Plant Archives **Vol. 25, Special Issue (ICTPAIRS-JAU, Junagadh) Jan. 2025 pp. 398-404**
e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.SP.ICTPAIRS-058

OHMIC HEATING BASED FOOD PROCESSING TECHNOLOGY FOR ENHANCING PRODUCT QUALITY AND PROCESS EFFICIENCY

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ABSTRACT

This paper investigated the effects of ohmic-heating characteristic parameters on mango pulp's biochemical properties. Ohmic heating is an emerging food processing technology that offers uniform and rapid heating by passing electric currents through food materials. This paper focuses on developing and optimizing an ohmic heating system, aiming to evaluate its efficiency and potential applications in food processing. The system development involved selecting appropriate electrodes, insulating materials, and control mechanisms to ensure consistent performance and safety. Experimental trials were conducted on mango pulp samples to measure heating rates and temperature distribution. Various pulp concentrations were subjected to different voltage levels till the pasteurized temperature of 70-80^{0}C was reached. The time needed for heating decreased as the voltage gradient increased for a specific pulp concentration, but it increased with higher pulp concentrations. Nevertheless, the electrical conductivities of the pulp rise with increasing pulp concentration and temperature. In this heating process before treatment and after treatment biochemical parameters are examined. These results indicated that the ohmic-heated pulp sample at the 20 V/cm and 75^{0}C pulp temperatures with preservatives could be stored for up to 90 days. The system effectively maintained food quality and safety, indicating its potential for broader applications in the food industry. Future work will focus on further system optimization and its applicability to various food products.

Key words : Electrical conductivity, Voltage gradient.

Introduction

Thermal processing is a widely used food preservation method that enhances shelf-life and ensures microbiological safety. Fresh fruits, being highly perishable due to their water content, require processing to extend their shelf-life, often into products like juices, purees, and smoothies. Common thermal techniques include blanching, pasteurization, and sterilization (Amit *et al*., 2023). Blanching, in particular, is used to inactivate enzymes and maintain product quality before further processing like canning or freezing. It also helps retain the product's color and nutritional value.

Pasteurization and sterilization act as final processes for perishable food items, to increase their shelf life by reducing harmful microorganisms to acceptable levels. Pasteurization is typically seen as a gentler method, while sterilization is regarded as more rigorous due to its greater time and temperature requirements (Leizerson *et al*., 2023). Moreover, thermal drying aids in extending shelf life by lowering the moisture content, which not only improves longevity but also diminishes the product's volume, reducing expenses for packaging, handling, storage, and transportation.

Novel methods of food processing are broadly categorized into two categories viz Non-thermal and Thermal. Non-thermal methods include pulsed electric field (Heinz *et al*., 2001), high-pressure processing, violet light/ pulsed light, ultrasound, ozone, cold plasma, and oscillating magnetic field, etc., whereas novel thermal processing includes Microwave heating, ohmic heating, and Infrared heating.

Ohmic heating, a novel thermal food processing method, generates heat by passing electric current through food, utilizing its resistance to rapidly raise

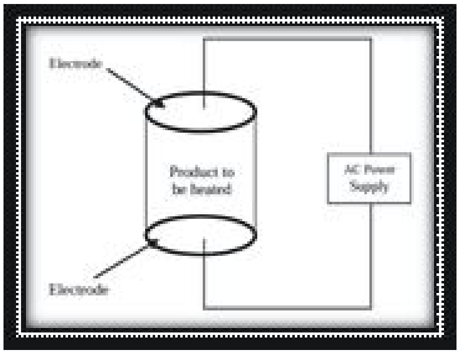

Fig. 1 : Principle of ohmic heating.

temperature shown in Fig. 1. Though known since the 19th century, its development lagged due to limited understanding. Modern advances from 1993 to 2013 have significantly improved equipment design, reducing process costs up to tenfold. Widely adopted in Europe and Japan for processing fruit in syrup or juice, ohmic heating's commercial use continues to expand as new applications emerge.

Ohmic heating offers rapid and volumetric heating of food materials, making it a compelling alternative to conventional thermal processing by reducing fouling and corrosion while causing minimal damage to key components such as flavorings. This method also has additional advantages over traditional thermal processing, including better preservation of rheological, textural, organoleptic, and nutritional properties, its suitability for processing particulate foods and greater energy efficiency. (Alkanan *et al.*, 2001).

