Chapter 3

Chapter-III

Material and Methods

This chapter includes an overview of the materials and methods utilized in the engineering properties study, along with an exploration of the potential applications of superheated steam for turmeric rhizomes. It also discusses the creation, design, and parts of the superheated steam dryer prototype for turmeric rhizomes. The procedures followed for the chemical examination of the sample to determine its quality are also given. The machine parameter optimization procedure is explained in great depth.

3.1 Material

We bought a range of turmeric rhizomes in 2018 from a farmer in Dolabari, Tezpur, which is nearby. The turmeric rhizomes were sealed in a plastic bag and stored in a ±4°C temperature- and humidity-controlled chamber prior to the trials. The turmeric rhizomes were cleaned to remove any foreign items before the experiment started, and any dirt that had adhered to them was then washed away with clean water.

3.2 Physical Properties of Rhizomes

Physical properties are essential for developing and running machines utilized in the agriculture processing sector. Understanding physical factors such size, shape, bulk density, actual density, surface area, and volume is essential when designing process equipment for turmeric. These properties are not only important for accurate design calculations, but they also help predict how the boiling and drying processes would behave analytically. Consequently, the physical properties of dried, boiled, and fresh turmeric rhizomes were determined following Saha et al., (2022).

3.2.1. Size and Shape

Fresh turmeric rhizomes were found to have an initial moisture content of 84% (w.b.) using the AOAC, 2002 procedure. The axial dimensions major, intermediate, and minor diameters also known as length-l, width-a, and thickness-b, respectively, were measured using a digital Vernier Caliper with 0.01 mm resolution. Three batches of samples, each weighing one kilogram, were chosen at random to determine the size of the turmeric rhizomes. These three batches were merged into a heap, and 25 randomly selected samples were taken out to ascertain the size. Since the turmeric rhizomes showed secondary growth developments, the dimensions

of the primary and secondary fingers were measured. Following Prasath et al., (2024) the tertiary developments were ignored in five percent of the rhizomes.

3.2.2 Moisture Content

The moisture content of fresh, dried and cured-dried rhizomes was determined by toluene distillation method as described in Method 2.0 of American Spice Trade Association (ASTA, 1997). Approximately 5 g of sample (fresh turmeric rhizome pieces) was taken in a round bottom flask. One hundred milliliters of toluene was added to flask; a moisture trap and condenser were fixed to the flask (Dean-Stark apparatus). The flask was kept for reflux over heating mantle, until constant volume was collected in the moisture trap. Moisture content was estimated as percent (v/w). Dried and cured-dried powder (10 g each separately) were taken and moisture content was estimated as mentioned above. The analysis was performed on triplicate samples and result was reported as mean±SD, following Kebede et al. (2021).

3.3 Preliminary Study

An initial study on the immediate decompression aided steam curing (IDASC) method of processing rhizomes was carried out prior to the construction of the actual immediate decompression assisted dryer for turmeric rhizomes. The first study was built up using a lab-scale prototype boiler, steaming chamber with instant steam release to atmosphere, hot air dryer, and other components. This study looked at the properties of instant decompression assisted steam and the requirements for using IDASC on turmeric rhizomes without sacrificing product quality. It helped to support the design and conduct of the experiment by facilitating the development of several trial procedures and data collection methods.

Based on the results of preliminary research, several components of the steaming chamber with the provision of instant decompression to vacuum was created to address the problem and achieve the objective.

