_{90^\circ C}$ – 10 min for pineapple in reciprocation agitation thermal processing (RATP)

Time to achieve $F_{90^\circ C}$ - 10 min				
Temperature	**Frequency**			
	0 Hz	1 Hz	1.5 Hz	2 Hz
90˚C	26.1 ± 0.6	24.0 ± 0.4	21.8 ± 0.4	17.2 ± 0.5
95˚C	17.5 ± 0.5	15.7 ± 0.1	13.0 ± 0.6	10.1 ± 0.3
100˚C	13.5 ± 0.4	12.2 ± 0.3	9.9 ± 0.7	8.2± 0.5

Table 3.2. Time to achieve $F_{90^\circ C}$ - 10min for peach in reciprocation agitation thermal processing (RATP)

Time to achieve $F_{90^\circ C}$ - 10 min				
Temperature	**Frequency**			
	0 Hz	1 Hz	1.5 Hz	2 Hz
90˚C	25.9 ± 0.5	22.2 ± 0.2	17.9 ± 1.5	17.6 ± 0.6
95˚C	15.6 ± 0.6	13.1 ± 0.1	12.00 ± 1	10.5 ± 0.1
100˚C	12.2 ± 0.3	11.4 ± 0.1	10.2 ± 1.3	7.6 ± 0.4

With an increase in temperature and reciprocating frequency, the processing time decreased. The longest processing time of 26.1 min for pineapple and 25.9 min for peach was when the processing temperature was the lowest at 90˚C and there was no agitation. The shortest processing time of 8.2 min for pineapple and 7.6 min for peach was when the processing temperature was highest at 100˚C with a reciprocating frequency of 2Hz. The time taken from initial to the target temperature was reduced with the increase in reciprocation speed. This implied that high reciprocating speeds resulted in reduced process time which could potentially lead to achieving better quality of final products.

Heating rate index (f_h) is an indicator of the rate of heat transfer, and not a direct measure of the heating rate. The lower value of heat rate index is, the faster the heat transfer is. Heating rate index can be obtained by plotting the logarithm of (Tr-Tp) against heating time. The processing temperatures of 90˚C, 95˚C and 100˚C along with the four reciprocation speeds of 0, 1, 1.5, 2 Hz were selected and increase in temperature and reciprocation speed was found to have a considerable effect on heating rate index.

Figure 3.1 & 3.2, show the graphical representation of f_h values of pineapple and peach in glass jars obtained from the time-temperature data while processing at different temperatures and at different reciprocating speeds. For both pineapple and peach, f_h values were found to decrease with the increase in processing temperature and increasing reciprocating speeds. The highest value of f_h for pineapple was 14.45 min which was in the slowest mode of heating which is the still mode along with the lowest processing temperature of 90˚C, while the lowest value for pineapple was 5.12 min when the reciprocating frequency was at 2 Hz with processing temperature set at 100˚C. The highest value of 12.8 min for f_h for peach was also in still mode with the lowest processing temperature, while the lowest value of f_h for peach was 5.47 min also when the reciprocating frequency was at 2 Hz with processing temperature set at 100˚C. At every processing temperature the highest value of f_h was obtained when there was no reciprocation agitation (0Hz) and the lowest value of f_h was obtained with the highest reciprocating frequency of 2 Hz.

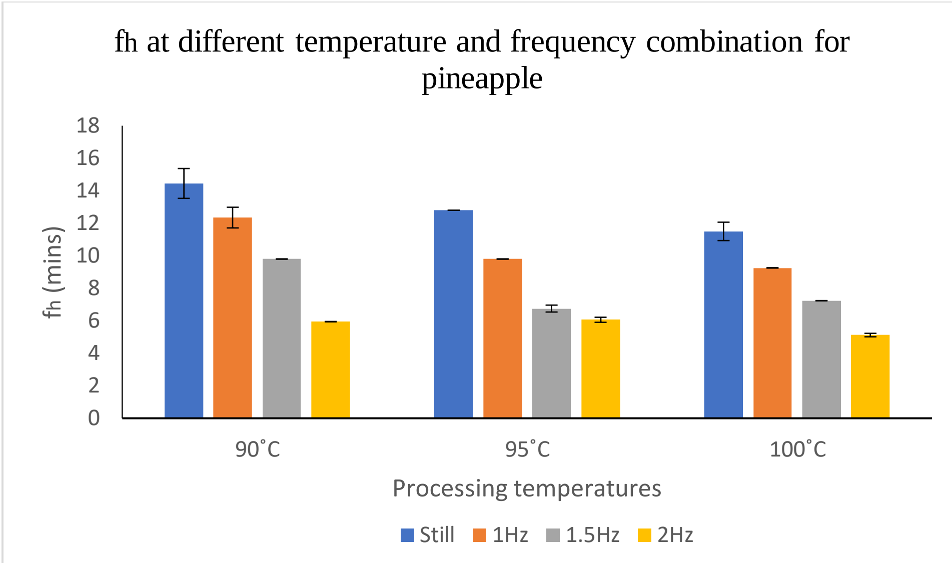

Figure 3.1. f_h at different processing parameters for pineapple in RATP

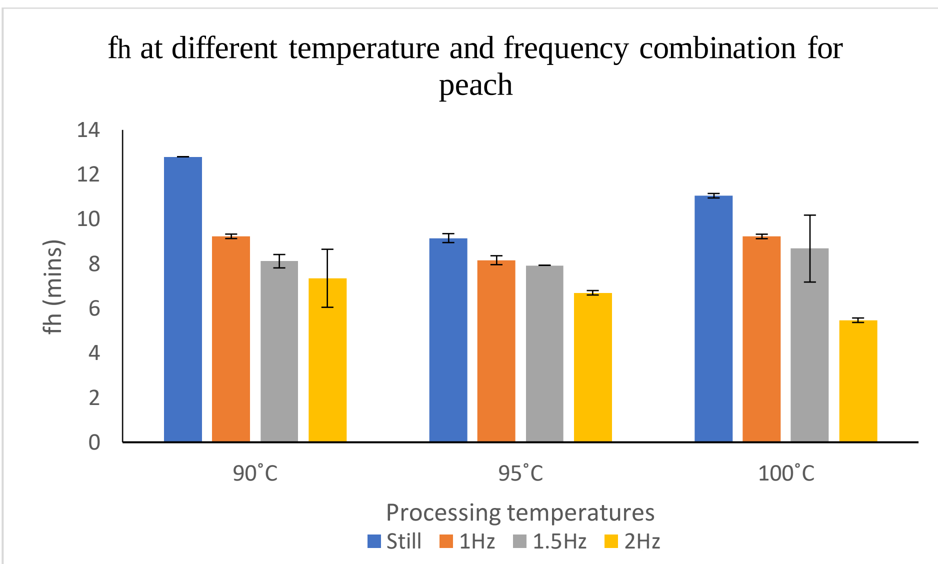

Figure 3.2. f_h at different processing parameters for peach in RATP.

The lower heating rate index value demonstrates that higher heat transfer occurs at higher reciprocating agitation speeds and temperatures, resulting from better mixing of can liquid and particles. The results are consistent with previous literature studies, which reported that lower heating rate index values are obtained at higher rotational speeds (Dwivedi and Ramaswamy, 2010b; Singh et al., 2015).

Figure 3.3 and 3.4 shows the internal temperature recorded and lethality values obtained for pineapple at different processing temperatures with a reciprocating frequency of 1.5 Hz and different processing temperatures along with application of ultrasonic waves.

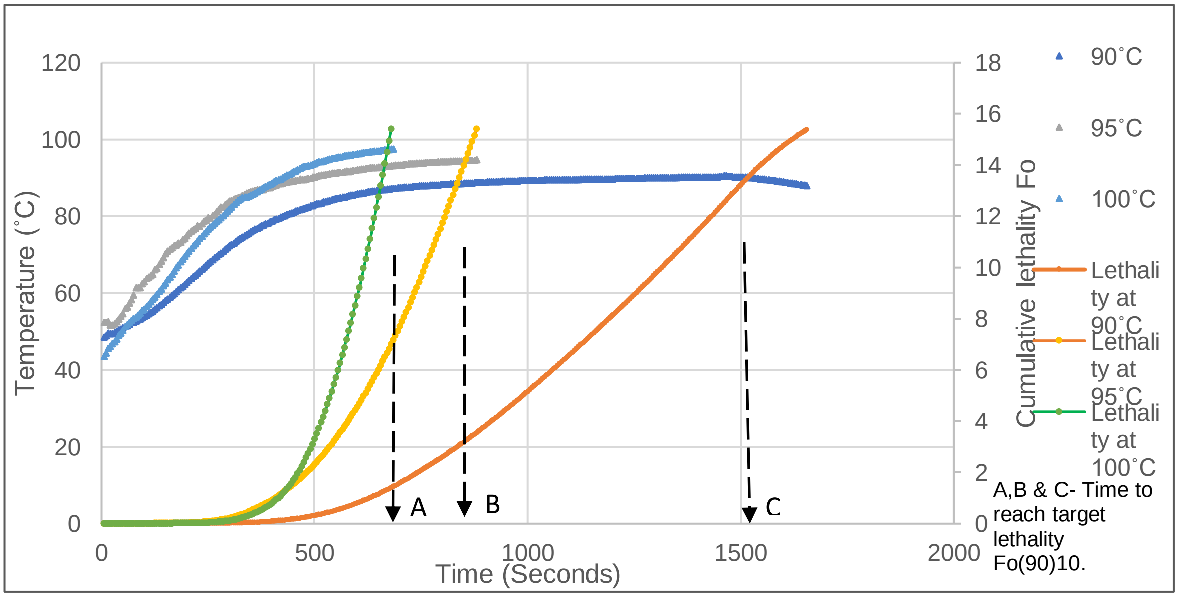

Figure 3.3. Internal temperature recorded and lethality values obtained for pineapple for RATP

