CHAPTER I

INTRODUCTION

Dragon fruit (*Hylocereus spp*.), commonly referred to as Pitaya, is a tropical fruit from the Cactaceae family native to southern Mexico, Central America, and South America. It is now extensively cultivated in various tropical and subtropical regions worldwide. Vietnam stands as the largest producer of dragon fruit globally (Lakshmeshwara *et al.*, 2024). In India, the cultivation of dragon fruit is rapidly growing, with Gujarat, Karnataka, and Maharashtra emerging as the leading producing states. As of 2020, India's dragon fruit production exceeded 12,000 tons, covering an area of 3,000 to 4,000 hectares (Wakchaure *et al*., 2021).

The commercially significant varieties of dragon fruit include *Hylocereus undatus* (white pulp with red peel), *Hylocereus polyrhizus* (red flesh with red peel), and *Selenicereus megalanthus* (white pulp with yellow peel). Among these, red dragon fruit (*Hylocereus polyrhizus)* is particularly favored for its numerous health benefits. This fruit is noted for its antioxidant, anti-diabetic, anti-lipidemic, anti-inflammatory, anti-bacterial, anti-fungal, and anti-cancer properties (Nishikito *et al*., 2023). Additionally, it is low in sugar and fat while being rich in dietary fiber, making it an appealing option for individuals with diabetes and cardiovascular conditions. The bioactive compounds contributing to the health benefits of dragon fruit include betacyanins, polyphenols, flavonoids, vitamins, and minerals (Hipni *et al.,* 2023). Polyphenols are aromatic compounds containing one or more hydroxyl groups, and they are categorized into four primary families: flavonoids, lignans, stilbenes, and phenolic acids (Rana *et al*., 2022) all of which significantly support cardiovascular health (Fraga *et al.,* 2010). Dragon fruit's primary pigments are betalains, which are nitrogen-based, water-soluble pigments derived from the amino acid tyrosine and classified into two types: red-violet betacyanins and yellow-orange betaxanthins. Betalains offer antioxidative, anti-inflammatory, lipid-lowering, anti-diabetic, and anti-obesity benefits (Calvi *et al.*, 2023). These pigments are relatively rare in nature, making dragon fruit an excellent source. Arivalagan *et al*. (2021) reported that the total phenolic content (TPC) in the fruit ranges from 25 to 55 mg GAE (Gallic Acid Equivalents), betalains from 14 to 23 mg BCE (Betacyanin Equivalents), and flavonoids from 15 to 35 mg CE (Catechin Equivalents) per 100 grams .Temperature is important in maintaining betalain stability during food processing and storage, as higher temperatures can speed up the degradation of these pigments (Dos Santos *et al.*, 2018).

Due to its high perishability, processing dragon fruit into various value-added products is essential. It has significant potential for use in the production of juice, jam, jelly, marmalade, syrup, squash, and other fruit beverages (Jalgaonkar *et al.*, 2022). Fresh fruit juices are always preferred by consumers due to their bioactive potential. Juice is an important value-added product from dragon fruit and it forms the basis for preparation of squash, jelly, syrup and many other value added products. Fruit juice is a beverage made entirely from pure fruit, typically free of preservatives and additives. Research indicates that compounds in fruit juices may help prevent heart disease, certain cancers, diabetes, cataracts, Alzheimer’s disease, and asthma. They also play a role in building collagen, cartilage, blood vessels, and muscles (Ahmed *et al*., 2018). One study found that a three-day juice diet altered gut microbiota, leading to weight loss, increased levels of the vasodilator nitric oxide (NO), and decreased lipid oxidation (Henning *et al.*, 2017)

One of the main obstacles in extracting juice from dragon fruit is finding ways to boost the yield of both the juice and its beneficial compounds from the fruit's pulp (Tan *et al.*, 2023). This extraction difficulty is largely due to the high pectin content present in the pulp cell walls of the dragon fruit. The pectin in dragon fruit primarily consists of homogalacturonans, rhamnogalacturonans, and various neutral sugars, forming a complex matrix that enhances the fruit’s firmness and resistance to mechanical breakdown during juicing. During juice extraction, pectin forms a gel-like network that traps water and other solubles, hindering their release. This gelation increases the viscosity of the pulp, making it difficult to separate the juice from the solid material (Lara-Espinoza *et al*., 2018). Traditional techniques to enhance juice extraction include mechanical pressing, thermal processing, and enzymatic maceration. However, these conventional methods often require significant energy, are costly, and take a considerable amount of time. Processes like grinding, heating, or adding chemicals or enzymes can deteriorate the quality of the juice by affecting its purity, clarity, color, taste, and nutritional content. Enzymatic maceration, in particular, is not ideal for producing high-quality juices where maintaining a fresh flavor is crucial (Bobinaitė *et al.*, 2015a). Alternative technologies are essential for enhancing the extraction of juice and functional compounds. Non-thermal technologies such as pulsed electric field (PEF) and ultrasound (US) are gaining importance in juice extraction, as they help maintain both sensory and nutritional qualities.

Enzyme activity in fruit and vegetable juices may cause problems like particle settling, discoloration, and the onset of undesirable flavors (Brito & Silva, 2024). As a result, closely monitoring enzyme activity is vital to preserving the juice's sensory, nutritional, and functional quality over time Polyphenol oxidases (PPO) and peroxidases (POD) are two of the most studied enzymes in fruits and vegetables because of their roles in discoloration and off-flavor formation, making them a key focus for food technologists (Vámos-Vigyázó & Haard, 1981; Tinello & Lante, 2018). PPO contributes to browning and the breakdown of natural pigments and polyphenols, which leads to discoloration and reduces antioxidant capacity. POD is involved in various plant metabolic processes, such as auxin breakdown, cell wall lignification, and browning reactions, where it catalyzes oxidation processes (Marszałek *et al.*, 2017).