3.4 Overall Methodology

The flow of activities in the research is shown in Fig 3.1

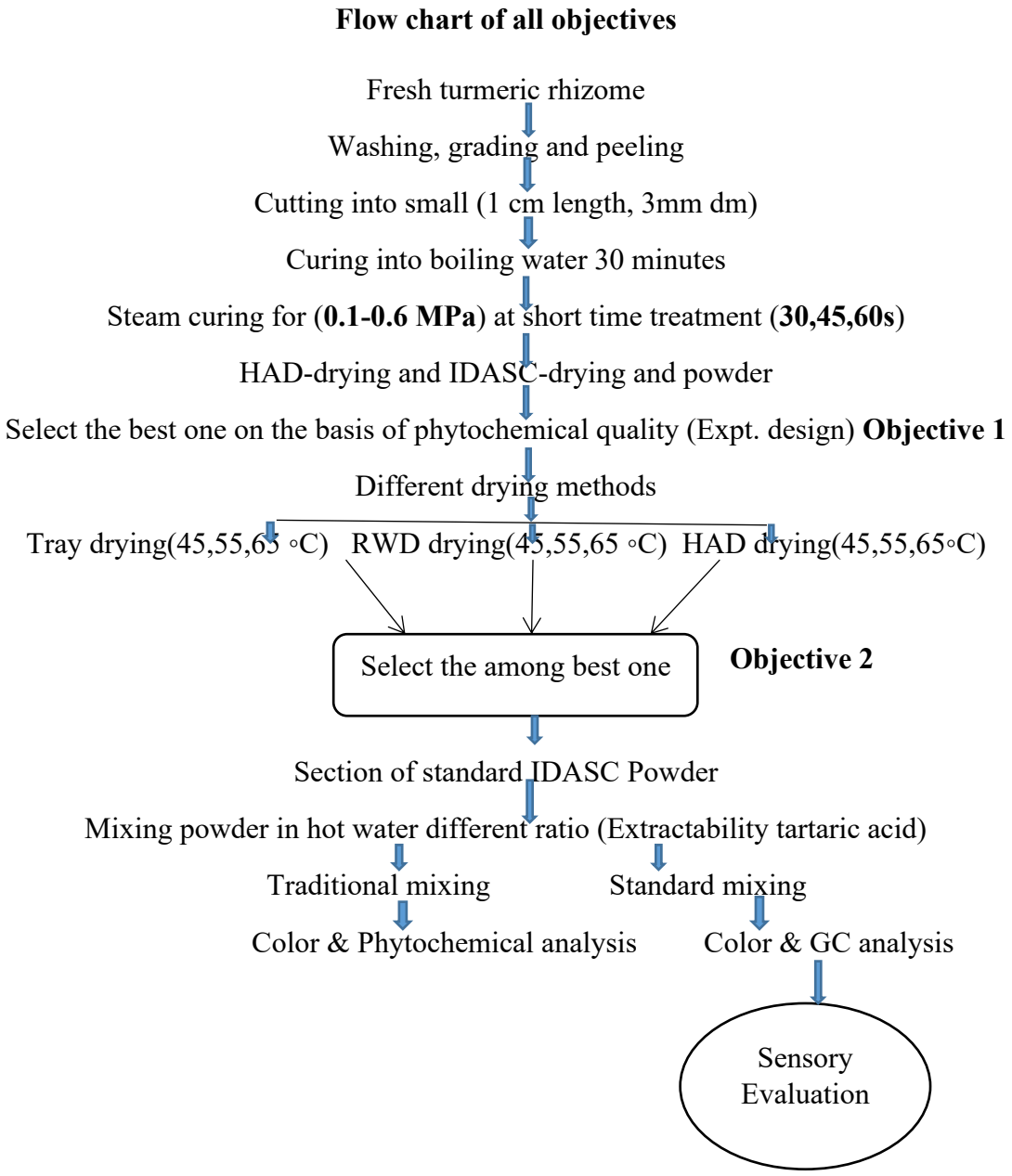

Fig No.3.1 Overall flowchart of all objective

3.5 Operation Requirement

Figures 3.2, and 3.3 show the operational requirements for the study. The components include a saturated steam boiler, a drying chamber, a pressure gauge, a K-type thermocouple, and pressure pump, steam supply system comprising pipes and valves.

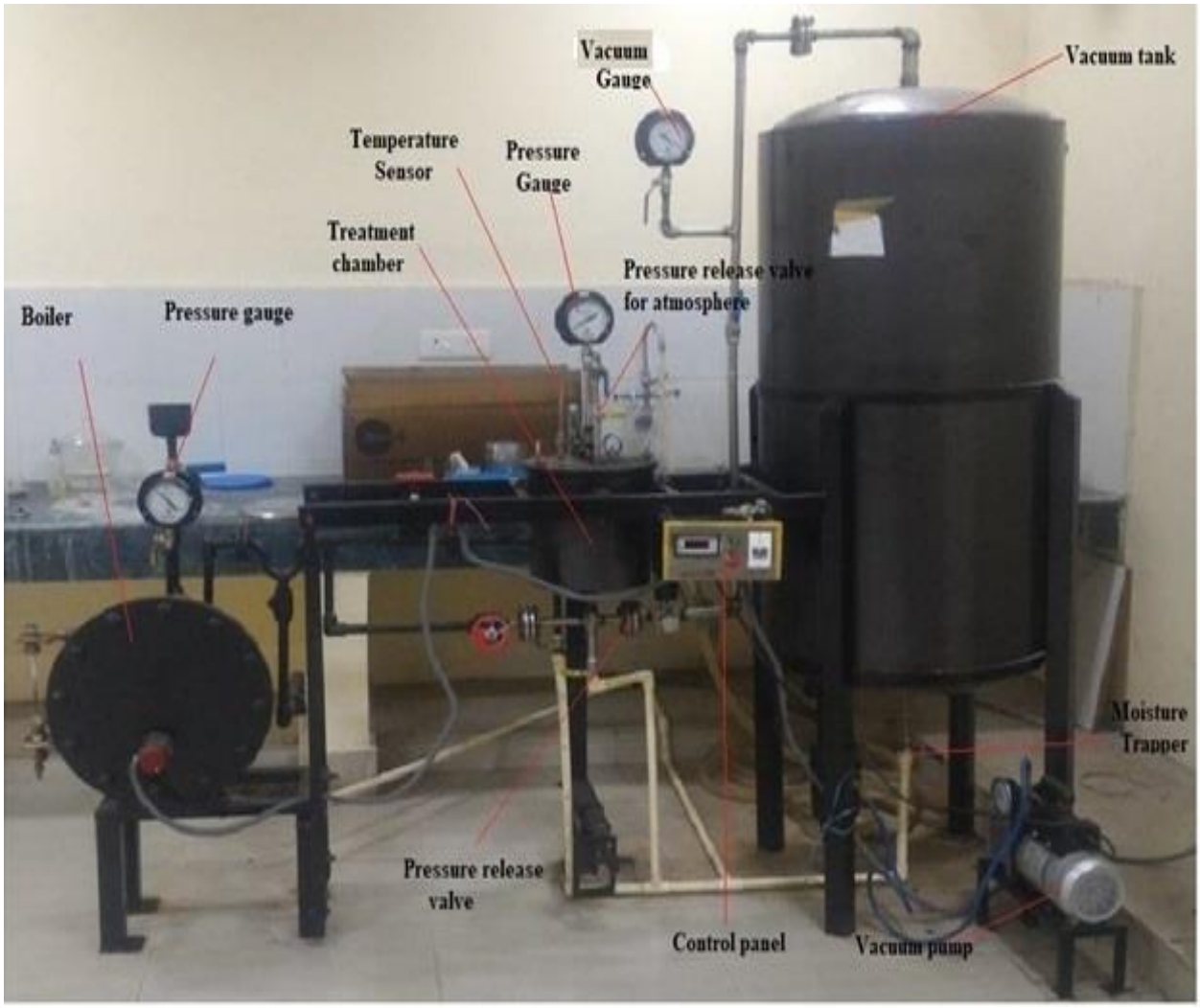

Fig 3.2 Instant controlled pressure drop technology machine for food processing unit

Fig 3.3 (a) Turmeric rhizome

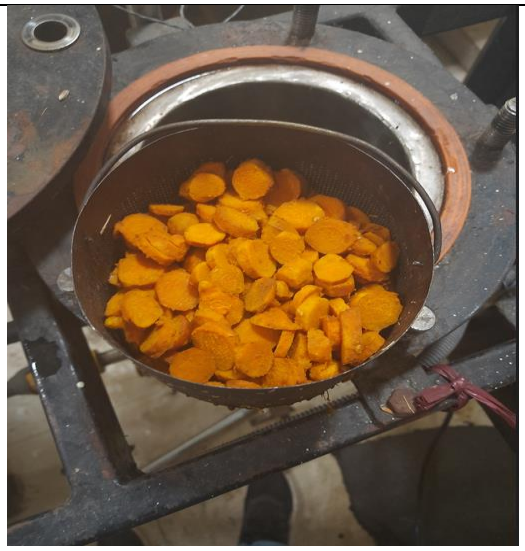

Fig 3.3 (b) Turmeric slices for treatment in ICPD

3.5.1 Characteristics of ICPD Treatment Unit

The ICPD treatment unit must fulfill the following design requirements:

1. Creation of an initial vacuum stage to eliminate air that may affect the contact between steam and the products.
2. Creation of a high steam pressure (0.1-1.0 MPa) treatment for a short duration of 5-60 s.
3. Causing an instant pressure drop towards vacuum which is accomplished by opening the solenoid valve between treatment chamber and vacuum tank
4. Maintaining the vacuum stage for 5-20 s.
5. Maintaining a pressure drop rate of greater than 0.25 MPa/s.
6. Release of vacuum towards atmosphere.