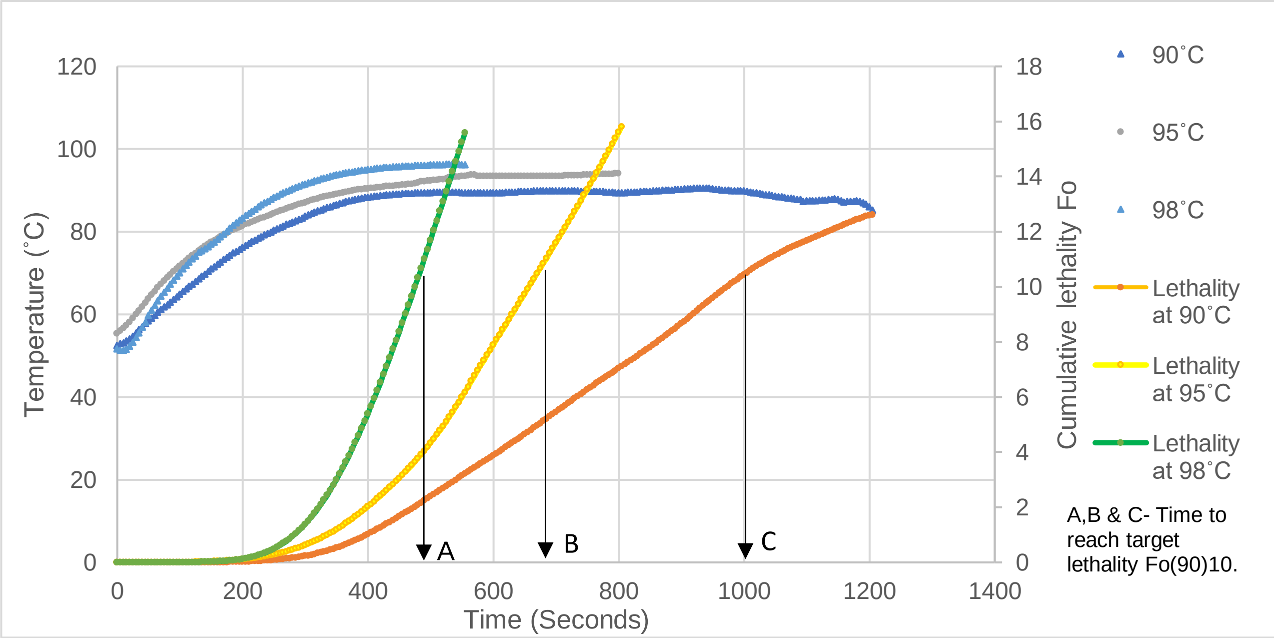

Figure 3.4. Internal temperature recorded and lethality values obtained for pineapple for USWB

In this study, the processing time was calculated to achieve a process lethality of $F_{90^{\circ}C}$ of 10 min while carrying out ultrasonic water bath processing. Table 3.3 and 3.4, show the time to achieve the set lethality at different processing temperatures with and without the application of ultrasonic waves for pineapple and peach in pouches respectively.

Table 3.3. Time to achieve $F_{90^{\circ}C}$ - 10 min for Pineapple in USWB

Time to achieve $F_{90^{\circ}C}$ - 10 min Pineapple			
Ultrasound	Temperature		
	90˚C	95˚C	98˚C
Off	17.5 ± 0.1	10.5 ± 0.0	8.6 ± 0.0
On	16.25 ± 0.3	11.0 ± 0.1	7.9 ± 0.1

Table 3.4. Time to achieve $F_{90^\circ C}$ - 10 min for Peach in USWB

Time to achieve $F_{90^\circ C}$ - 10 min Peach			
Ultrasound	Temperature		
	90˚C	95˚C	98˚C
Off	17.6 ± 0.1	13.3 ± 0.07	11.7 ± 0.03
On	16.25 ± 0.3	11.9 ± 0.1	10.5 ± 0.6

With increase in temperature and application of ultrasonic waves, the processing time decreased. The longest processing time of 17.5 min for pineapple and 17.6 min for peach was when the processing temperature was the lowest at 90˚C and there was no agitation by application of ultrasonic waves. The shortest processing time of 7.9 min for pineapple and 10.5 minutes for peach was when the processing temperature was highest at 100˚C with agitation by application of ultrasonic waves. The application of ultrasonic waves resulted in reduced process time which could potentially lead to achieving better quality of final products.

Figure 3.5 & 3.6, show the graphical representation of f_h values obtained from the time-temperature data while processing pineapple and peach in pouches at different temperatures with and without the application of ultrasonic waves. The highest value of f_h for pineapple was 7.25 min which was with the processing temperature of 95˚C while ultrasonic waves were applied, while the lowest value for pineapple was 4.6 min when ultrasonic waves were not applied with processing temperature set also at 95˚C. The highest value of 12.65 min for f_h for peach was in absence of ultrasonic waves at 95˚C processing temperature, while the lowest value of f_h for peach was 8.6 min when ultrasonic waves were applied with processing temperature set at 90˚C.

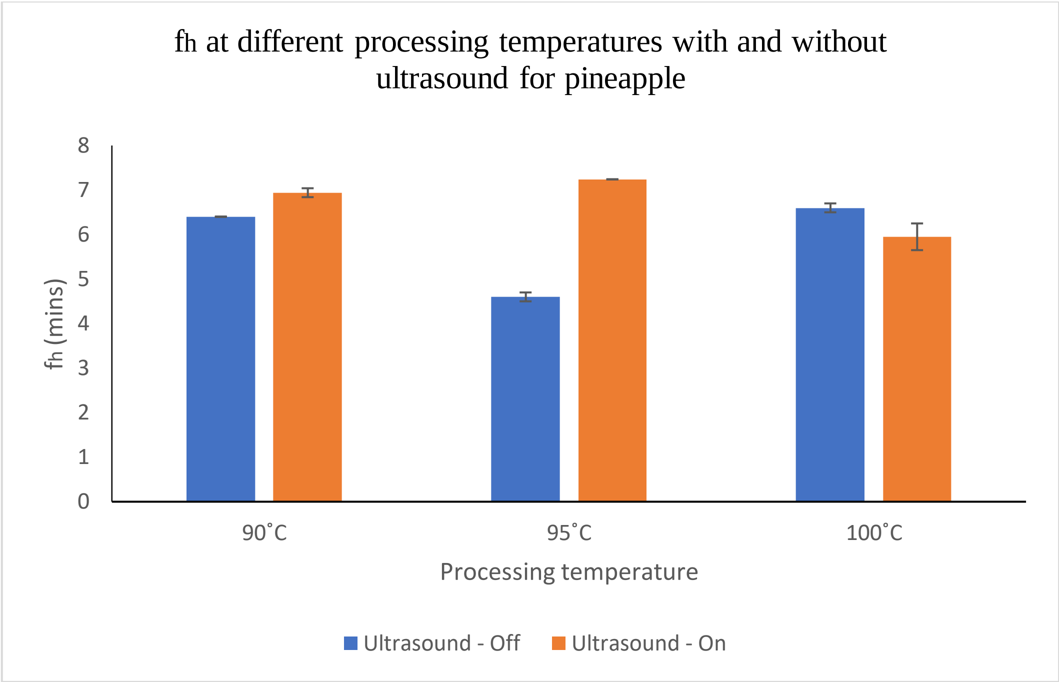

Figure 3.5. f_h at different processing parameters for pineapple in USWB

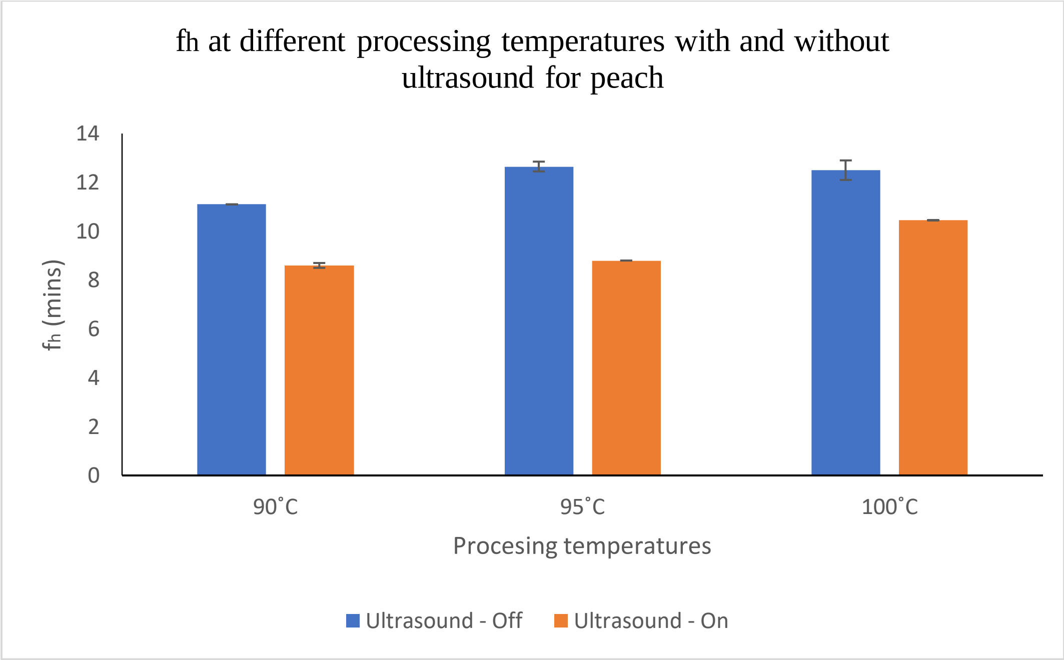

Figure 3.6. f_h at different processing parameters for peach in USWB

3.5 Conclusions

In steam heating medium, reciprocation speed had a significant impact on heating rate index (f_h) and processing time (Pt). Under high reciprocation speeds, the associated heating rate index was lowered, which meant the heat transfer rate was more rapid. The increased heat transfer rate due to agitation resulted in reduced processing times. High reciprocation speed could have a positive effect on the quality attributes as the processing times were reduced. However, excessive agitation could result in particle breakage. In ultrasonic water bath processing, application of ultrasound had much lower effect on improving heat transfer and reducing processing times. The reason could be the inefficiency in providing adequate agitation to the sample.

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PREFACE TO CHAPTER 4

The previous chapter was focused on heat penetration parameters associated with pineapple wedges and peach slices at various reciprocating frequencies, and establishment of thermal processing conditions for a target lethality of $F_{90^{\circ}C}$ - 10 min at different reciprocation speeds and processing temperatures in RATP process as well as in the ultrasound water bath (USWB). The focus of this chapter is to evaluate the quality retention of pineapple wedges and peach slices under these calculated processing conditions and identify the ones that offer better retention of product quality. The product quality parameters tested included the appearance factor (color parameters) and texture attributes (hardness, gumminess, chewiness, skin strength and elasticity) as well as retention of ascorbic acid (nutritional).

Based on this study, the following manuscript has been prepared for publication.

Dhariwala, Husain and Ramaswamy, H. S., 2023. Reciprocation agitation thermal processing and ultrasonic water bath processing of pineapple (Ananas comosus) and peach (Prunus persica). (draft manuscript prepared for publication)

Chapter 4

Evaluation of quality retention in reciprocation agitation thermal processing and ultrasonic water bath processing of pineapple wedges and peach slices

4.1 Abstract

The study was carried out to evaluate the influence of reciprocation agitation thermal processing (RATP) of pineapple (*Ananas comosus*) wedges and peach (*Prunus persica*) slices in glass jars and ultrasonic water bath processing (USWB) of pouch-packaged pineapple wedges and peach slices, in order to identify conditions that better retain the quality attributes in the processed product. The quality attributes studied were color and texture parameters, and ascorbic acid content under different processing conditions (retort processing temperature: 90ºC 95˚C & 100˚C, and agitation speeds 0, 1, 1.5 & 2 Hz for RATP and water bath temperature: 90ºC 95˚C & 98˚C for USWB). The samples were filled into glass jars or pouches with 15% sugar syrup and screw cap closed/heat sealed. A pilot scale steam retort modified to accommodate reciprocation agitation was used for RATP. A digital ultrasound cleaner was used for USWB. The color and texture parameters along with ascorbic acid content were evaluated for each processing condition. The study indicated a significant influence of process variables on the evaluated quality parameters, especially with RATP and provided processing opportunities for better retention of product quality.

