CHAPTER 1

Introduction

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Orange (*Citrus sinensis* L.) is a citrus fruit from the Rutaceae family. Globally, oranges contributed to the highest production, accounting for 46.70% (75.57 million tons) within the citrus fruits category in a cultivated area of 9.93 million hectares (Gonzatto and Santos, 2023). Orange-based products available in the market are jam, marmalade, juice, extract, jest, essential oil, flavoured cosmetics, byproducts, and extract supplements. Of these, orange juice is one of the important products, gaining popularity because of its high nutritional value and characteristic flavors (Pan et al., 2023). Nevertheless, orange juice is also well-known for containing its rich bioactive compounds (polyphenols, flavonoids, carotenoids, and ascorbic acid, respectively). It is widely popular owing to its potential health benefits for preventing skin problems, cancer, stroke, high blood pressure, cholesterol, and kidney disorders (Kim et al., 2021; Vavoura et al., 2022).

In India, orange is an important citrus fruit of the horticultural crops commercially cultivated across the tropical and sub-tropical zones of the different states, where Maharashtra occupied first in production (Dohale et al., 2024). However, Arunachal Pradesh of Northeast (NE) India is a famous state that grows a unique variety of mandarin known as Wakro orange (Arunachal mandarin), which accounts for 90% of the total citrus fruit production. This variety’s high ascorbic acid content and total soluble solids, medium acidity, sweet-sour flavor, abundant juice content, medium-thick rind, and attractive color are attributed to Arunachal Pradesh's unique agro-climatic conditions. Wakro orange achieved a geographical indication (GI) tag in 2014 for its distinctive qualities (Datta et al., 2021). Another cultivar, Malta, is the second most cultivated seasonal orange after mandarin, commonly consumed as fresh. It is mainly grown in Punjab, Uttarakhand, and Haryana in India (Sharma et al., 2014). With the growing demand for citrus juice, processing orange juice is crucial to making it available to consumers throughout the year. However, processing methods are key in determining product quality, safety, and shelf life. It is acknowledged that conventional heat-based treatment can increase the shelf life of juice while ensuring safety. However, it also causes the loss of beneficial nutrients, colors, and bioactive substances (Gómez et al., 2011).

Consumers are now looking for scrumptious, wholesome, high-quality, and safe food products with a natural taste, flavour, and freshness due to the scientific evidence regarding product attributes and health benefits (Abid et al., 2013). Researchers have been investigating non-thermal food processing technologies to resolve the quality loss issues associated with thermal processing. To combat this, different kinds of non-thermal technologies, such as ultrasound, pulsed electric field, high-pressure processing, pulsed light, cold plasma, and ozone technology, have been employed to retain the quality and nutritive value of fruit juices (Abid et al., 2013; Xu et al., 2017; Lopes et al., 2023). Cold plasma (CP) technology has been explored for its potential applications, such as surface disinfection, pesticide degradation, packaging, alteration of food properties, and enzyme and microbial inactivation (Mehta and Yadav, 2022). CP can be generated by providing electrical energy to the gas, which ionizes the gases between the electrodes at ambient temperature. The "plasma" refers to the fourth state of matter, characterised by an ionised gas mixture containing ultraviolet (UV) rays, reactive species, both excited and ground states of atoms, free radicals, and electrons (Tappi et al., 2014).

There are many plasma generation sources, including radio frequency (RF), gliding arc discharge (GAD), plasma jet, dielectric barrier discharge (DBD), and corona discharge, respectively (Zargarchi et al., 2024). However, DBD source CP has been frequently used in food processing due to its relative simplicity, flexibility, use of different gases, lower gas flow rate, and uniform discharge, respectively (Farooq et al., 2023).

DBD-source atmospheric cold plasma is one of the emerging technologies that has been significantly used as an alternative non-thermal technology for fruit juice processing (Souza et al., 2023). In most cases, atmospheric gas and pressure are used for plasma production because of their high chemical character. Therefore, it is called atmospheric cold plasma (ACP) (de Jesús et al., 2022). Several studies have investigated the effect of DBD-based ACP on different fruit and vegetable juices, such as white grape, apple, pineapple, kiwifruit, carrot, orange, and sugarcane, respectively (Liao et al., 2018; Umair et al., 2019; Pankaj et al., 2017; Kumar et al., 2023; Pipliya, et al., 2023; Xu et al., 2017; Shi et al., 2011; Manzoor et al., 2020).

Some studies have been reported on developing a pilot-scale continuous system for decontaminating in-packaged fruits and vegetables (Ziuzina et al., 2016; Ziuzina et al., 2020). From an industrial perspective, a continuous mode of operation is preferred for juice processing because it allows for scaling up, which is difficult to attain in a batch-type ACP system.

Research gap

Limited studies have attempted to use CP treatment on orange juice in terms of quality, safety, and shelf-life enhancement. However, the effect of DBD-based ACP treatment at varying juice depths and process standardization has not been reported on Wakro and Malta cultivars of orange. On the other hand, continuous-type DBD-based ACP treatment on orange juice (cv. Wakro) has also not been reported in the literature so far.

Objectives

This research mainly focuses on exploring the feasibility of DBD-based ACP processing of orange juice. To achieve the aim of the present work, the following objectives have been addressed:

1. To standardize the process parameters for atmospheric cold plasma (ACP)-assisted processing of orange juice from different cultivars.
2. To model the inactivation kinetics of enzyme (pectin methylesterase) and microbe (*Escherichia coli)* in orange juice during atmospheric cold plasma processing.
3. To study the shelf life of atmospheric cold plasma (ACP) treated orange juice during storage.
4. To develop a lab-scale continuous system of atmospheric cold plasma (ACP) for juice processing and its performance evaluation with orange juice.

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