3.5.2 Conceptual Requirements and Setting-up of ICPD Unit for IDASC process

The ICPD unit was used to implement the IDASC processing with the intention of improving the process performance and end product quality features of the necessary modifications in food material, specifically turmeric. In the current study, IDASC treatment was applied to turmeric during the steaming process in order to address the issue of an extended cooking time, produce swell drying with a lower percentage of broken (usually less than 3%), shorten the hot air drying time after steaming (two to three hours), and enhance the textural and biochemical characteristics of the steamed turmeric. Saturated steam was used to create pressure inside the treatment chamber during the IDASC-based steaming procedure.

The steam release valve for the treatment chamber or treatment chamber casing (SRVTC/SRVTCC) controlled the steam feed into the treatment chamber. For the duration that the product needed, the pressure was maintained at the same level. After the steam treatment, steam was swiftly released into a large tank that had been maintained at a high vacuum, resulting in a rapid reduction of pressure to a high vacuum state. This results in swelling, textural alterations, and a rapid immediate decompression of the moisture from the material, all of which raise its specific surface area and porosity. The sudden drop in pressure that followed the seaming process was controlled by a solenoid valve.

As required for the product, pressure was released into the atmosphere after the decompression stage. During the IDSAC integrated steaming process, a pressure gauge attached to the treatment chamber was used to monitor its pressure, and sensor data collected from the unit's

control panel was used to monitor the temperature of the chamber. The temporary establishment of IDASC has been the subject of numerous studies.

On the basis of the conceptual design and design criteria, the IDASC treatment unit was developed. The device was divided into four main sections: the boiler, treatment chamber, vacuum tank with vacuum pump, and instantaneous controlled pressure release system. A control panel, temperature and pressure gauges, a moisture trapper, and a pressure release valve to the atmosphere were among the additional parts. The I treatment unit's design was made using CATIA software. The designs were shown from a variety of perspectives, including front, side, top, and isometric views. Multiple perspectives were used to illustrate the construction of the experimental unit.

3.5.3 Components of the IDASC Treatment Unit

The dimensions and specifications of the major sections of the ICPD treatment unit are as follows.

Boiler: The boiler delivered steam to the treatment chamber at a controlled pressure. A three-phase heating system was used to heat the water inside the boiler. The boiler has the capacity to hold thirteen liters of water at once. The size and specifications of the boiler used for the IDASC treatment are shown in Fig. 3.2.

In the IDASC treatment chamber, turmeric samples were treated under a preset pressure. It has an internal height (IH) of 20.0 cm and an internal diameter (ID) of 15.0 cm. It has a capacity of 3.5 liter. Its outside height measured 25.0 cm and external diameter measured 29 cm. The steam releasing valve towards vacuum (SRVTV), temperature gauge, pressure gauge, and solenoid valve connections were all linked to the IDASC treatment chamber. The dimensions and specifics of the IDASC therapy chamber are displayed in Fig. 3.2.

Vacuum tank: The pressure that had built up inside the IDASC therapy chamber was released using a vacuum tank. The vacuum tank's capacity was calculated using the ~1:80-100 IDASC treatment chamber to vacuum tank volume ratio. As a result, when the vacuum tank was constructed, a 300-liter capacity was taken into account. The vacuum tank measured 67 cm in diameter and 127 cm in height. One end of the vacuum tank, which housed the IDASC treatment chamber connection pipe and the instantaneously controlled pressure release valve (solenoid valve), had a moisture trapper and vacuum pump attached to it.

Vacuum pump: To create an evacuation inside the vacuum tank, a vacuum pump was utilized. The vacuum tank was coupled to a moisture collection and vacuum pump. In the current configuration, a two-stage vacuum pump with a 2.0 horsepower output was utilized. Additional parameter details are shown in Fig. 3.2.

An instantaneously controlled pressure release device was used to relieve the pressure that had built up inside the ICPD treatment chamber and toward the vacuum tank. A solenoid valve was used for this type of pressure release device.

It was permitted for the expanding slices to expand at a pressure decrease rate faster than 0.3 MPa/s. An electromechanically operated valve is the name given to this kind of valve. The magnetic field created when an electric current is applied powers it. The control panel supplied the electric current. This valve is situated between the vacuum tank and the IDASC treatment chamber.

3.5.4 Decompression Rate (PDR)

To enhance the steamed turmeric slice' quality qualities, appropriate PDR is required. PDR stands for pressure drop rate per unit of time. In this work, PDR was calculated for treatment pressures between 0.1 and 0.6 MPa. PDR was calculated by dividing the required decompression time by the pressure gradient required to reduce the whole treatment pressure to zero, following Hajji et al (2024).

3.5.5 Standard Processing Condition for IDASC Parameter for Improve Quality of Turmeric Powder

Improving the quality of turmeric powder by optimizing the IDASC parameter (drying time, yellowness value and curcumin content requires a systemic research conditions. The research methods to improve the overall quality of turmeric powder by optimizing the IDASC parameters. The specific goal was to enhance color retention, minimizing nutrient loss, and achieving uniform particle size.

3.6 Experimental Design and Optimization

The experimental design for the present carried out using Response Surface Methodology with BBD. The phytochemical from turmeric power using instant controlled pressure drop technology. The range of parameters will be set as description in the following table 1.