4.2 Introduction

Fruit and vegetable consumption has considerably increased in the past decade. In fact, they have now become an omnipresent part of the human diet. Pineapple (*Ananas comosus*) is one fruit that is appreciated for its taste and juiciness (Lenevue-Jenvrin et al., 2020). Pineapple belongs to the *Bromeliaceae* family and is cultivated in tropical and subtropical zones. It has a unique shape with wide leaves and fruits that differentiates them from other monocotyledons plants (Wali, 2019).

There has been a growing demand for pineapple fruit and its products since the past few years. It only comes after banana and mango in the most-produced tropical fruit category (Hamzah et al., 2021). There are numerous pineapple varieties based on their colors, shapes, sizes and flavors (Ali et al., 2020). It is reported that Smooth Cayenne, Queen, Spanish and Abacaxi are the four primary pineapple categories (Pandit. et al., 2020). Among the number of varieties that exist, Smooth Cayenne is the most marketed variety (Campos et al., 2020). Pineapple is one of the most cultivated fruits, and the primary pineapple producers are Costa Rica, Philippines, Brazil, Thailand and India (Ali. M et al., 2020). According to Food and Agriculture Organization (FAO), the world pineapple production increased to 28,179,348 tonnes in 2019, compared to 28,430,017 tonnes in 2018 (FA0, 2021). The major commodities in which processed pineapple is exported are canned pineapple, juice and concentrated juice as stated by FAO. In 2018, Thailand was the country that exported the highest volume of canned pineapple (FAO, 2021).

Pineapple presents many nutritional benefits, being a good source of antioxidants, minerals and vitamins (Septembre-Malaterre et al., 2018). Pineapple has 47.8 mg of vitamin C and 13 mg of calcium per 100 g of pineapple (Azevedo. A et al., 2021). Antioxidants present in pineapple are, bromelain, ascorbic acid, and other flavonoids (Sun, G.M et al., 2015). Oxidative reactions in the body can lead to the initiation of cancer. The consumption of antioxidant compounds has been implicated in preventing the onset of cancers. Antioxidant compounds are also susceptible to heat.

Peach (*Prunus persica*), is another one of the most consumed fruits, belongs to the genus *Prunus* from the Rosaceae family that encompasses about 230 species (Giovannini et al., 2014). There are deciduous and evergreen species, trees, and shrubs (Lesmes-Vesga et al., 2022) considered economically important fruit and nut crops, such as peaches, *P. persica*, and almonds, *P. dulcis* that belong to the genus (Rehder, 1940). Peaches are the major stone fruits consumed worldwide, of which China and the European Union are the largest producers in the world. (USDA-NASS, 2019).

The moisture content in fresh fruits like peaches is high, peaches approximately contain 88.87 g water per 100 g of fruit (USDA, 2021). The distinct sweet taste of peach is credited to sucrose that accounts for 40–85% of the total soluble sugars content, followed by glucose and fructose (10–25%) and sorbitol (< 10%) (Cirilli et al., 2016). Malic acid and ascorbic acid are the predominant organic acids of peach fruit, contributing to the intensity of sourness (Crisosto & Crisosto, 2005). In addition, phytochemical compounds, such as polyphenols and carotenoids further contribute both to the flavor (astringency, bitter taste), nutritional quality and to the overall appearance of the peach fruit, respectively. (Drogoudi et al., 2016). Peaches are not harvested throughout the year and requires more consideration regarding the planning of process operations. This along with its perishability poses a problem for the industry in its transportation and storage.

Since the moisture content is high in fresh fruits, they are highly perishable. This poses a problem for industry as they face difficulties in its transportation and storage. With the application of heat, fresh fruits can be processed into canned foods that have a longer shelf life. Canned fruits are widely consumed throughout the world since they are convenience foods and have a stable shelf life at room temperature (Premi and Khan, 2018). In order to destroy microorganisms of public health and spoilage concern a wide range of temperature and time combinations have been applied to process fruits. However, many quality attributes are also susceptible to heat and would be lost to some extent, including texture, color, antioxidant compounds and vitamins. Therefore, the food industry is seeking efficient methods that impart a rapid and uniform heating treatment and minimize the quality deterioration and destruction of nutrients; however, without compromising on the safety guarantee. Moreover, rapid heating processing can reduce the required processing time by improving heating efficiency, saving energy, and also increasing production output (Dwivedi and Ramaswamy, 2010).

Thermal texture softening occurs during processing and these texture changes in most fresh fruits are undesirable and affect consumer acceptance. Texture changes in thermal processing of fruits can be attributed to cellular degradation, breakdown of cell wall and pectin structures resulting from enzymatic and non-enzymatic reactions (Anthon et al., 2005). Color of the product is the first quality attribute that persuades the customer in deciding. Heat treatment degrades or changes the naturally occurring pigments in foods, affecting, or completely changing them (Pathare et al., 2013). Quality of canned peach is seriously compromised by the loss of their flesh firmness during pasteurization (Ribas-Agustí et al., 2017). Therefore, the food industry is seeking efficient methods that impart a rapid and uniform heating treatment and minimize the quality deterioration and destruction of nutrients; however, without compromising on the safety guarantee.

Some studies have attempted to find the optimal agitation frequency for reciprocating agitation for processing fruits or fruit products. In one study, RATP has been shown to be effective to obtain tomato puree with a brighter red color (closer to fresh) at 3 Hz reciprocation frequency (Singh et al., 2017). The study also concluded that a very high reciprocation frequency (>3 Hz) is not necessarily needed, and significant quality improvement can be obtained at lower frequencies (~2 Hz). In another study with banana puree subjected to reciprocating agitation, reduced processing times and better quality have been reported in comparison to still processing (Batmaz and Sandeep, 2015). For canned products containing soft particulates which might be susceptible to damage under rapid agitation, operating at lower frequencies, would be preferable and more advantageous to preserve the overall quality of food product (Singh et al., 2016). The influence of reciprocation agitation thermal processing on fruits as particle in fluid particle mixed type of foods is limited in literature. The influence of thermosonication on fruits as particle in fluid type of foods is further limited in literature.

Therefore, the objective of this work was to study the influence of reciprocation agitation thermal processing and thermosonication on pineapple and peach in light syrup as particle in fluid type of foods.

4.3 Materials and Methods

4.3.1 Processing conditions

The processing time for each experimental condition were calculated from the heat transfer studies conducted and are detailed in Chapter 3. The experiments were performed in the reciprocating agitation retort and ultrasonic water bath. There were three processing temperatures of 90˚C, 95 ˚C & 100 ˚C along with 4 agitation speeds (0,1, 1.5 & 2 Hz) in reciprocating agitation retort. For ultrasonic water bath there were three processing temperatures of 90˚C, 95 ˚C & 98 ˚C along with the presence and absence of ultrasonic waves.

4.3.2 Sample preparation

Pineapple (*Ananas comosus)* were purchased from the local market and then stored at 4ºC. Pineapple was sliced in 1.5 cm thickness using an industrial grade slicer. The core was removed from the slices, and it was cut into wedges of length 2 cm using a sharp knife.

Peach (*Prunus persica*) were purchased from the local market and then stored at 4ºC. Peaches were rinsed and were immersed in a tub containing hot NaOH solution (0.50 mol/L, 90 °C) for 120 s. After peeling, peaches were washed in tap water at ambient temperature to cool down (Wang et al., 2018). Following removal of the skin, the peaches were cut into slices of 1 cm thickness using a sharp knife.

The prepared fruit were weighed into batches of 250 grams and filled in glass jars and pouches to process in the retort and the ultrasonic water bath respectively. They were filled with hot, light sugar syrup (15% w/v) keeping 15mm headspace in the jars.

4.3.3 Experimental setup

The experimental setup is same to the one discussed in Chapter 3.

4.4 Quality measurement

4.4.1 Texture measurement

Processed pineapple samples were subjected to a two-cycle compression test using TA-XT Plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/ Stable Micro Systems, Godalming, Surrey, UK) with a 2 kg load cell and a circular probe. Processed peach samples were subjected to a two-cycle compression test using TA-XT Plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/ Stable Micro Systems, Godalming, Surrey, UK) with a 2 kg load cell and a penetrating. Pre-test, test, and post test speeds were 1.0, 0.5 and 0.5 mm/s respectively. Textural parameters, such as hardness, chewiness and gumminess for pineapple and elasticity and skin strength for peaches were obtained by using Texture Exponent 32 software (Texture Technologies Corp., Scarsdale, NY/ Stable Micro Systems, Godalming, Surrey, UK).

4.4.2 Color measurement

The color characteristics were evaluated by using a Minolta Tristimulus Colorimeter (Minolta Corp., Ramsey, NJ, USA). The color parameters L* and b* were obtained by software (SpectraMagic, Minolta Corp., Ramsey, NJ, USA).

4.4.3 Ascorbic acid content measurement

50g of sample was blended with 50ml of 6% HPO_3 using a blender. 30g of this blend was mixed with 100 ml of 3% HPO_3. The mixture was filtered using Wattman filter paper and the solution was collected. 10ml of this solution was titrated against the dye that is 0.025% DCPIP. The dye was standardized using a standard ascorbic acid solution beforehand.

The ascorbic acid content was calculated using the following formula:

$$\text{Mg of ascorbic acid per 100 g of sample} = ((V * T) / 3) * 100$$

where,
V = volume of dye used
T = 1 / standardization value

A one-way ANOVA was carried out using graph pad prism software, $P < 0.05$ was considered as statistically significant to confirm the significance of the results.

4.5 Results and discussions

4.5.1 Pineapple

4.5.1.1 Texture parameters

The measurement of different texture attributes is done with the help of a texture analyzer. Values for hardness, chewiness & springiness among others are measured by the texture analyzer. The values are depicted in relative terms so as to take into account the variance of different pineapples that were used for the processes.

Figures 4.1 and 4.2 show changes in hardness, as influenced by different processing parameters of RATP and USWB. The increase in processing temperature showed an increase in relative hardness for USWB and for RATP too up to a frequency of 1Hz demonstrating that agitation processing slightly improved the retention of hardness.