The rate of energy generation during OH also depends on voltage gradient and EC of the material (Dervish *et al.*, 2023). The EC is the most critical property effecting energy generation, during conventional heating, EC increase sharply with temperature at around 60°C as a result of break-down of cell wall materials. In case of OH, EC increases linearly with temperature, possibly due to electro-osmotic effect, which could increase the effective conductivity at low temperatures. Since electrical conductivity is related to the concentration of ionic constituents, it is possible to alter porous solid property by infusion of salts. For liquids, EC-temperature relationship (Athmaselvia *et al.*, 2014) is linear regardless of the mode of heating used and electrical conductivity decreases with increasing pulp content, as a result of non-polar constituents in the pulp. The size of the suspended solid has also been shown to affect electrical conductivity, increase in particle size results in the decrease of the electrical conductivity.

Mango (*Mangifera indica* L.) is a vital source of essential nutrients, vitamins and phyto-chemicals, contributing significantly to human health. While it can be processed in various ways, thermal processing of mango pulp remains the most common commercial method. This processed pulp is utilized in the production of beverages, candies and products within the dairy and confectionery industries. However, traditional thermal processing methods for mango pulp can be inefficient in terms of time and energy, highlighting the need for improved, alternative approaches (Owino *et al.*, 2021).

Researchers have begun exploring novel processing techniques for mango products, including High Pressure, Pulse Electric Field, Ultra-violet Light, Cold Plasma and Microwave Heat treatment (Aggarwal *et al.*, 2017). Despite these advancements, there appears to be a scarcity of literature specifically focusing on OH studies related to mango and its products. As a response to this gap, the current study has been proposed.

Materials and Methods

The primary objective of our project is to design an ohmic heating setup and apply it to the heat treatment of kesar mango pulp. Ohmic heating is a process that involves passing an electric current through food materials, resulting in heating through electro-resistive means. This method, known for its volumetric heating characteristics, has the potential to minimize over-processing significantly. Also referred to as Joule heating, electrical resistive heating, direct electrical resistance heating, electro heating, or electro-resistive heating, ohmic heating requires essential components for food processing equipment, including a pair of electrodes, a container for the food being processed, and an alternating power supply (Priyadarshini *et al.*, 2017).

The present work required various materials and equipment, which is given in Table 1.

Methods

The main object of our project is design of an Ohmic heating setup and work on heating treatment on Kesar Mango pulp. Ohmic heating occurs when electric current is passed through food materials to be heated. This electro resistive heating is volumetric by nature, therefore has potential to significantly reduce over processing. Ohmic heating is also called Joule heating, electrical resistive heating, direct electrical resistance heating, electro heating, or electro resistive heating (Priyadarshini *et al.*, 2017). The fundamental requirements for ohmic heating equipment for food processing are a pair of electrodes, a container for the food to be processed and an alternating power supply.

Tabel 1 : Materials required in the ohmic setup.

	Ohmic Heating setup	Food samples	Equipment	Chemicals/Reagents
	Electricity supply		Voltmeter	80% Methanol
	Variac transformer		Ammeter	0.1 N NaOH
	Glass chamber		Thermocouple	Phenolphthalein
Materials	SS electrodes	Kesar Mango Pulp	pH meter	4% Oxalic acid
			Refractometer	Sodium bicarbonate
			UV Spectrometer	2, 6 Dichloroindophenol
				5% Phenol
				Conc H_2SO_4

Design and development of ohmic heating (OH) setup

Design requirements

The OH setup must fulfil the following design requirements:

1. The setup should have a holding volume of 500 mL of liquid food in a batch operation.
2. The heating cell should not be an electric conductor and heat conductor to avoid the chance of short circuit and heat loss.
3. The electrodes should resistant to corrosive reaction with liquid food.
4. The system must be capable for maintaining varying electric field across the electrodes.
5. The system should be portable in nature so that it can be accommodated in the laboratory.
6. The set-up should be compatible with 220V, 50 Hz Indian system.
7. The system must have an easy drainage facility for discharge of processed liquid food.
8. The system must be easy to clean after dismantling of the component.