Table 3.1: Design experiment table of different variable

S.No	Independent parameter	Dependent parameter
1	Treatment pressure (0.1 to 0.4 MPa)	Drying (min)
2	Treatment time (10-50s)	Curcumin content (%)
3	Temperature of drying (45-65 ºC)	Yellowness Value

Optimization by RSM approach

- Process variables viz. treatment pressure (TP) and treatment time (TT) and temperature of drying (TD).
- Quality characteristics viz. drying time (DT) and yellowness value (YV) and curcumin content (CC).
- $Y = \beta o + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ii} x_i^2 + \sum_{i=1}^{3} \sum_{j=i+1}^{3} \beta_{ij} x_i x_j$ .....(1)
- Where β_0 (constant term), β_i (linear effects), β_{ii} (quadratic effects), β_{ij} (interaction effects) are the coefficient of the polynomials and x_i's are the coded independent variables.
- The RSM models developed between different factors and responses were integrated with optimize IDASC-HAD process conditions.
- The RSM algorithm was programmed in MATLAB R2018b.
- Optimization of ICPD of polyphenols from dried turmeric was done using Response Surface Methodology (RSM). The experimental design followed was the Box-Behnken design that was prepared using Design Expert Version 7 software (State-Ease Inc., Minneapolis, MN, USA).

- The Box-Behnken design consisted of 17 experiments and comprised of three levels and three factors. Total phenolic content, total flavonoid content, and DPPH radical scavenging activity were taken as the dependent variables. The design was executed to maximize the dependent variables. Validation of the model was done by comparing experimental values with the predicted values

3.7 Product Characterization

3.7.1 Measurement of Moisture Content

Moisture content of turmeric samples was determined as per the AOAC method 2000. In this method, 3-5 g of turmeric was cut into pieces and taken in an empty dish. The prepared sample was kept in hot air oven (Ms. Armstrong Smith, India) at temperature of 105°C until two consecutive readings were constant. The weight of the dish and sample were measured after the experiment and moisture content on wet basis was calculated as below following Hailemariam, (2023).

Moisture content (%)= $\frac{W_1 - W_2}{W_1} \times 100$ .....(2)

Where,

W_1= weight of sample before drying (g)

W_2= Weight of sample after drying (g)

Table 3.2: Model fitting parameter of drying kinetic of turmeric slices

S. no	Name of Model	Model Equation	Parameters description	References
1	Lewis Model	$MR = e^{-kt}$	k = constant	(Jha & Sit, 2020)
2	Henderson and Pabis	$MR = ae^{-kt}$	a, k =constant	(Avhad & Marchetti, 2016)
3	Logarithmic	$MR = ae^{-kt}$+c	a, k, c =constant	(Jha & Sit, 2020)
4	Page	$MR = e^{-kt^n}$	k, n = constant.	(Avhad & Marchetti, 2016)
5	Midlli model	$MR = ae^{-kt} + bt$	a, b, k= constant	(Wang et al., 2018)

3.7.2 Estimation of Rehydration Ratio

The rehydration of the dehydrated turmeric slice was studied in terms of the rehydration ratio. It is defined as the ratio of the mass of rehydrated samples to the dried samples and can be represented by Equation 3, following Link et al., (2017).

Rehydration ratio=Mass of rehydrated sample (g)/Mass of dry samples (g)…..…. (3)

Rehydration experiments were performed in boiling water in a beaker kept on a hot plate. At every five-minute interval, the turmeric slice were taken out from the beaker. The samples were placed on tissue paper for removing surface moisture before weight measurement of the samples following Ranganna et al., (1983).

3.7.3 Estimation of Shrinkage Ratio

The dried sample's shrinkage ratio was evaluated with the toluene displacement method. The proportion was computed by expressing the percentage change in volume from the initial apparent volume by Eq. (4) (Long et al., 2022)

$$S = V_r/V_o \quad \text{..... (4)}$$

Where, Vr The volume displaced by the dried sample and Vo The volume displaced by fresh sample

3.7.4 Texture Measurement

The crushing strength of the dried turmeric samples was evaluated using a texture analyzer (TA-XT, Surrey, UK). The maximum force (g) required to overcome the sample's compression resistance to a cylindrical probe with a diameter of 3.0 mm was evaluated (Chakraborty et al., 2020).

3.7.5 Colour

Using a Hunter color spectrophotometer (Hunter Colour Lab Ultrascan Vis, USA), the sample of turmeric's color was examined. Before measuring the samples, the equipment was standardized using the standards following Jha & Sit (2020). The color analysis scale parameters were b* (blue for positive to yellow for negative), a* (negative for green to positive for red), and L* (0 for darkness and 100 for lightness). The sample's hue angle (color perception) was computed using Eq. 5.

Hue angle = $\tan^{-1}$ (a*/b*) ……(5)

3.7.6 Scanning electron microscopy

The microstructure of foam dried powder samples were obtained using scanning electron microscope (Jeol, JSM-6390LV, Jeol Ltd., Japan). Prior to analysis, powder samples were coated on SEM stubs with double-sided tape using auto fine coater (Jeol JFC1600) and images of x 500 magnification were captured. The microstructure of turmeric powder and slices (raw and agglomerated) samples was examined by employing a scanning electron microscope. The sample was dried in a hot air oven, maintained at a temperature of 50°C for 5 h following Jha and Sit (2020). The dried samples were coated with a thin film of gold employing a sputter coater followed by microscopically examination at an accelerating voltage of 20 kV at a magnification of 500X to observe the shape, size and adhesion of particles in the samples. Representative photomicrographs are presented.

3.7.7 X-Ray Diffraction Studies

The X-ray diffraction pattern of isolated starch and turmeric powder in triplicates was obtained using a X-ray diffractometer. The diffraction intensity of the powder sample was measured from 10° to 40°, which covered all the significant peaks of starch as a function of 2θ at a scanning speed of 4°/min following Chopra et al., (2021). Percentage crystallinity of the samples was calculated as reported in Trotta et al., (2023). The area of crystalline reflection was divided by the sum of the areas of crystalline reflection and amorphous reflection, and expressed as percentage crystallinity.