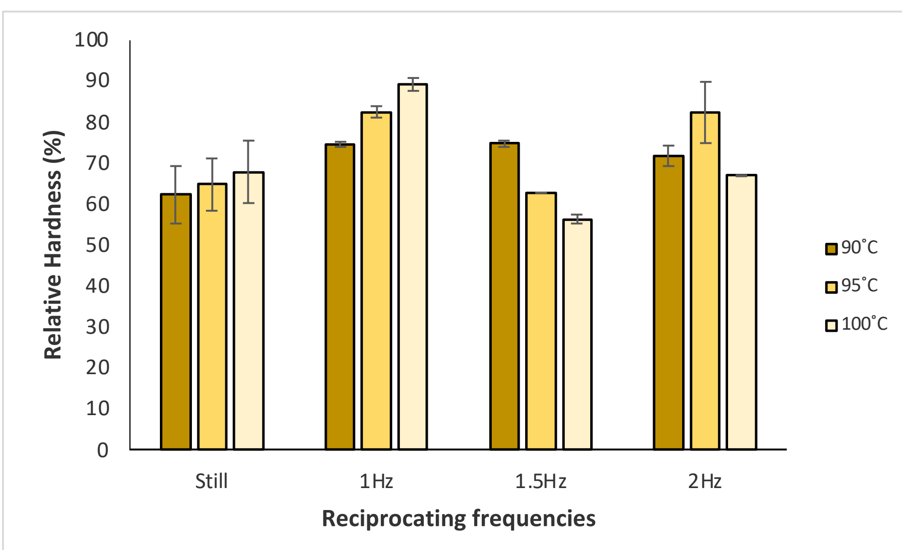


Figure 4.1. Relative hardness for pineapple in RATP

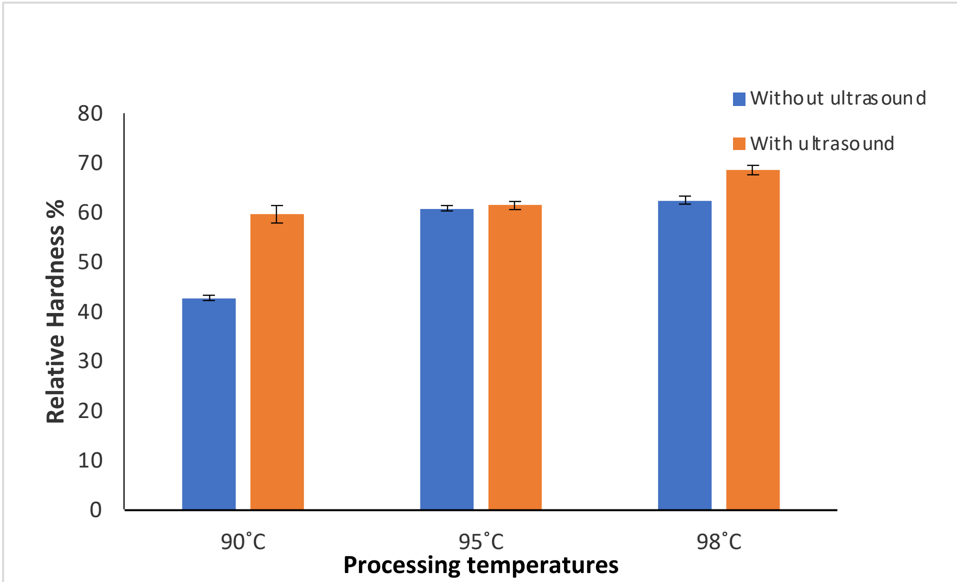


Figure 4.2. Relative hardness for pineapple in USWB

Figures 4.3 and 4.4 show changes in springiness, as influenced by different processing parameters of RATP and USWB. In terms of quality retention, RATP provided significant retention of springiness at a frequency of 2Hz only. Low reciprocating frequencies did not show significant influence on retention of springiness. Providing agitation using ultrasound, however, had a negative impact on retention of springiness for every processing temperature.

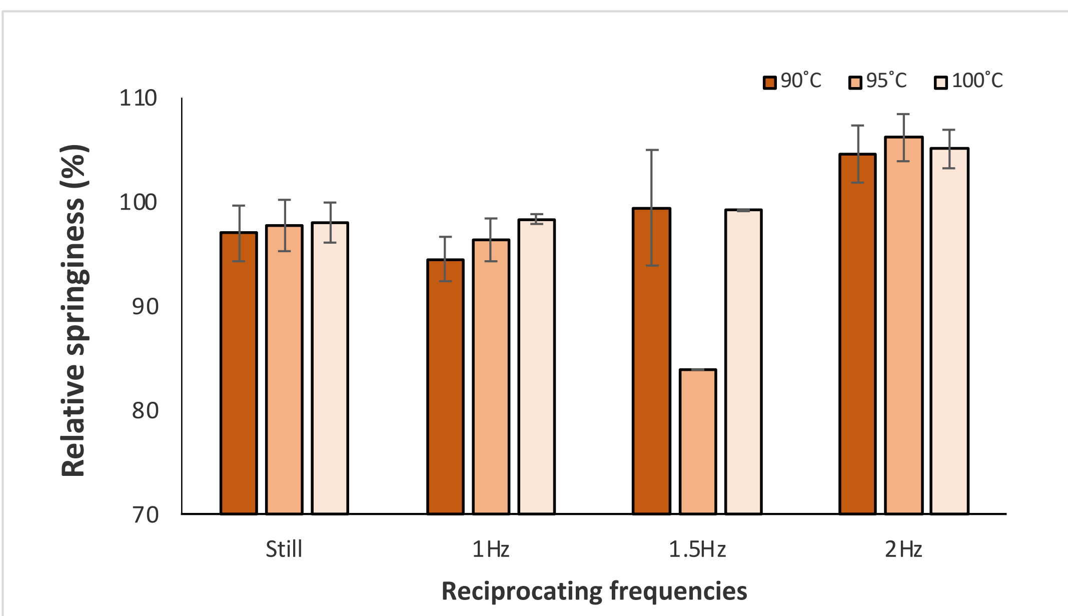


Figure 4.3. Relative springiness for pineapple in RATP

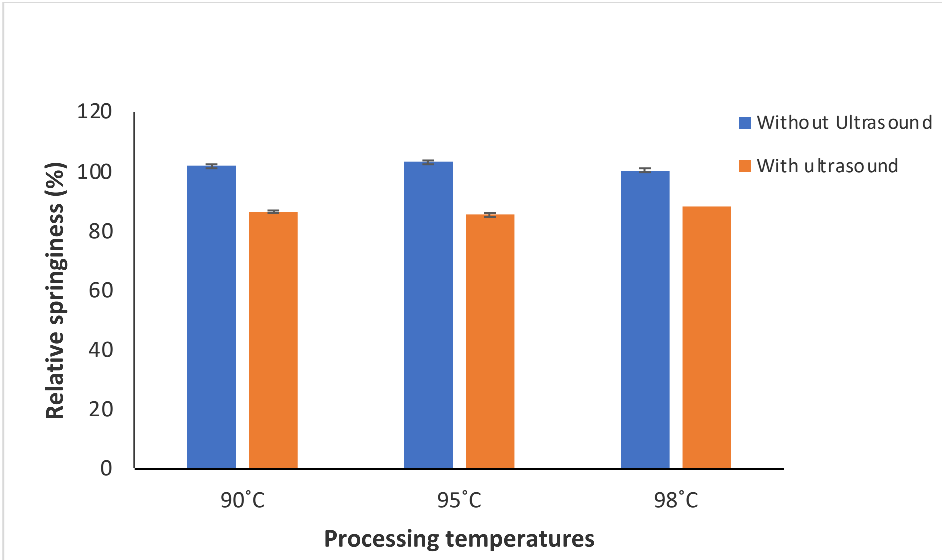


Figure 4.4. Relative springiness for pineapple in USWB

Figures 4.5 and 4.6 show influence of different processing parameters of RATP and USWB on chewiness. Up to 1 Hz reciprocating frequency, the chewiness slightly increased with increase in processing temperature. At 2Hz, the chewiness decreased with increase in processing temperature. For USWB, providing agitation did not provide any improvement in retention of springiness except at the processing temperature of 90˚C.

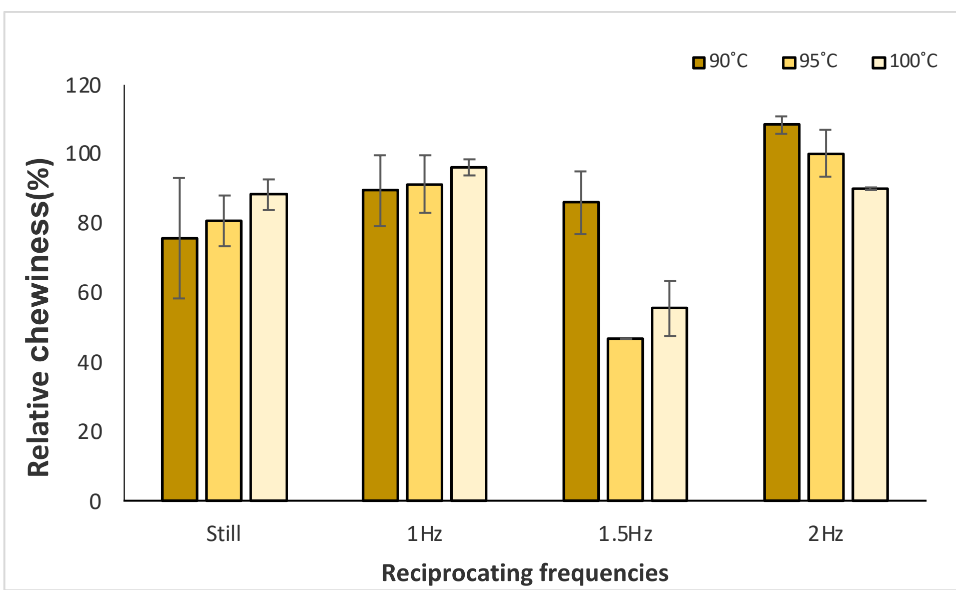


Figure 4.5. Relative chewiness for pineapple in RATP

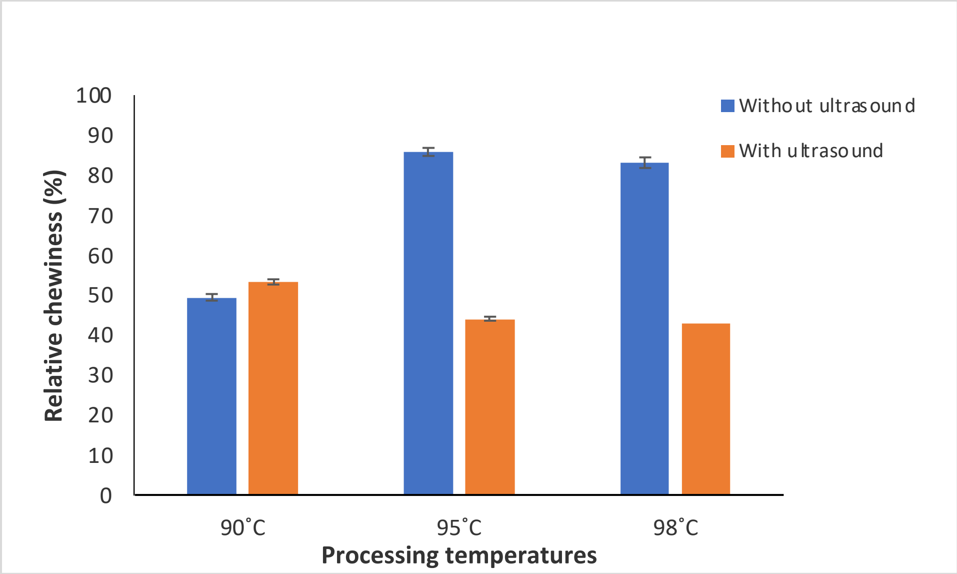


Figure 4.6. Relative chewiness for pineapple in USWB

For RATP, the highest relative hardness achieved was 89% while being processed at 100˚C with a frequency of 1Hz. The highest relative springiness achieved was 106% while being processed at 95˚C with a frequency of 2Hz. The highest relative chewiness achieved was 108% while being processed at 90˚C with a frequency of 2Hz.