Conceptual design

The ohmic heating (OH) system was designed with an aim so that an electrically conductive food material can be heated by the joules heating concept. The setup should be comprised of a space in between two electrodes and supply of electric voltage to be applied across the electrodes. The food material in between the electrodes gets heated once the electrical current gets induced due to applied electric voltage and the resistance to the induced current results in the increase in the temperature following the joules law of heating. The electric voltage could be controlled by the variac transformer to set the desired electric field strength without changing the distance between the electrodes. The schematic diagram of the design is illustrated in Fig. 2.

Design and fabrication of ohmic heating setup

Based on the conceptual design, a lab scale OH setup was developed. The lab scale ohmic heating assembly comprised of the following components:

(i) Heating chamber

(ii) Electrodes

Power supply and voltage control

Heating chamber

Ohmic heating chamber is a rectangular tank with two electrodes, which are closely fixed on the length sides of the chamber. The material to be heated is filled in the tank in between the electrodes and when current is applied, heating takes place (Duguay *et al*., 2016). The main criteria used for the construction of the ohmic heating chamber are as follows:

It should be electrically non-conductive. It should be able to withstand process temperature which is 120^0C. It should not impart off-flavour to the product. Based on the above criteria for the construction of ohmic heating chamber, borosilicate glass was selected. Length, Width

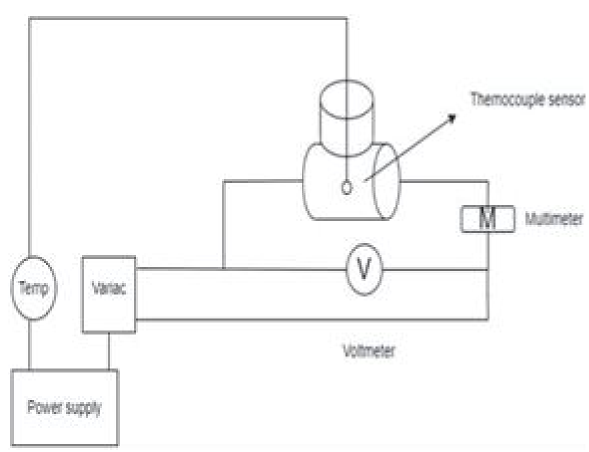

Fig. 2 : Schematic diagram of OH setup.

Fig. 3 : Heating Chamber.

Table 2 : Characteristics of Borosilicate glass.

Properties	Value
Density	2.23 g/cm^3
Hardness	6.5 Mohs'
Young's Modulus	6680 N/mm^2
Bending strength	120-160 MPa
Poisson's ratio	0.20
Thermal Expansion Coefficient	32-35 × 10^{-6} cm/cm ^{0}c
Thermal Conductivity	0.82 W/m ^{0}c
Specific Heat	820 J/kg ^{0}c

and Height of heating chamber are 19 cm, 7 cm and 21 cm, respectively. Weight of Heating chamber is 1594.8 gm and Capacity of Heating chamber is 500 ml. Heating chamber is shown in Fig. 3. Characteristics of borosilicate glass is given in Table 2.

Chemical composition of Borosilicate glass is given in Table 3.

Electrodes

The material used as an electrode inside the ohmic heating chamber must have the following features:

It should be of food grade and non-corrosive. It should be workable and provide smooth finish. To meet out the above said minimum requirement the food grade stainless steel 316 was selected as an electrode material. Height, Width and Thickness of Electrodes are 6.5 cm, 7.7 cm and 0.1 cm, respectively. Electrodes are shown in Fig. 4. Some of the important properties of electrodes are given in Table 4.

Power supply and voltage control

Domestic electrical power supply of 240 V, single phase and 50 Hz alternative Current (AC) was supplied

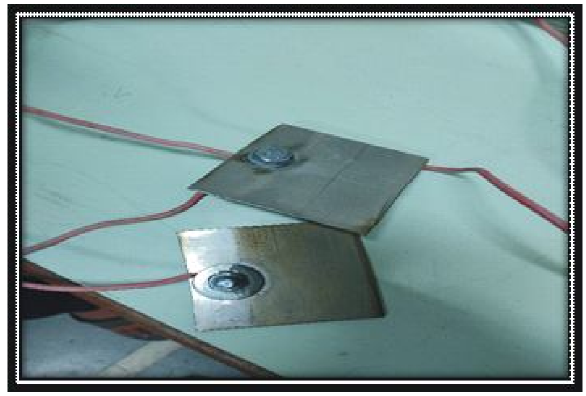

Fig. 4 : Electrodes.