3.7.8 Evaluation of Rheological Parameters of Powder

Turmeric starch was subjected to three successive cycles of compression and decompression for characterization of its flow behaviour employing the powder flow analyzer attachment of the texture measuring system following Kutti Gounder et al., (2011) and Kutti Gounder & Lingamallu, (2012). The powder flow analyzer can provide rotational movement of the blades while traversing in vertical directions (up and down) through a distance of 70 mm and records the associated resistive forces. A fixed volume of powder (180 ml) was poured into the sample container having a total capacity of 200 ml; the internal diameter of the sample container was 50 mm. Compaction property of powder was tested when the blades move downwards while it measured cohesion property when moving upward at a constant tip speed of 50 mm. The

maximum force required for compaction studies was known from the peak value of force while moving downward from each of the three curves and latter averaging them. Work or energy required for compression and decompression were calculated from positive and negative areas, respectively of the force-distance curves using the software supplied by the equipment manufacture. Each experiment was repeated thrice and results were reported as mean ± standard deviation (SD)

3.8 Biochemical Analysis of Turmeric Powder

Biochemical analysis is a critical tool in scientific research, encompassing the study of chemical processes within and related to living organisms. Its applications span diverse fields, including medicine, agriculture, environmental science, and food technology. By analyzing biomolecules such as proteins, carbohydrates, lipids, nucleic acids, and metabolites, researchers can gain valuable insights into physiological functions, disease mechanisms, and the quality of biological materials.

3.8.1 Total Phenolic Content

The total phenolic content (TPC) in turmeric was determined according to Nisar et al., (2015), For the analysis, an aliquot of 0.5 mL of diluted sample extracts was taken in test tubes and mixed with 2.5 mL of Folin-Ciocalteu reagent (diluted 1:10). For blank, sample extract was replaced with distilled water. After 5 min of incubation, 2 mL of sodium carbonate (7.5%) was added into each test tube, vortexed and kept for 2 h in a dark place at room temperature. Absorbance was read by UV-Vis spectrophotometer (Thermo Fischer Evolution A600) after incubation time against the reagent blank mixture. Gallic acid was used as the standard, and results were expressed in mg GAE/100g.

3.8.2 Total Flavonoid Content

According to Nisar et al., (2015), the total flavonoid content (TFC) of turmeric samples was ascertained. To conduct the analysis, a 0.5 mL sample aliquot was combined with 1.5 mL of 95% ethanol, 0.1 mL of 10% aluminum trichloride, 0.1 mL of potassium acetate (1M), and 2.8 mL of deionized water. After the test tube was vortexed, it was left for two hours at room temperature in a dark area for forty minutes. The sample's absorbance was measured at 415 nm using a blank in a UV-Vis spectrophotometer (Thermo-Fischer Evolution A600). The standard utilized was quercetin, and the results were given in milligrams of QE per 100 grams following Ali et al., (2019)

3.8.3 DPPH radical Scavenging Activity

DPPH radical scavenging activity of turmeric was calculated according to Trivedi et al., (2023) with some modification. In a test tube, 200 µL of sample extract was taken, followed by the addition of 2.8 mL of DPPH radical prepared in methanol, vortexed and kept for 30 min in a dark place for incubation. The absorbance of sample was read at 517 nm using UV-Vis spectrophotometer (Thermo-Fischer Evolution A600) against blank.

$$\text{DPPH Activity (\%)} = \frac{(A° - As)}{A°} \times 100 \quad \text{.....(6)}$$

Where, $A°$ Absorbance of control black, A_s is sample absorbance

3.8.4 Curcumin Content

Estimation of curcumin content of turmeric was carried out as per the method given by BIS – 10925: 1984. In this method, the standard curcumin solution was first prepared by taking 25 mg of standard curcumin (Sigma Chemicals, Germany) in a 100 ml volumetric flask and diluted to mark with alcohol (95%) following Hmar et al., (2017).

One ml of the standard solution was transferred to 100 ml volumetric flask and diluted to mark with alcohol which contains 2.5 mg (0.0025 g/L) of curcumin (Hmar et al., 2017). Fifty mg of ground sample along with 50 ml alcohol were taken in a round bottom flask. The mixture was refluxed in an air condenser for the period of 2.5 h. The cooled and filtered extract was taken in 50 ml volumetric flask. One ml of the extract was diluted to 9 ml of alcohol. The absorbance of the standard solution and the extract were measured following Tabanelli et al., (2021), at 425 nm against alcoholic blank in a UV- Visible spectrophotometer (make: Systronics, Ahmadabad).

The curcumin content was estimated as follows:

$$\text{Curcumin content(\%)} = \frac{0.0025 \times A420 \times volume\ madeup \times dilution\ factor}{mass\ of\ sample \times 0.420 \times 1000} 100 \quad \text{.....(7)}$$

3.8.5 HPLC Analysis of Individual Curcuminoids in Extract

The individual curcuminoids were quantified using high performance liquid chromatograph equipped with 2487 dual UV–vis absorbance detector set at a sensitivity of 0.01 AUFS, fitted with a reverse phase SS Exsil amino column (4.6 x 250 mm, 5 µm) with an isocratic system.

The mobile phase used was of 2-propanol and deionised water (95:05, v/v) mixture at a flow rate of 0.6 ml/min. The extract from fresh, dried and cured-dried turmeric rhizome (10 mg, each) was dissolved in methanol and made up to 10 ml in standard volumetric flask. The solution was filtered through filter (0.45 µm) paper. The filtered solution was diluted suitably (100 µg) and 20 µl of the solution was injected to the HPLC system in triplicates. The standard calibration curve (peak area versus concentration) was plotted using different concentrations of standard curcuminoid mixture (0.5-2.0 µg), and the regression equation was obtained. The concentration of individual pigment was calculated using standard calibration curve and expressed as mg of individual curcuminoid per 100 g of turmeric powder, as per Chopra et al., (2021).

3.8.6 Ferric Reducing Antioxidant Potential (FRAP):

The total antioxidant potential of volatile oil samples were assessed using the ferric reducing ability of plasma FRAP assay following Kutti Gounder & Lingamallu, (2012). The assay was based on the reducing power of a compound (antioxidant) (Fig 3.3). This assay was based on the electron-transfer reaction. In this assay, ferric tripyridyltriazine Fe(III)$(TPTZ)_2Cl_3$ complex was reduced to ferrous [Fe (II)] form. An intense blue colour complex was formed with absorption maximum at 593 nm by the electron donating action of antioxidant following Huang et al., (2005).