For USWB, the highest relative hardness achieved was 68% while being processed at 98˚C with application of ultrasound. The highest relative springiness achieved was 103% while being processed at 95˚C without ultrasound. The highest relative chewiness achieved was 85% while being processed at 95˚C without ultrasound.

4.5.1.2 Color parameters.

Colorimeters give measurements that can be correlated with human eye–brain perception and give tristimulus (L, a and b) values directly. L* is an approximate measurement of luminosity, equivalent to a member of the greyscale, between black and white. b* takes positive values for yellowish colors and negative values for the bluish ones. Yellow color being the major component in pineapple justified selecting b* alone. The values depicted are in relative terms so as to consider the variance of different pineapples that were used for the processes.

Figures 4.7 and 4.8 show changes in color parameter of lightness as influenced by different processing parameters of RATP and USWB. With RATP, the lightness increased till a reciprocating frequency of 1.5Hz for every processing temperature. Providing agitation through USWB improved retention of lightness significantly for every processing temperature.

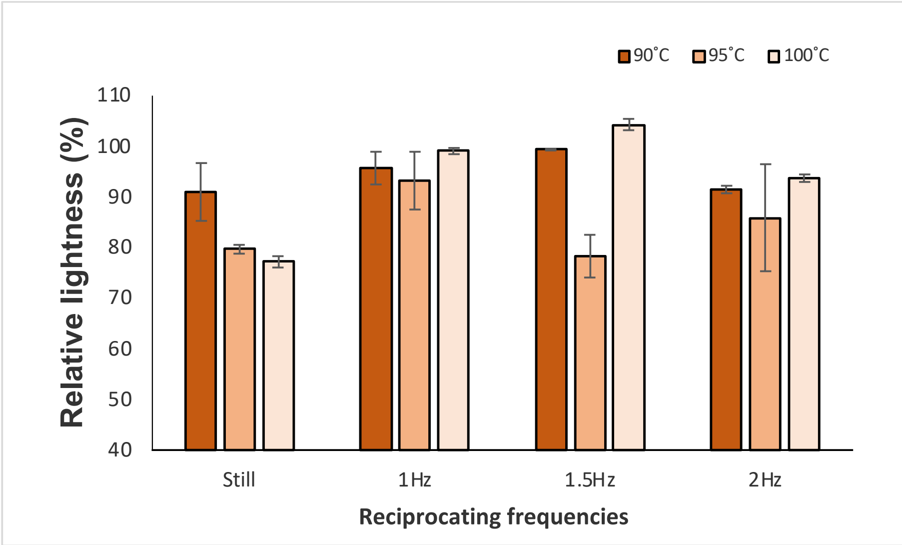


Figure 4.7. Relative lightness for pineapple in RATP

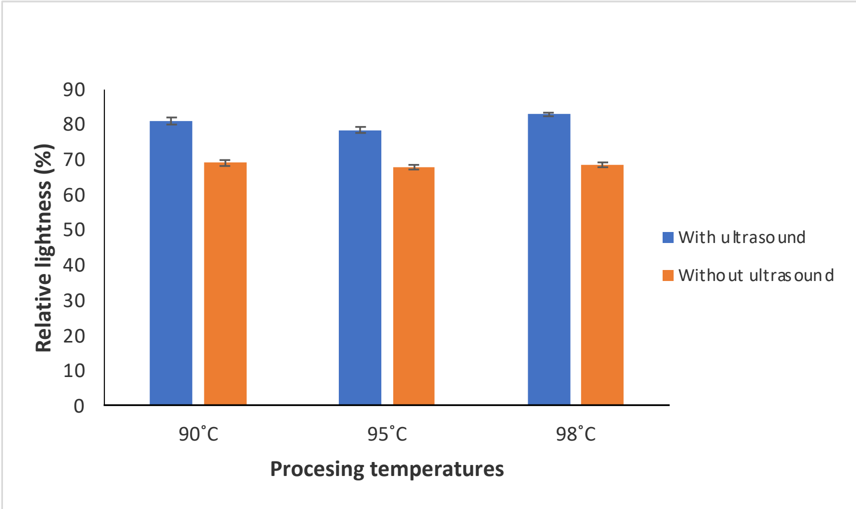


Figure 4.8. Relative lightness for pineapple in USWB

Figures 4.9 and 4.10 show changes in yellowness as influenced by different processing parameters of RATP and USWB. With RATP, the yellowness increased for every processing temperature at a specific reciprocating frequency except still processing. Providing agitation through USWB only showed slight retention at a processing temperature of 98˚C.

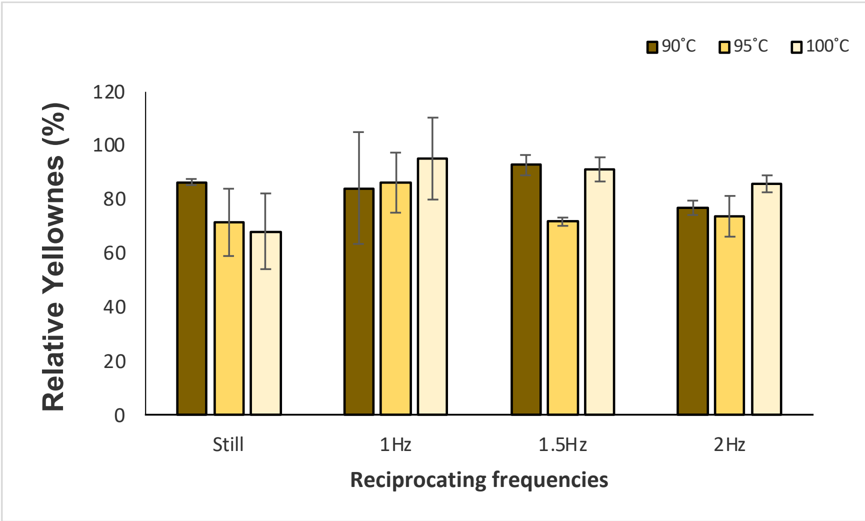


Figure 4.9. Relative yellowness for pineapple in RATP

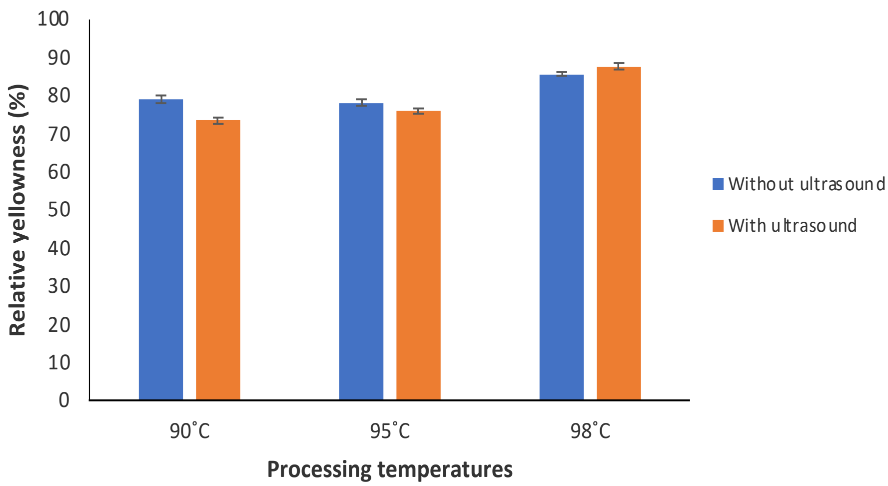


Figure 4.10. Relative yellowness for pineapple in USWB

For RATP, the highest relative lightness achieved was 104% while being processed at 100˚C with a frequency of 1.5 Hz. The highest relative yellowness achieved was 94% while being processed at 100˚C with a frequency of 1 Hz.

For USWB, the highest relative lightness achieved was 83% while being processed at 98˚C without ultrasound. The highest relative yellowness achieved was 87% while being processed at 98˚C with ultrasound.

4.5.1.3 Ascorbic acid content

Ascorbic acid (also known as vitamin C) is an antioxidant that is necessary for humans. Fruits and their juices are the most important supplier of it to the human diet. Ascorbic acid being heat sensitive requires minimal processing so as to be available for the human body.

Figures 4.11 and 4.12 show influence of different processing parameters of RATP and USWB on retention of ascorbic acid. With RATP, the ascorbic acid retention increased significantly upto a reciprocating frequency of 1.5Hz. Increase in processing temperature also showed an influence but only till 1.5Hz reciprocating frequency. Providing agitation through USWB showed slight retention at a processing temperature of 90˚C and 95˚C. At 98˚C, absence of agitation had a more significant effect on retention.

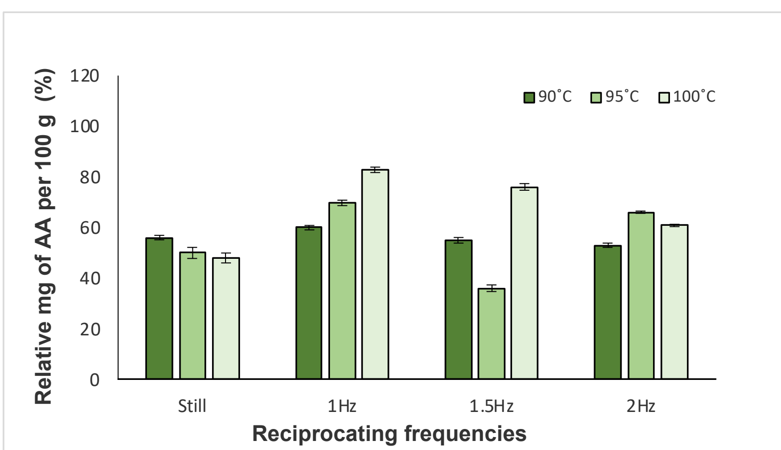


Figure 4.11. Relative Ascorbic acid for pineapple in RATP

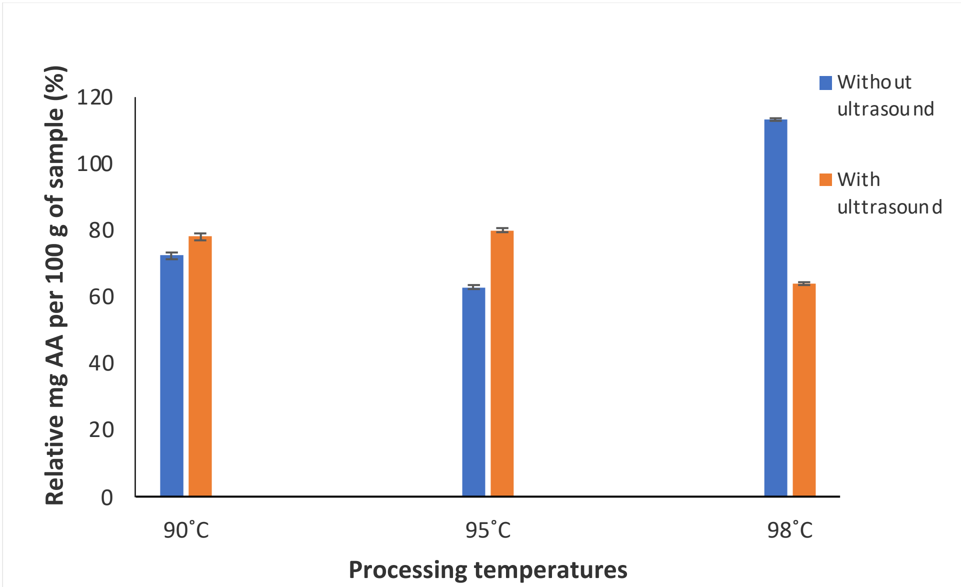


Figure 4.12. Relative Ascorbic acid for pineapple in USWB

For RATP, the highest relative milligram of ascorbic acid per 100 gram of sample was 83% while being processed at 100˚C with a frequency of 1 Hz. For USWB, the highest relative milligram of ascorbic acid per 100 gram of sample was 113% while being processed at 98˚C without ultrasound.