Fig. 5 : Variac Transformer.

Table 3 : Chemical composition of Borosilicate glass.

Chemical Composition	Value
SiO_2	81.0%
B_2O_3	12.5%
Al_2O_3	2.32%
Na_2O+K_2O	6.0%

to the electrodes of the ohmic heating assembly. The amount of voltage to be supplied to the food material via electrodes was controlled by variac transformer.. Therefore, the deigned OH system has the working range capacity of 0-45 V/cm Electric Field Strength (EFS). Variac Transformer is shown in Fig. 5. And Connection of all Equipment or Circuits is shown in Fig. 6.

Thermocouple

Thermocouple is used to measure temperature of food material during Ohmic Heating process. We used J type thermocouple and its range is 0-600^{0}C. It has screen attached with it which shows us the current temperature of Mango puree. Thermocouple with Output screen is shown in Fig. 7.

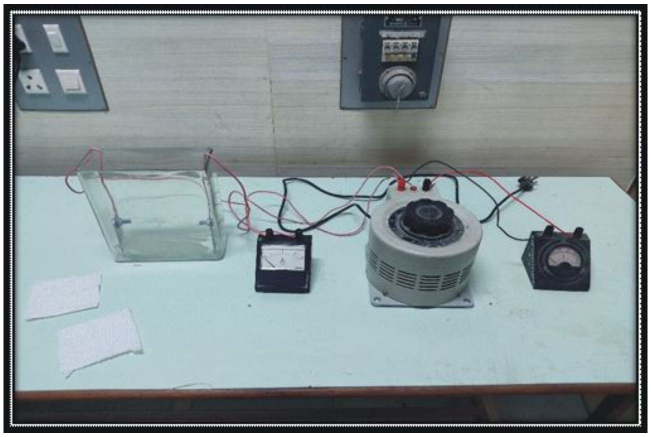

Fig. 6 : Circuit of setup.

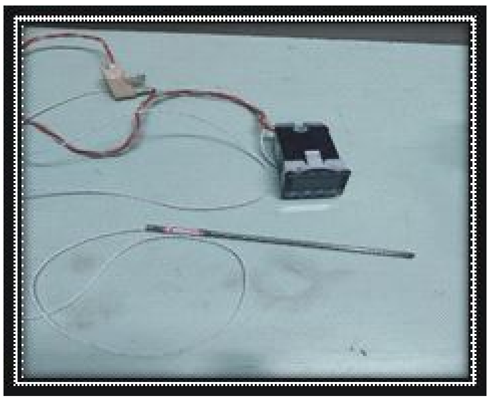

Fig. 7 : Thermocouple.

Fig. 8 : Hand Refractometer.

Samples for performance evaluation

Fruits were chosen based on their seasonal availability. We selected Kesar mangoes, a local variety found in the Gir area. The fresh, fully ripe fruits, free from any damage, were sourced from a nearby market at JAU in Junagadh, India. Upon arrival at the laboratory, the mangoes were thoroughly washed to remove any external dirt.

Sample preparation

We picked ripe kesar mangoes from local market junagadh, India. To ensure they were similar, we chose mangoes that were all golden yellow and ripe. We washed the mangoes well with running water to get rid of any dirt, debris and then soaked them in a mild bleach solution for five minutes. After that, we dried the mangoes.

The fruits were peeled/ pulped/ deseeded manually using stainless steel knives carefully to check the microbial contamination by using sterilized gloves and glass ware. Domestic mixer grinder was used to prepare mango pulp from slices of kesar mango, whereas the mango puree was prepared by blending the fresh pulp for almost 2 min. The fresh mango puree was analysed for various physio-chemical parameters such as Total Soluble Solids (TSS), Acidity and pH.