Thermal pasteurization is the conventional method of preserving fruit juices. It is mainly done to prevent the growth of pathogenic microorganisms. Moreover, it inactivates spoilage enzymes in the juice. Pasteurization is typically done at temperatures between 60 and 100°C, with varying time durations. Since it is a relatively mild heat treatment, it is frequently combined with additional methods, such as acidification or cold storage, to help prevent the growth of any remaining microorganisms or the activation of spores during the product's shelf life (Mezgebe, 2011). Retort pouch packaging is an advanced thermal processing technology that can improve the shelf life of food products. The retort pouch was invented in the 1950s by the United States Army Natick R&D Command, Reynolds Metals Company, and Continental Flexible Packaging (Fung *et al*., 2018). Retort packages are multilayer flexible packaging materials of polypropylene, aluminum foil, and polyester (Byun *et al.,* 2010). It combines the advantages of both metal and plastic packaging. Retort processing involves the following stages: filling, steam exhausting, sealing, traying, and retorting (Gopakumar & Gopal, 1987). Most often retort processing is used for sterilization of foods. As fruit juices are highly heat sensitive, to preserve the volatile aroma and bioactive compounds, pasteurization and refrigerated storage is preferred for their preservation over sterilization. The application of retort processing for preservation of red dragon fruit juice is an unexplored area of research.

On the other hand, PEF is a novel non-thermal method for preserving liquid foods. It is an effective alternative to conventional thermal pasteurization, which can often compromise fruit juices' color, flavor, and nutrients. The PEF technology involves applying short bursts of high voltage (usually between 0.1 to 80 kV/cm) to food materials positioned between two electrodes (Zhang *et al.*, 1995; Nowosad *et al*., 2021). Short processing time of a few microseconds to milliseconds is the major advantage of the PEF system. Microbial inactivation using PEF primarily occurs through a process called electroporation, which involves the irreversible disruption of cell membranes due to electric fields. The membrane in biological cells acts as an insulating layer for the cytoplasm. When exposed to an electric field, ions within the cells move towards the field's direction until they hit the membrane. This movement causes a build-up of charges on both sides of the membrane, increasing the trans-membrane potential. As opposite charges attract on the inner and outer surfaces, pressure is exerted, thinning the membrane. If the electric field strength exceeds a critical level, pores start to form or the membrane starts to break apart. Continued exposure to electric fields beyond this threshold leads to further membrane damage, ultimately resulting in the destruction of the cells (Nithya & Sudheer, 2023). These electric pulses create a field that makes cell membranes more permeable via electroporation, allowing for the release of intracellular substances like juice, bioactive compounds, and nutrients, which enhances extraction efficiency (Barba *et al.,* 2017). PEF pretreatment of fruit pulp is an emerging method aimed at improving both juice yield and quality. Recent research has shown notable improvements in juice yield with the use of PEF. Studies on fruits like blueberries (Bobinaitė *et al*., 2015) and citrus (El Kantar *et al.,* 2018) have reported promising results. For instance, Jaeger et al. (2012) found that PEF treatment of apple and carrot tissues resulted in a 20-30% increase in juice yield compared to untreated samples due to increased cell membrane permeability. In contrast, ultrasound (US) pretreatment employs high-frequency sound waves to break down cell structures. Multiple studies have shown that US pretreatment can significantly boost juice yield when compared to conventional methods. For example, research on citrus fruits such as oranges and lemons has revealed that US pretreatment can enhance juice yield by up to 30% compared to traditional pressing techniques likely due to more effective cell wall disruption and improved mass transfer dynamics (Chemat *et al*., 2017).

Multiple studies have demonstrated that PEF treatment is effective in enhancing bioactive compounds like phenols and flavonoids (Buitimea-Cantúa *et al.* 2022; Yildiz *et al.* 2021; Rahaman *et al.* 2020) as well as inactivating spoilage enzymes (Manzoor *et al.,* 2021; Ahmed *et al.,* 2021; Wibowo *et al.,* 2019; Tian *et al.*, 2018) in various fruit juices. However, in a review of the impact of PEF treatment on fruit and vegetable juices, Brito & Silva, (2024) identified a research gap, emphasizing the need to investigate essential PEF process variables, including electric field strength, pulse width, pulse frequency, and total treatment time. Limited research has explored the effects of PEF and US pretreatments on juice recovery and bioactive compounds in dragon fruit. In addition, studies focusing on PEF and retort pasteurization of dragon fruit juice are particularly limited, especially regarding its effects on important bioactive compounds like betacyanins, phenolics, and flavonoids, as well as the inactivation of spoilage enzymes.

Based on this background, this study was undertaken to investigate how PEF and US pretreatments influence the yield and quality of red dragon fruit juice, as well as to evaluate the linear and combined effects of key independent parameters (PEF: electric field strength, pulse width, and pulse number; US: amplitude and time) on juice extraction. Moreover, the scope of high intensity pulsed electric field (HIPEF) and retort processing technology for pasteurization of red dragon fruit juice and its shelf life will be investigated. The major objectives of the study are listed below.

1. Optimization of process parameters for PEF and ultrasonic pre-treatments for extraction of red dragon fruit juice
2. Optimization of process parameters for pasteurization of optimally extracted juice using HIPEF and retort processing
3. Characterization and shelf life evaluation of optimally pasteurized juice samples under refrigeration.