4.5.1.4 Appearance

The pictures of treated samples are shown in Figures 4.13 - 4.16 for pineapple. It is evident that pineapple samples treated at different temperatures with 0 Hz become prone to disintegration because of the long treatment time. At 1 Hz reciprocation frequency, the particles are the most intact and firm as compared to other reciprocation frequencies. At the higher speeds, the particle shape was maintained too, but it was the best at 1Hz. Also, the color of pineapple wedges became much more yellow in the treated samples as compared to raw when treated at higher temperatures.

Figure 4.13. Pineapple samples processed under still mode at 90˚C, 95˚C & 100˚C.

Fig 4.14. Pineapple samples processed under 1Hz at 90˚C, 95˚C & 100˚C.

Figure 4.15. Pineapple samples processed under 1.5Hz at 90˚C, 95˚C & 100˚C.

Figure 4.16. Pineapple samples processed under 2Hz at 90˚C, 95˚C & 100˚C.

Overall results for pineapple

Table 4.1 shows the various combinations of processing parameters required to achieve highest values of different quality attributes of pineapple for RATP and USWB.

Table 4.1. Temperature and agitation combinations for different quality attributes of pineapple

Highest value of	Temperature and agitation combination	
	RATP	USWB
Relative hardness	100˚C and 1Hz	98˚C with ultrasound
Relative springiness	95˚C and 2Hz	95˚C without ultrasound
Relative chewiness	90˚C and 2Hz	95˚C without ultrasound
Relative lightness	100˚C and 1.5Hz	98˚C with ultrasound
Relative yellowness	100˚C and 1Hz	98˚C without ultrasound
Relative Ascorbic acid content	100˚C and 1Hz	98˚C without ultrasound

4.5.2 Peach

4.5.2.1 Texture parameters

The measurement of different texture attributes is done with the help of a texture analyzer. Values for skin strength and elasticity are measured by the texture analyzer. Figures 4.17 – 4.20 show changes in texture parameters like elasticity and skin strength as influenced by different processing parameters of RATP and USWB. The values are depicted in relative terms so as to take into account the variance of different peaches that were used for the processes.

Figures 4.17 and 4.18 show changes in skin strength of peaches, as influenced by different processing parameters of RATP and USWB. The processing temperature of 95˚C showed the highest skin strength for RATP for all frequencies but was highest for the frequency of 1 Hz. Providing agitation through ultrasound slightly improved the retention of skin strength at 90˚C and 95˚C, but showed significant increase at a temperature of 98˚C.

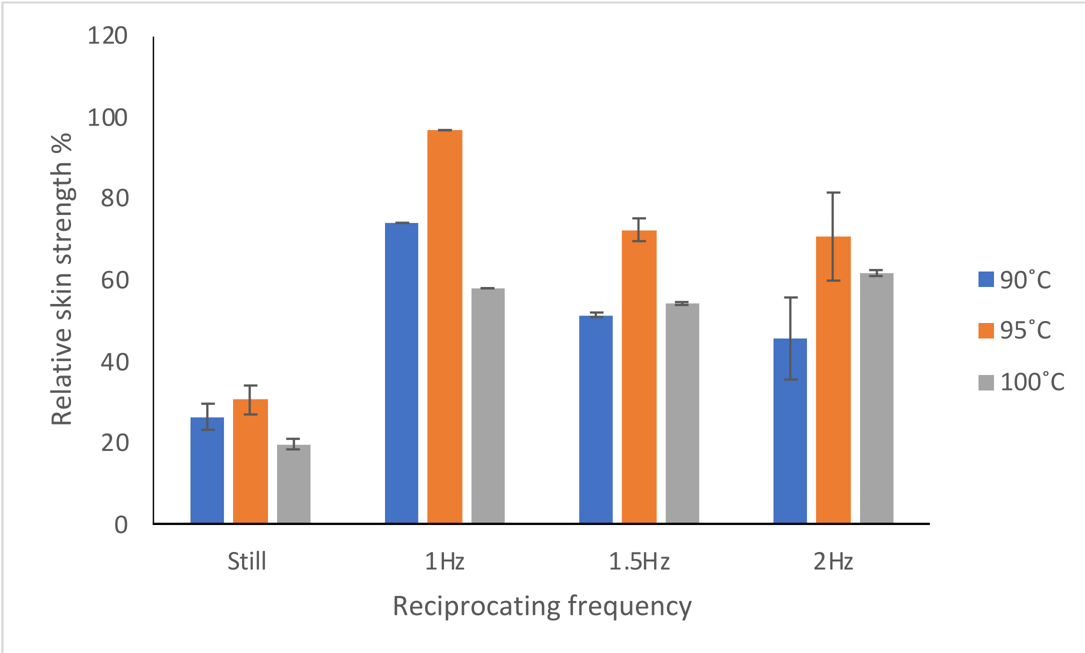


Figure 4.17. Relative skin strength for peach in RATP.

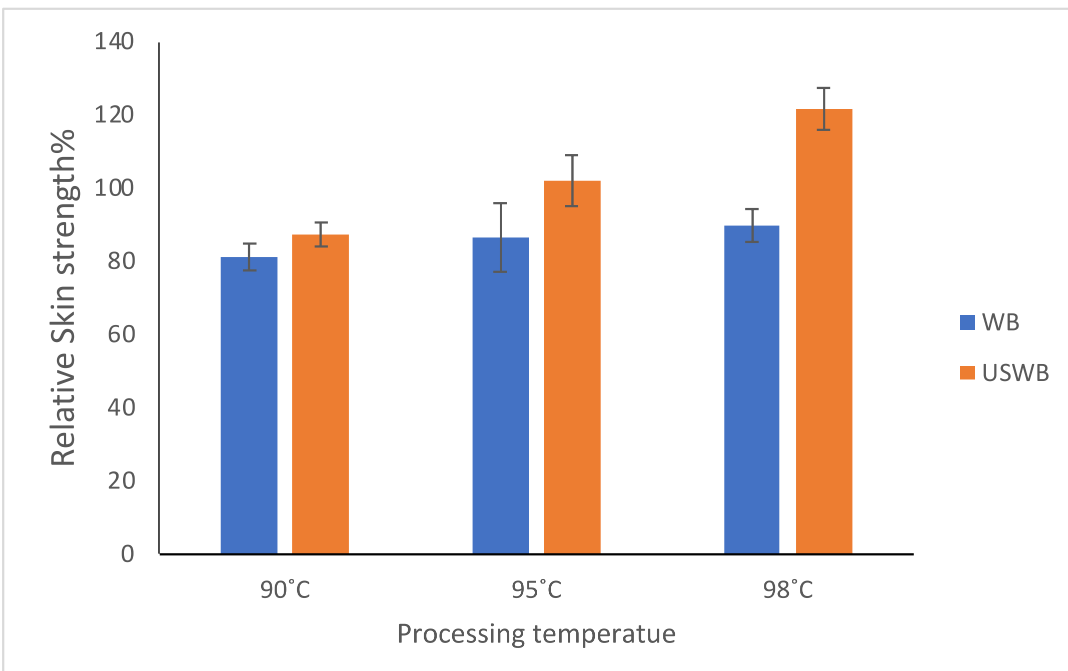


Figure 4.18. Relative skin strength for peach in USWB.

Figs. 4.19 and 4.20 show changes in elasticity of peaches, as influenced by different processing parameters of RATP and USWB. In terms of quality retention, RATP provided slight retention of elasticity. But here too the processing temperature of 95˚C showed the highest elasticity at every reciprocating frequency except 1Hz. Providing agitation using ultrasound had a negative impact on retention of elasticity for every processing temperature.