3.9 Drying of Turmeric Slices

3.9.1 Quality Evaluation of Turmeric Rhizomes

Turmeric rhizomes dried under-developed super-heated steam dryer were analyzed for its quality in terms of curcumin, essential oil, oleoresin, color and moisture content. The procedure for the measurement of biochemical properties were as per Ioannis et al., (2024)

3.9.2 Instant Decompression Assisted - Hot Air Drying

Instant decompression assisted hot air drying is an advanced technique employed in the field of drying processes, particularly for materials sensitive to temperature, such as food products, pharmaceuticals, and certain chemicals. This method enhances the efficiency and effectiveness of drying by integrating two critical elements: rapid decompression and controlled hot air application. Here, we delve into the principles, mechanisms, applications, and advantages of this drying method (Gautam et al., 2021).

The core principle behind instant decompression assisted hot air drying lies in the combined use of hot air and sudden reduction in pressure to expedite the drying process. This technique leverages the following scientific principles

1. Thermodynamics of Drying: Drying is fundamentally a heat and mass transfer process where heat is supplied to evaporate moisture, and the resulting vapor is carried away. Hot air drying relies on the principle that increasing air temperature enhances the vaporization rate of moisture from the material.
2. Decompression Effect: Decompression lowers the ambient pressure surrounding the material. According to the ideal gas law, reducing pressure decreases the boiling point of water. Thus, at lower pressures, water can evaporate at lower temperatures, which is particularly beneficial for heat-sensitive materials.
3. Combined Effect: By instantly decompressing the environment around the material and applying hot air simultaneously, the drying process becomes more efficient. The reduced pressure allows moisture to evaporate more quickly, while the hot air speeds up the heat transfer required for evaporation (Chakraborty et al., 2024).

The process of instant decompression assisted hot air drying involves several steps:

1. Preparation of Material: The material to be dried is prepared and placed in a drying chamber. The chamber is designed to handle rapid changes in pressure and temperature.
2. Hot Air Application**:** Hot air is introduced into the drying chamber. The temperature of the air is carefully controlled to ensure that it is high enough to facilitate evaporation but not so high as to cause damage to the material.
3. Instant Decompression: At a specific point in the drying cycle, the chamber undergoes a rapid decompression. This sudden drop in pressure lowers the boiling point of water within the material, causing moisture to evaporate quickly (Gautam et al., 2021).
4. Moisture Removal: As the moisture evaporates, it is carried away by the hot air stream. The airflow within the chamber is designed to ensure efficient removal of water vapor and to maintain a consistent drying environment.
5. Continuous Monitoring: Throughout the process, sensors and controls monitor the temperature, pressure, and humidity levels within the chamber to optimize drying conditions and prevent overheating or incomplete drying.

3.9.3 Swell Drying or ICPD Assisted Hot Air Drying

Instant decompression assisted hot air drying is an innovative and efficient drying technique that combines the benefits of hot air and rapid decompression to enhance the drying process. By reducing the boiling point of moisture and accelerating heat transfer, this method offers significant advantages in terms of speed, quality preservation, and energy efficiency. Its applications span across food, pharmaceuticals, chemicals, and biomaterials, showcasing its versatility and effectiveness. Despite the challenges associated with equipment costs and process complexity, the benefits of this drying technique make it a valuable tool in modern drying technologies following Abi et al., (2022).

3.9.4 Instant Decompression Assisted Refractance Window Drying

The procedure combines the principles of refractance window drying with the benefits of instant decompression to create a highly effective drying process. This overview will delve into the principles, mechanisms, applications, and advantages of this technique.

Fig 3.4 Refractance window drying unit

Fig 3.5 Turmeric drying in refractance window

Instant decompression assisted refractance window drying is an advanced and innovative drying technique designed to efficiently remove moisture from sensitive materials while preserving their quality. This method combines the principles of refractance window drying with the benefits of instant decompression to create a highly effective drying process. This overview will delve into the principles, mechanisms, applications, and advantages of this technique (Moldenhauer, 2023).

Refractance window drying is a unique drying method that involves the use of a thermal window created by infrared radiation to transfer heat to the material being dried (Talukdar et al., 2025). This process is based on the following principles:

1. **Infrared Radiation:** In refractance window drying, infrared radiation is used to heat the surface of the material. Infrared light is absorbed by the material and converted into heat, which promotes the evaporation of moisture.
2. **Thermal Window:** The term "refractance window" refers to the thin layer of water vapor that forms above the material being dried. This layer acts as a thermal barrier, allowing heat to pass through but trapping some of the heat within the drying chamber, creating a favorable drying environment.
3. **Surface Heating:** Unlike conventional drying methods that rely on convection or conduction, refractance window drying heats the material directly through infrared radiation, which allows for more efficient and uniform heat transfer.

Instant decompression is a process that involves rapidly reducing the pressure around the material to lower the boiling point of moisture. This is based on:

1. **Pressure Reduction:** By instantly decreasing the ambient pressure, the boiling point of water is lowered. This allows moisture to evaporate at lower temperatures, which is particularly beneficial for heat-sensitive materials.
2. **Enhanced Vaporization:** Lowering the boiling point accelerates the rate of moisture evaporation, which can significantly reduce drying time and improve the efficiency of the process.

Instant decompression assisted refractance window drying is an advanced drying technique that combines the benefits of infrared radiation and rapid decompression to create a highly efficient and effective drying process (Chakraborty et al., 2019, Trivedi et al., 2023). By leveraging the principles of refractance window drying and instant decompression, this method offers enhanced drying speed, quality preservation, and energy efficiency. Its applications span across food, pharmaceuticals, biomaterials, and chemicals, showcasing its versatility and effectiveness. Despite the challenges associated with equipment costs and process complexity, the benefits of this drying technique make it a valuable tool in modern drying technologies.