Properties of the sample

The juice or puree of kesar mengo was analysed for the following parameters:

Total soluble solids (TSS) : Total soluble solids were measured with the help of a hand refractometer calibrated with double distilled water before the measurement. Unit of TSS is brix. Hand Refractometer is shown in Fig. 8.

pH : The pH of the samples was measured by using a pH meter, the instrument was calibrated with water having pH of 7 before taking the sample reading, the measurements were carried at room temperature (Assiry *et al.*, 2003). pH meter is shown in Fig. 9.

Titratable acidity : Titrable acidity is a measure of the total amount of acids present in a food sample. Titratable acidity is an important parameter in food and beverage production, as it helps control fermentation, flavour development and product stability. Standard titration procedure was used to measure the titratable acidity of the samples. The samples were titrated with 0.1 N NaOH solution using phenolphthalein as indicator, the acidity was calculated by using the following Equation (Mohsen *et al.*, 2013).

$$\text{Titrable acidity} = \frac{\text{Titre value} \times \text{Normality (NaOH)} \times \text{Volume makeup} \times 64 \times 100}{\text{Volume of aliquot} \times \text{Volume of sample} \times 1000} \times 100$$

Ascorbic acid

Ascorbic acid otherwise known as vitamin C is antiscorbutic. It is present in citrus fruits, mango, gooseberry, bitter gourd etc. in high amount. Generally, it is present in all fresh vegetables and fruits. It is water soluble and heat-labile vitamin. Chemicals required in test is listed below (Assiry *et al.*, 2003).

I. Oxalic Acid

II. Sodium Bicarbonate

III. 2,6-dichlorophenol indophenol

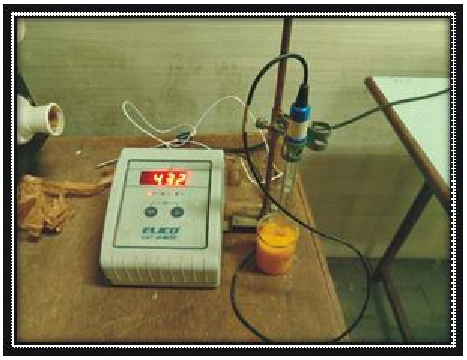

Fig. 9 : pH meter.

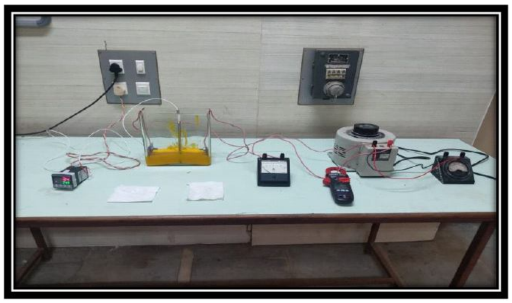

Fig. 10 : Ohmic Heating Setup.

Pipette out 5ml of the working standard solution into a 100ml of conical flask. Add 10ml of 4% oxalic acid and titrate against the dye (V_1 ml). End point is the appearance of pink colour, which persists for a few minutes. The amount of dye consumed is equivalent to the amount of ascorbic acid. Extract the sample in 4% oxalic acid and make up to a known volume (100ml) and centrifuge. Pipette out 5ml of this supernatant, add 10ml of 4% oxalic acid and titrate against the dye (V_2 ml) and then it calculated by following equation.

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Titre value of sample} \times \text{Dye factor} \times \text{Volume madeup} \times 100}{\text{Aliquot taken for estimation} \times \text{Sample weight}}$$

Total sugar content

Total sugar content tells us the total sugar present in food sample. It is measured by UV Spectrophotometer. First fill bottles with 0.1 gm sample and 10 ml 80% methanol solution then let the sample settle down for around half an hour. Then fill 0.1 ml solution of sample in test tubes also make one blank test tube for calibration.

Table 4 : Characteristics of Electrodes

Properties	**Value**
Density	7.90 g/cm^3
Melting range	1390-1440 ^{0}C
Thermal Conductivity	14.6 W/mK
Specific Heat	450 J/kgK
Electrical Resistivity	740 nΩm

Then fill 0.9 ml distilled water in all tubes and 1 ml distilled water in blank tubes. Then add 1ml 5% phenol solution in all tubes. Then add 5 ml Concentrated H_2SO_4 in all tubes. Then keep the sample 30 min. in room temperature to cool down. Then note down the Optical Density of Samples using UV Spectrophotometer by calibrating it with blank solution. And then Calculate the total sugar content by putting values in following equation.