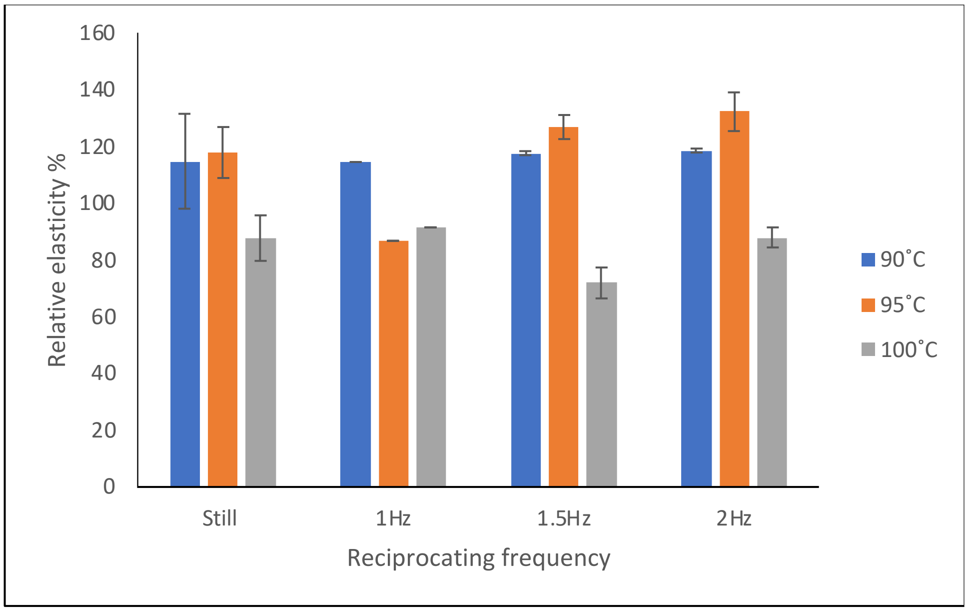


Figure 4.19. Relative elasticity for peach in RATP

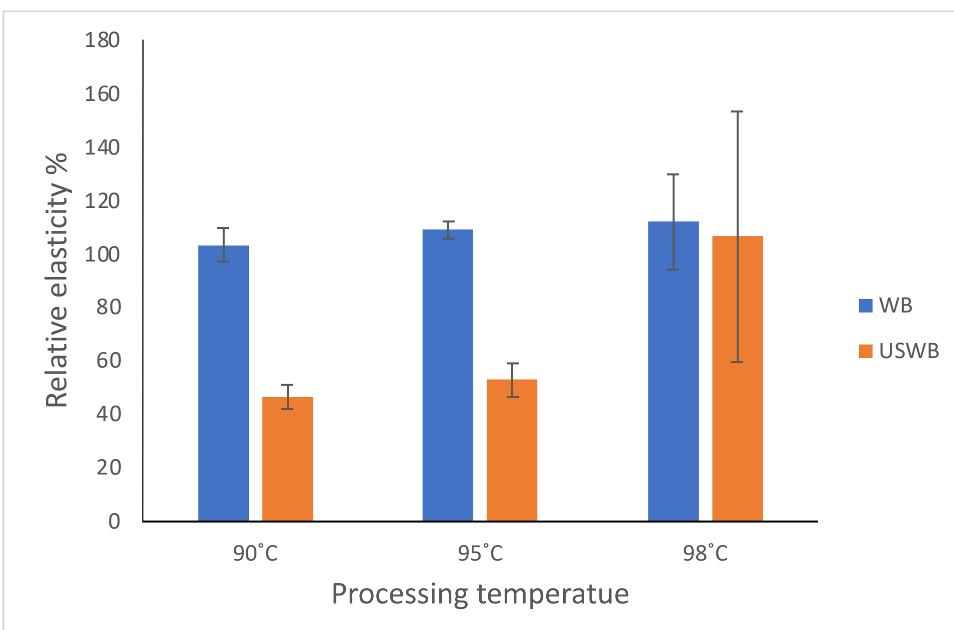


Figure 4.20. Relative elasticity for peach in USWB

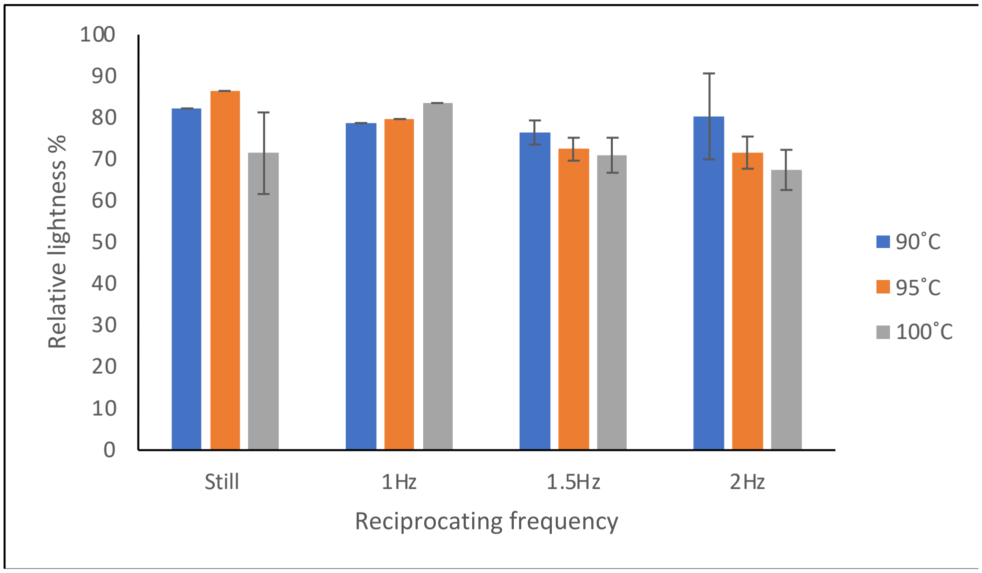
For RATP, the highest relative skin strength achieved was 97% while being processed at 95˚C with a frequency of 1Hz. The highest relative elasticity achieved was 132% while being processed at 95˚C with a frequency of 2 Hz.

For USWB, the highest relative skin strength achieved was 121% while being processed at 98˚C with application of ultrasound. The highest relative elasticity achieved was 112% while being processed at 98˚C without ultrasound.

4.5.2.2 Color parameters.

Colorimeters give measurements that can be correlated with human eye–brain perception and give tristimulus (L, a and b) values directly. L* is an approximate measurement of luminosity, equivalent to a member of the greyscale, between black and white. b* takes positive values for yellowish colors and negative values for the bluish ones. Yellow color being the major component in peaches justified selecting b* alone. The values depicted are in relative terms so as to consider the variance of different peaches that were used for the processes. Figures 4.21 – 4.24 show changes in color parameters of lightness and yellowness as influenced by different processing parameters of RATP and USWB.

Figures 4.21 and 4.22 show changes in color parameter of lightness as influenced by different processing parameters of RATP and USWB. With RATP, the lightness of peach was not influenced significantly. Providing agitation through USWB improved retention of lightness significantly for every processing temperature except 90˚C.



Figures 4.21. Relative lightness for peach in RATP

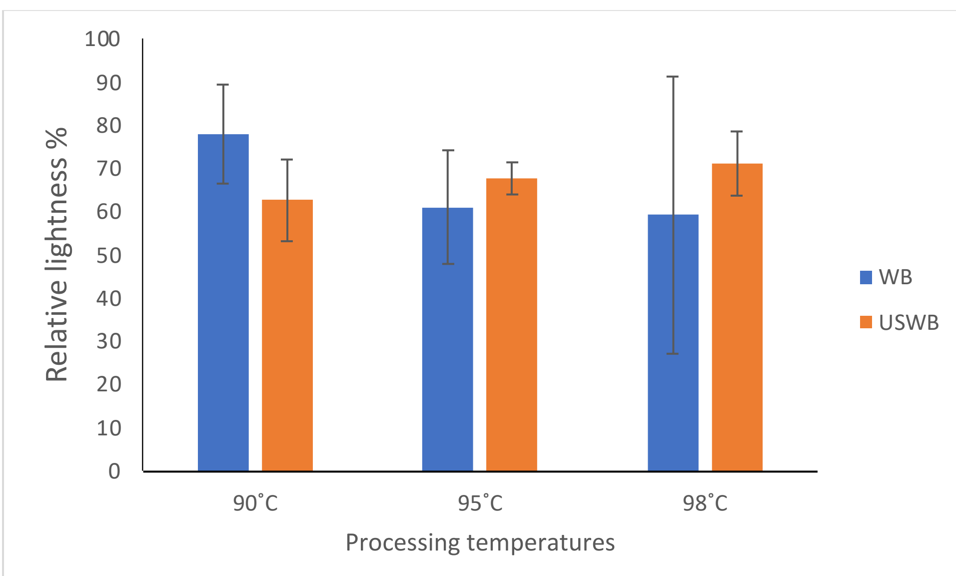


Figure 4.22. Relative lightness for peach in USWB

Figures 4.23 and 4.24 show changes in color parameter of yellowness as influenced by different processing parameters of RATP and USWB. For RATP, the lightness of peach was influenced significantly with increase in reciprocating frequency and processing temperature. Higher reciprocating frequency had positive impact whereas increasing processing temperature had a negative impact for that frequency. Providing agitation through ultrasound did not improve retention of yellowness significantly for any processing temperature.

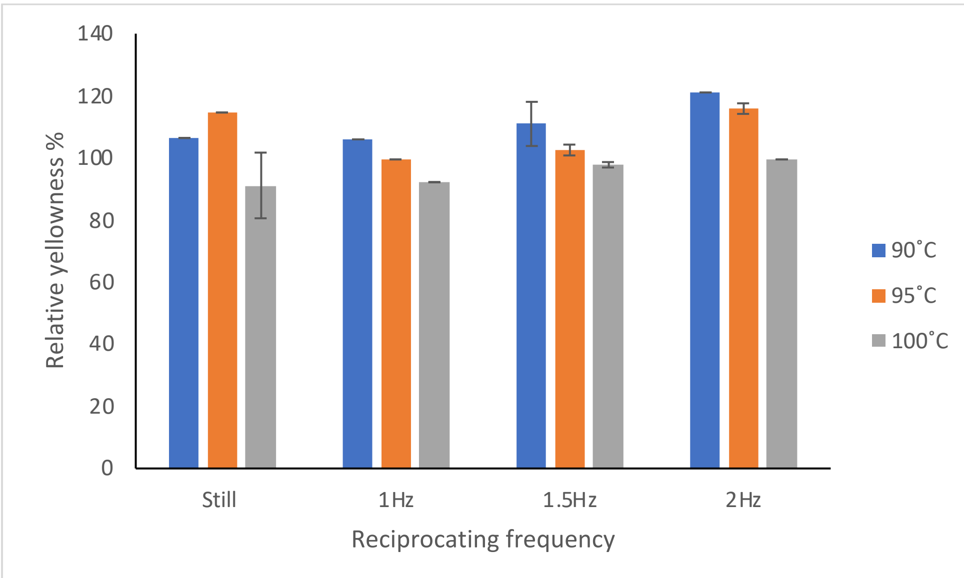


Figure 4.23. Relative yellowness for peach in RATP

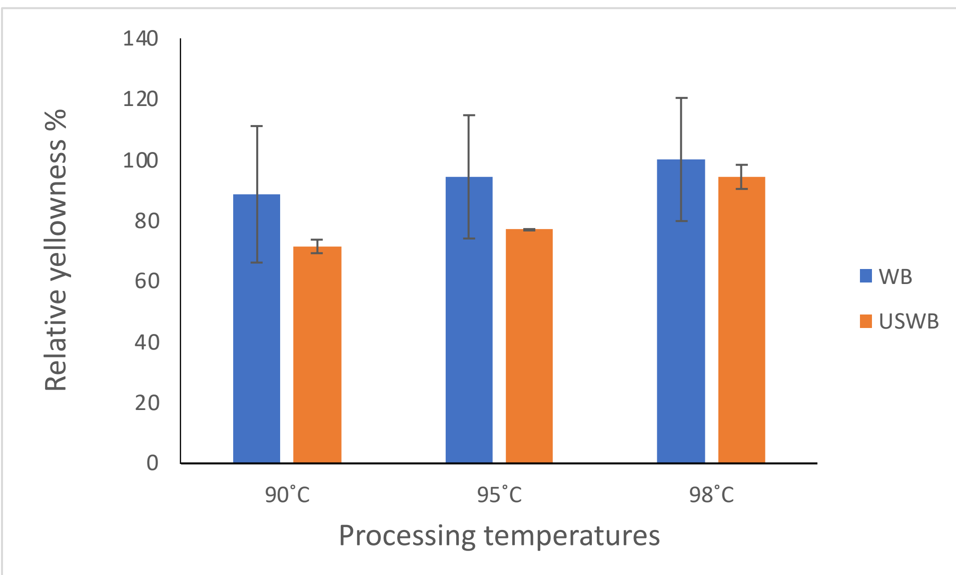


Figure 4.24. Relative yellowness for peach in USWB

For RATP, the highest relative lightness achieved for peach was 86% while being processed at 95˚C without reciprocation. The highest relative yellowness achieved was 121% while being processed at 90˚C with a frequency of 2 Hz.