3.9.5 Experimental Procedure

Studies were conducted in three different set up such as RW drying (IRD) (Fig 3.4 and Fig 3.5), hot air drying (HAD) and ICPD combined with RW drying (ICPD-RWD). The preliminary studies were conducted to standardize the different slice (3 mm and 5 mm) and bed thicknesses (25 mm and 50 mm). The optimal drying rate and superior product quality were obtained at a slice thickness 5 mm and bed thickness 25 mm. Slicing the rhizomes had reduced the drying time and allowed for better curcuminoid extractability (Gautam et al., 2021), also highlighted that the yield of curcumin content was higher at a slice thickness of 5 mm. The experiments were performed at three drying temperatures (45, 55, and 65 ◦C) with fixed slice thickness (5 mm) and bed thickness (25 mm).

A mass of 2 kg rhizome was taken for each experiment. For all the drying studies, air velocity of 2 m/s (make and model: Lutron AM4202 Digital Anemometer) The weight was recorded at an interval of 30 minutes using digital electronic balance. Drying of sample was undertaken until it reached the required moisture content. The dried samples were packed in an airtight lowdensity polyethylene cover (60 µm) and stored in refrigerator at ± 4ºC for further quality analysis. The data logger was fixed in the dryer for measuring the temperature and RH for the defined period of time. All the experiments were performed in triplicate.

3.10 Evaluation of a Curcumin Enriched Infusion Drink Turmeric Powder Obtained by RW Drying

The demand for functional drink with health benefits has grown significantly, and turmeric, rich in curcumin, has emerged as a key ingredient for such products. The formulation of a curcumin-enriched infusion mix using turmeric powder prepared via Refractance Window (RW) drying combines advanced drying technology with functional ingredient optimization. This essay details the systematic method of achieving a high-quality product with enhanced curcumin content and excellent solubility (Moldenhauer, 2023).

The process begins with the selection of high-quality turmeric rhizomes, preferably from varieties known for their high curcumin content, such as *Curcuma longa* (Salem or Alleppey varieties). Fresh rhizomes are chosen for their vibrant color and high bioactive compound levels. Additional ingredients, such as natural flavor enhancers like ginger powder, cinnamon, and sweeteners (e.g., stevia or jaggery powder), are selected to complement turmeric's flavor and enhance consumer appeal.

RW drying is an innovative technique chosen for its ability to retain bioactive compounds while preserving the natural color and aroma of turmeric. A uniform slurry is prepared by blending turmeric slices with water in a 2:1 ratio. This slurry is spread thinly (1–2 mm) over the RW drying surface, where it is exposed to gentle heat (75–95°C) for 10–20 minutes. The unique mechanism of RW drying, which uses water as a medium to transfer heat efficiently, ensures rapid moisture removal without thermal damage. The end product is a vibrant, nutrient-rich dried turmeric powder with moisture content below 8%.

3.10.1 Evaluation of the Infusion Drink

The turmeric powder is make drink with other ingredients to create the infusion drink. The base composition includes the curcumin-enriched turmeric drink in and added natural flavor enhancers, and optional sweeteners or solubility aids for masking flavor. During preparation of drink added some of ingredient for better flavor and masking like honey, vallina, lemon, peperine and rock sugar. The blending process is carried out using a ribbon blender or similar equipment to ensure uniformity. Each ingredient is selected and proportioned to balance flavor, functionality, and ease of use (Abd et al., 2022).

3.10.2 Fuzzy Logic Sensory Evaluation of drink

Sensory evaluation of drink plays a critical role in product development and quality assurance, providing insights into consumer preferences and product acceptability. However, the inherent subjectivity of human sensory perception poses a challenge in obtaining consistent and reliable data. Fuzzy logic offers a robust methodology to address this issue by accommodating the imprecise and ambiguous nature of sensory evaluations. This chapter outlines the methodology employed for the fuzzy logic-based sensory evaluation of drink following Chakraborty et al., (2021).

Fuzzy logic is a mathematical approach that handles uncertainty and imprecision by allowing partial membership in multiple sets. Unlike traditional binary logic, where variables are either true or false, fuzzy logic assigns a degree of truth ranging between 0 and 1. This feature makes it particularly suitable for sensory evaluation, where panelists' perceptions often vary in intensity and interpretation.

- Linguistic data obtained from the sensory evaluation were utilized by this method. On the basis of triangular fuzzy membership distribution, the ranking of the samples was done (Sinija & Mishra, 2011).

- During the fuzzy analysis, triplet values were obtained from the initial scores given by the panellists. In order to estimate similarity values, the triplets were utilized and ultimate ranking of the samples was done.

- For the sensory analysis on the basis of fuzzy logic, following steps were performed:

    1. Sensory scales associated triplets determination;
    2. Triplets estimation in context to samples and all attributes;
    3. Triplets estimation as associated with relative weightage of the traits;
    4. Overall sensory scores (OSS) based triplets estimation;
    5. Overall membership function (OMF) estimation for the sensory scores;
    6. Similarity value estimation for various samples and quality attributes;
    7. Final Ranking of the samples and their associated attributes.

The fuzzy logic-based sensory evaluation of beverages was conducted in a structured framework to ensure accuracy and reproducibility. The following steps were undertaken:

3.10.3 Selection of Infusion Samples

Representative samples of the infusion category under study were selected based on market relevance and diversity in flavor profiles, textures, and visual attributes. For example, for fruit juices, samples included variations in sweetness, acidity, and pulp content.

A panel of 15 to 20 individuals was involved, comprising of semi-trained participants to balance expertise and consumer perspective. Panelists were trained on the sensory attributes to be evaluated, such as appearance, aroma, taste, mouthfeel, and aftertaste, to standardize their understanding and reduce variability.

A focus group discussion was conducted to identify the key sensory attributes that significantly influence beverage acceptability. The attributes were categorized into primary (e.g., sweetness, sourness, bitterness) and secondary (e.g., clarity, aroma intensity) dimensions.

Conventional sensory evaluation employs ordinal or interval scales, such as 9-point hedonic scales. In contrast, fuzzy logic utilizes linguistic descriptors (e.g., "low," "moderate," "high") for each attribute. These descriptors were translated into fuzzy sets with corresponding membership functions.

Fig 3.6: Sensory Panel for scoring grade

Fig. 3.7 Turmeric drink for sensory evaluation

3.10.4 Development of Fuzzy Logic Model

Membership functions were defined for each sensory attribute based on expert input and preliminary tests. For instance, sweetness might have fuzzy sets such as "low sweetness," "medium sweetness," and "high sweetness," with triangular or trapezoidal membership functions representing their ranges following Das et al., (2022).