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Graph factor} \times \text{Optimal density} \times \text{Total volume} \times 100 \times 10^{-6}}{\text{Sample aliquot} \times \text{Weight of sample}}$$

Factors influencing heat generation rate

Factors affecting Heat generation rate is given below:

Electrical field strength (EFS) : In ohmic heating, generation of heat is internal. The rate of heating depends on the field strength or voltage gradient (VG) (Doan *et al*., 2021). Unit of electrical field strength is V/cm. It is calculated through the voltage applied (V) per unit distance between the two electrodes (cm).

Electrical conductivity (EC) : The electrical conductivity values are determined by the concentration and mobility of charge particles. Unit of EC is Siemens per meter (S/m). Product suitability for ohmic heating is determined from its conductivity value. A trend of increase in Electrical conductivity values were observed in rise in temperature (Darvishi *et al*., 2013), since the ionic content of food influences EC.

Temperature : The rise in temperature increases the electrical conductivity value of foods. Electrical conductivity was increased linearly up to a temperature of 55°C. Then the conductivity values decreased, which might be due to bubble formation.

Ohmic heating Process

A 500 ml ohmic heater was designed and built, as depicted in Fig. 10. Constructed from borosilicate glass, the dimensions of the system are 19 cm in length, 7 cm in width, and 5 cm in height. Treatments were performed at a frequency of 50 Hz, with the voltage adjustable using a power variac. Temperature measurements were taken at different voltage gradients (10, 20, 30 and 40 V/cm) using digital thermometers placed at the center of the vessel. We performed ohmic heating on 500 ml of mango pulp at different voltage gradients and different TSS concentration (Brix°) (8, 12, 16, 20 tss) and subsequently measured various parameters of the pulp (Bhat *et al*., 2017).

Results and Discussion

The 500 ml of mango pulp was heated using four different voltage gradients–10, 15, 20 and 25 V/cm. The temperature was raised to a preset pasteurization range of 70-80°C and the pulp was held at this temperature for

180 seconds. This process was repeated for four different mango pulp concentrations (8, 12, 16 and 20 °Brix). To test the impact of ohmic heating on sensory qualities such as color, flavor, and taste, both treated and fresh samples were evaluated. All samples are also stored in glass bottle for storage analysis. The results are shown that, where the temperature of each sample rises from 35°C to the desired level as heating time progresses when voltage is applied. The rate of temperature increase depends on the voltage gradient. At 10 V/cm, the temperature rises slowly, but at voltages above 20 V/cm, the increase is much faster. The heating time decreases as the voltage gradient increases, regardless of pulp concentration. For example, at 8°Brix, the desired temperature is reached in 2.5min, 3.5min, 4.5min and 7mins at 40, 30, 20 and 10 V/cm, respectively. Similar trends are seen for other pulp concentrations.

Conclusion

Different concentrations of mango pulp were subjected to varying voltage gradients until they reached the pasteurization temperature range of 70-80°C. The time required to achieve this temperature decreased as the voltage gradient increased for each specific pulp concentration. However, when the pulp concentration increased, the heating time also rose. Additionally, the electrical conductivity of the pulp increased with both the temperature and the concentration of the pulp. Throughout the heating process, various biochemical parameters were examined both before and after treatment to assess the impact of ohmic heating.

The results of the study showed that the mango pulp sample heated at a voltage gradient of 20 V/cm and a temperature of 75°C, with the addition of preservatives, could be stored for up to 80-90 days while maintaining its quality. This demonstrated that ohmic heating, when combined with appropriate preservation techniques, can effectively extend the shelf life of food products without compromising safety or quality. The findings suggest that this method has significant potential for broader applications in the food industry, offering an efficient and reliable way to ensure food quality during storage. This also highlights the promising use of ohmic heating for pasteurization, as it can provide uniform and rapid heating while preserving the nutritional and sensory qualities of food products.

Future research scope

Future research is expected to focus on the application of ohmic heating to a broader range of vegetables and fruits, optimization of heating parameters, exploration of synergies with other technologies, development of advanced mathematical modelling and process control techniques and assessments of sustainability and life cycle impact. Additionally, studies on consumer acceptance and market potential are anticipated to be carried out by other researchers.

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