For USWB, the highest relative lightness achieved was 78% while being processed at 90˚C without ultrasound. The highest relative yellowness achieved was 100% while being processed at 98˚C without ultrasound.

4.5.2.3 Ascorbic acid content

Ascorbic acid (also known as vitamin C) is an antioxidant that is necessary for humans. Fruits and their juices are the most important supplier of it to the human diet. Ascorbic acid being heat sensitive requires minimal processing so as to be available for the human body.

Figures 4.25 and 4.26 show influence of different processing parameters of RATP and USWB on retention of ascorbic acid. With RATP, the ascorbic acid retention increased significantly up to a reciprocating frequency of 1.5Hz. Increase in processing temperature showed a negative influence. Providing agitation through USWB did not show improved retention at any processing temperature. Providing agitation through reciprocating agitation or ultrasound did not show any positive influence on retention of ascorbic acid.

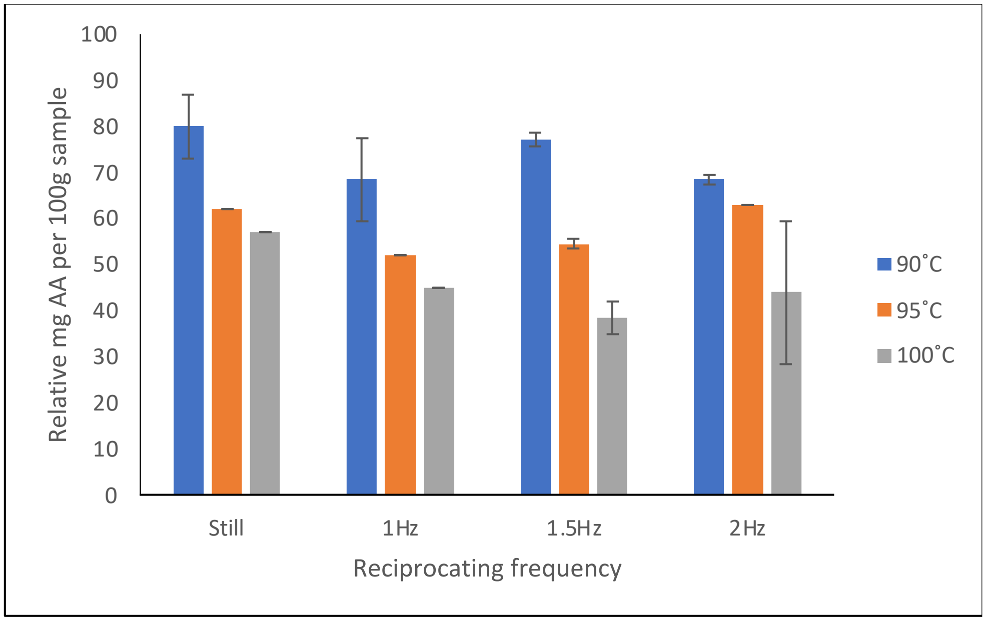


Figure 4.25. Relative ascorbic acid for peach in RATP

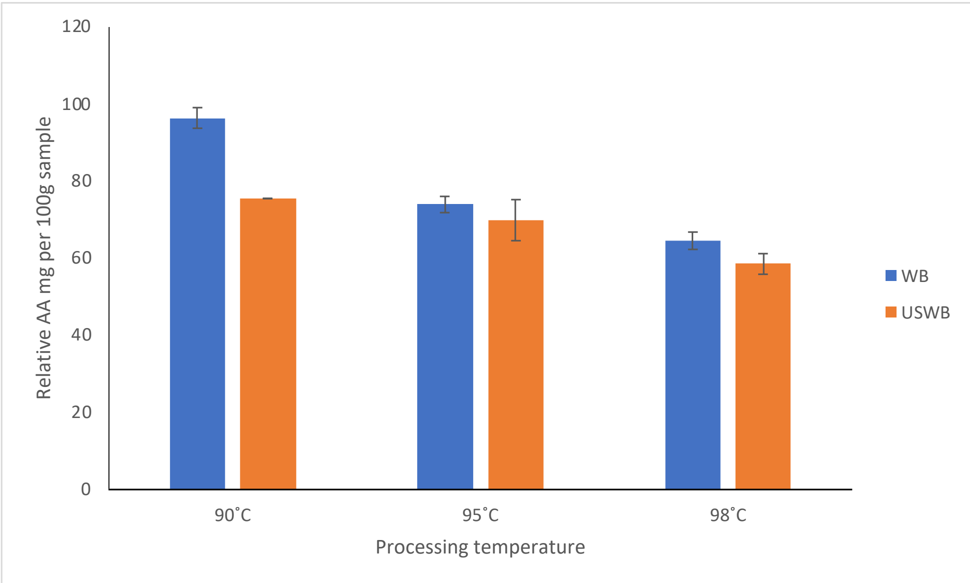


Figure 4.26. Relative ascorbic acid for peach in USWB

For RATP, the highest value of relative milligram of ascorbic acid per 100 gram of sample was 80% while being processed at 90˚C without reciprocation. For USWB, the highest value of relative milligram of ascorbic acid per 100 gram of sample was 96% while being processed at 90˚C without ultrasound.

4.5.2.4 Appearance

The pictures of treated samples are shown in Figures 4.27 - 4.30, for peach. It is evident that peach samples treated at different temperatures with 0 Hz became very soft due to the long treatment time. At 1Hz reciprocation frequency, the particles are the most intact and firm as compared to other reciprocation frequencies. At the higher speeds, the particle structure was affected due to the temperature and reciprocation combination. The color of peach slices became much more yellow in the treated samples at higher temperatures as compared to raw.

Figure 4.27. Peach samples processed under still mode at 90˚C, 95˚C & 100˚C.

Figure 4.28. Peach samples processed under 1Hz at 90˚C, 95˚C & 100˚C.

Figure 4.29. Peach samples processed under 1.5 Hz at 90˚C, 95˚C & 100˚C.

Figure 4.30. Peach samples processed under 2Hz at 90˚C, 95˚C & 100˚C.

Overall results for peach

Table 4.2 shows the various combinations of processing parameters required to achieve highest values of different quality attributes for RATP and USWB.

Table 4.2. Temperature and agitation combinations for different quality attributes of peach

Highest value of	Temperature and agitation combination	
	RATP	USWB
Relative skin strength	95˚C and 1 Hz	98˚C with ultrasound
Relative elasticity	95˚C and 2 Hz	98˚C without ultrasound
Relative lightness	95˚C and 0 Hz	90˚C without ultrasound
Relative yellowness	90˚C and 2 Hz	98˚C without ultrasound
Relative Ascorbic acid content	90˚C and 0 Hz	90˚C without ultrasound

4.6 Conclusions

Providing reciprocating agitation of various frequencies while thermally processing pineapples in glass jars showed to have an effect on retention of hardness, springiness, chewiness, lightness, yellowness and ascorbic acid content. The processing combination of 100˚C and 1Hz had the highest positive effect on hardness, yellowness and ascorbic acid content. Agitation with a higher frequency of more than 1Hz results in decrease of hardness which could be explained by the excessive collision between the particles in the jars. The cooking effect of high temperature would explain the increase in yellowness of the pineapple with increase in processing temperature.

Providing agitation via ultrasound only had a positive effect in retention of hardness and lightness of the pineapple. For both attributes, the processing temperature of 98˚C along with application of ultrasound waves gave the highest retention. For springiness, chewiness, yellowness and ascorbic acid content the absence of agitation had a positive effect on their retention.

Providing reciprocating agitation of various frequencies while thermally processing peaches in glass jars showed to have a positive effect on retention of various quality attributes like skin strength, elasticity, lightness, yellowness, and ascorbic acid content. The processing temperature of 95˚C along with various frequencies had the highest positive effect on retention of quality attributes. Even when the processing time was reduced due to higher processing temperature there was a loss of structural attributes which could be explained due to the tender nature of the peach.

For ultrasonic water bath processing, providing agitation via ultrasound waves only had a positive effect in retention of the skin strength of the product. For elasticity and yellowness, the processing temperature of 98˚C in the absence of ultrasound waves gave the highest retention. The cooking effect of high temperature would explain the increase in yellowness of the peach with high processing temperature. For lightness and ascorbic acid content , the processing temperature of 90˚C in the absence of ultrasound waves gave the highest retention.

The quality was better retained when processed at higher temperatures which is in accordance with the HTST principle, Nevertheless, excessive agitation can result in loss in product quality. Visual results demonstrate that not all high frequency RA-TP may be desirable even though they may have rapid rate of heat transfer and short process times. At higher temperatures and with agitation, process times were lower, and hence thermal effects were less severe. This directly resulted in better antioxidant retention, even under high temperature processes. To sum up, for canned products containing soft-particulates like pineapple wedges and peach slices that are susceptible to damage under rapid agitation, operating at lower frequencies, would be preferable and more advantageous to preserve the overall quality.

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Chapter 5
General Conclusions

In steam heating medium, reciprocation speed has a great impact on heating rate index (F_h) and processing time (Pt). Under high reciprocation speeds, the associated heating rate index was lowered, which meant the heat transfer was faster. Values of processing time were also reduced with the increasing reciprocation speed. The results of this study could be useful for practical applications in order to benefit from both the lower energy cost and superior product quality.

Reciprocating agitation of different frequencies when thermally processing pineapples and peaches in glass jars showed to have a high impact on heating rate index (F_h) and processing time. Under high reciprocation speeds, with steam as the heating medium, the associated heating rate index was lowered, which meant the heat transfer was faster. For both pineapple and peaches, the heating rate index decreased with increase in reciprocating frequency at each specific processing temperature. Processing time were also considerably reduced by simultaneously increasing reciprocation speed and processing temperature. For pineapples, the processing combination of 100˚C and 1Hz had the highest positive effect on hardness, whereas for peaches, the processing combination of 95˚C and 1Hz had the highest positive effect.

Application of ultrasonic waves also had a positive effect on retention in hardness at each of the three processing temperatures studied for both pineapple and peaches. Providing agitation could have a positive effect on the quality attributes as the processing times were reduced. The results of this study could be useful for practical applications in order to benefit from both the lower energy cost and superior product quality.

Canned products containing soft-particulates like pineapple wedges and peach slices are susceptible to damage under vigorous agitation, operating at lower frequencies and providing gentle agitation would be preferable and more advantageous to preserve the overall quality.

Recommendations for Future Studies

Further studies are suggested to evaluate the influence of other process variables such as headspace, reciprocation amplitudes, fluid viscosity etc. Quality attributes like antioxidant activity and others can be studied. Detailed sensory and microstructure analysis can be incorporated in the further studies to provide a thorough insight into quality loss during reciprocation agitation thermal processing and ultrasonic water bath processing. Microbiological validation could also be added to validate the selected process for optimal quality.