The panelists' ratings were converted into fuzzy values using the defined membership functions. This process, known as fuzzification, allows the representation of subjective evaluations in a mathematical form.

A rule base was developed to map the relationships between sensory attributes and overall acceptability. For example:

- If sweetness is "medium" and sourness is "low," then overall acceptability is "high."
- If sweetness is "high" and bitterness is "moderate," then overall acceptability is "moderate."

These rules were derived from panelist feedback and expert judgment. The fuzzy inference engine applied the rule base to the fuzzified data to calculate the degree of truth for each possible outcome. The widely used Mamdani inference method was employed in this study. To convert the fuzzy output into a crisp value for easier interpretation, defuzzification was performed using the centroid method. The resulting crisp scores represented the overall acceptability of each beverage sample.

The de-fuzzified scores were analyzed statistically to identify trends and significant differences among the drink samples. Additionally, correlation analyses were conducted to explore relationships between individual sensory attributes and overall acceptability. The fuzzy logic-based sensory evaluation results were validated by comparing them with traditional sensory evaluation methods. Consistency in findings confirmed the reliability and robustness of the fuzzy logic approach.

The fuzzy logic methodology offers several advantages, including:

- Accommodating variability in panelists' perceptions.
- Providing a more nuanced understanding of sensory data.
- Enhancing decision-making in product development by identifying subtle differences among sample

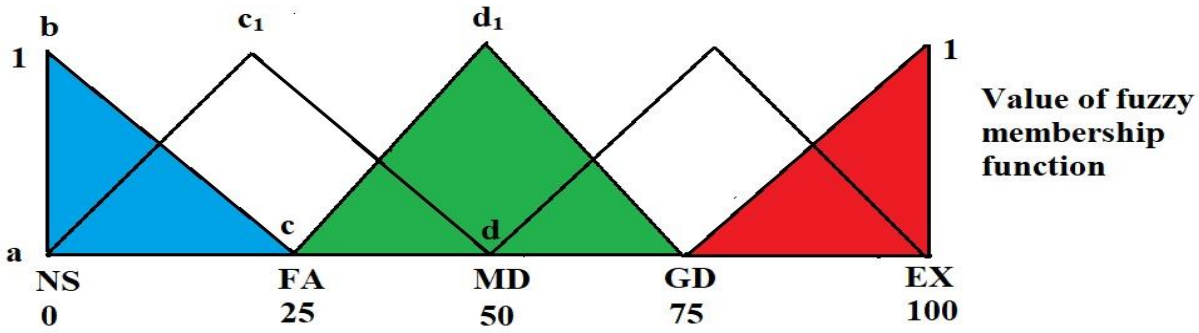

Fig 3.8 Sensory evaluation of all membership function

3.10.5 Radar Chart for Sensory Evaluation

A radar chart is a graphical representation commonly used in sensory evaluation to visualize and compare the performance of different samples based on multiple sensory attributes. It is particularly valuable in the food, drink, and cosmetic industries for product development, quality control, and consumer preference studies following Das et al., (2022).

1. Selection of Sensory Attributes

- Identify key sensory attributes relevant to the product category. Attributes can be:
    - **Appearance:** Color, gloss, or uniformity.
    - **Texture:** Crispness, smoothness, or hardness.
    - **Flavor:** Sweetness, saltiness, bitterness, umami, etc.
    - **Aroma:** Intensity, complexity, or specific aromatic notes.
    - **Overall acceptability:** General liking or preference.

2. Panel Training

- Train a sensory panel (either trained experts or untrained consumers) to evaluate the identified attributes consistently.
- Provide reference standards to help panelists understand and score the attributes.

3. Sample Preparation

- Prepare samples under controlled conditions to ensure consistency (e.g., same temperature, portion size).
- Randomize the order of presentation to avoid bias.

4. Scoring and Data Collection

- Use a structured sensory evaluation form with a scale (e.g., 1–10 or 1–5) for each attribute.
- Panelists assign scores based on the intensity or quality of the attributes.

5. Data Analysis

- Calculate the average score for each attribute across panelists for each sample.
- Normalize the data if necessary to fit within a common scale.

3.10.6 Storage Study of Turmeric Infusion Drink

For storage study, the turmeric infusion drink was stored at 25 °C in an incubator and the changes in the pH, TSS, Curcumin content were calculated according to methods adopted following Abd et al., (2022). The TPC and *in-vitro* antioxidant property of the turmeric infusion drink were calculated accordingly. Microbial analysis, the total microbial count (TMC) of the turmeric infusion drink was analyzed.

3.10.7 Statistical Method

The Box Behnken method of response surface methodology (RSM) design was chosen as it is best suitable for three factors with three level variables. It was to analyze the interaction of process variables on quality of dried turmeric in 17 experiments, out of which 4 experiments were for center point and 13 were for non-center point. The process variables were maintained in different combinations (Table 3.1). The response parameters were curcumin, moisture content, oleoresin, essential oil and color values in terms of L*, a*, b*. All experiments were done in triplicate. The analysis of variance (ANOVA) tables and have to use fuggy logic sensory evaluation were generated and the effect of individual linear, quadratic and the interaction term was studied using design expert program V.6.0.8 of the state ease software (Design expert-2002, Minneapolis, Minnesota, US). The significance of all the polynomial was judged statistically by computing the F value; the significance of the F value was judged at a probability level (p) of 0.01 and 0.05.

3.11 Chapter Summary

The methods section of a thesis is a critical part of the research, detailing the systematic procedures followed to achieve the study's objectives. It provides a clear roadmap of the techniques and processes used to collect, analyze, and interpret data, ensuring transparency and reproducibility of the research. This section varies depending on the discipline but generally adheres to a structured approach. Below is an essay summarizing the key components and strategies for writing the methods section of a thesis.

The methods section establishes the credibility of the research by detailing the techniques used to achieve the study's goals. It should provide sufficient information for others to replicate the study while being concise and precise. A well-written methods section balances comprehensiveness with clarity, ensuring the audience understands the rationale and execution of each step in the research process.