Chapter 2

Chapter II

Review of Literature

2.1 Turmeric and Health Beneficial Effect

Turmeric (*Curcuma longa L.,)* has been utilized for ages in Chinese and Indian traditional medicine. Curcumin is the primary component of turmeric, which is made up of naturally occurring bioactive hydrophobic polyphenols known as curcuminoids that are extracted from the herb's rhizome. Antioxidant, anti-cancer, antibacterial, anti-inflammatory, and anti-diabetic qualities are among their many pharmacological effects. Curcumin's bioactive activities have been the subject of scientific advancements, with particular attention paid to its anticancer, inflammatory, and antioxidant properties (Ben Haj Said et al., 2015). Bioactive compounds having therapeutic qualities can be found in turmeric. It is beneficial to eat it with piperine-containing black pepper. A naturally occurring chemical called piperine increases curcumin absorption by 2000% (Haq et al., 2021).

One naturally occurring anti-inflammatory substance is curcumin. It is now thought that certain illnesses and conditions may be influenced by persistent low-level inflammation. These include conditions including Alzheimer's disease, metabolic syndrome, cancer, and heart disease, among others. Turmeric can boost the body's antioxidant capability. Because of its chemical makeup, curcumin is a strong antioxidant that can counteract free radicals (Galano et al., 2009). Brain-derived neurotrophic factor (BDNF) can be increased by curcumin. The brain regions in charge of eating, drinking, and body weight contain the BDNF protein, which is involved in memory and learning. Curcumin might reduce your chance of developing heart disease. Unchecked cell development is a hallmark of the condition known as cancer. Cancer prevention may be aided by turmeric (Ojo et al., 2022). Supplements containing curcumin seem to have an impact on a wide range of cancer types. Alzheimer's disease may be treated with curcumin. Up to 70% of dementia cases may be caused by Alzheimer's disease, which is the most prevalent type of dementia. Supplements containing curcumin are effective for people with arthritis. Curcumin helps prevent depression. Curcumin may help prevent chronic diseases associated with aging and postpone aging (Ariyarathna & Karunaratne, 2016).

2.2 Turmeric Processing

IDASC turmeric processing represents a modern advancement that elevates the benefits of turmeric beyond traditional knowledge. While ancient practices valued turmeric for its color, flavor, and medicinal properties, the IDASC (Instant Controlled Pressure Drop) technique especially when paired with refractance window drying enhances these attributes through precise control over heat and drying conditions. This process preserves higher curcumin content, improves antioxidant activity, and maintains vibrant color by minimizing thermal degradation. Compared to conventional drying, IDASC achieves superior bioactive retention, making the turmeric more potent and bioavailable. Such scientific optimization aligns with contemporary demands for functional foods and nutraceuticals, bridging heritage with innovation. By combining traditional wisdom with validated technology, IDASC transforms turmeric into a high-value ingredient for global health, cosmetic, and wellness markets.

After harvesting, turmeric is traditionally processed by removing roots, rhizoids, soil, dust, and other undesirable materials. Following cleaning, the rhizomes undergo a procedure known as "curing" in which they are heated in water until they are cooked (Gagare et al., 2015). It is uncommon for farmers to boil fingers and bulbs separately in order to speed drying and promote uniform cooking. After being cooked, the rhizomes are spread out unevenly on bamboo mats or other drying surfaces and left in the sun for ten to fifteen days, until they are brittle and hard. Manual rubbing is used to "polish" dried rhizomes. Poor post-harvest handling practices are the primary cause of dried turmeric's lower quality.

Alleppey turmeric, Madras turmeric, and West Indian turmeric are the three main varieties that are typically traded on the international market. The main challenges that farmers must deal with during processing include underground nature, high initial moisture content (IMC), and highly specialized skin. In addition to being extremely time-consuming and labor-intensive, indigenous approaches also result in significant material and quality loss (Chavalittumrong & Jirawattanapong, 1992; Jayashree, & Zachariah, 2016). Typically, turmeric is placed on roadways, in otherwise dirty areas, or on floors that have been soiled by cow dung in order to dry in the open sun. Depending on the farmer and the region, farmers frequently dry the turmeric rhizome till the final moisture content ranges from 15% to 35%. Non-uniform and uneven drying encourage microorganisms, particularly fungi, to begin growing right away. According to reports, the conventional drying procedure may cause some of the light-sensitive oil elements to be destroyed and result in a 25% evaporation loss of volatile oil. Moisture, curcumin, oleoresin, volatile oil, insect infestation, appearance, microbiological incidence, and all other organic and inorganic pollutants are some of the parameters that affect the quality of dried turmeric (Hailemariam, 2023).

Frequent quality revisions and commodity rejections at the export sector due to inadequate quality indicate that India's turmeric processing situation is not encouraging. Despite the fact that research on solar drying spices has advanced significantly worldwide, farmers and scientists have not yet discovered a standardized technique that is appropriate for the scientific processing of turmeric (Hailemariam, 2023). Due to improper handling and unsanitary drying techniques, there is a significant postharvest loss of spice content. Therefore, this study's goal was to create appropriate post-harvest techniques to raise turmeric's quality.

Examining the impact of post-harvest processing conditions on turmeric quality, it was discovered that while peeling resulted in a 30% mass loss, the resulting powder had more intense yellow and red hues than the unpeeled variety. In addition, compared to the control, the heat treatment of turmeric before dehydration shortened the drying time and produced a powder with less moisture, more curcuminoid pigments, and more intense yellow and red (Saha et al., 2022).

Turmeric, or the crushed rhizomes of *Curcuma longa L.*, is extracted solventily to produce curcumin, an orange-yellow crystalline powder. The extract is then purified by crystallization. Turmeric contains three to five percent coloring components. Curcumin, also known as 1,7-bis-(4-hydroxy-3-methoxy-phenyl)-hepta-1,6-diene-3,5-dione, and its desmethoxy- and bis-desmethoxy-derivatives in different ratios make up the majority of the product. Turmeric may include trace levels of naturally occurring oils and resins. Curcumin can be used as a food additive to create color.

Numerous biological benefits, including anti-inflammatory, antioxidant, and hypolipidemic properties, have been demonstrated for curcumin. Additionally, curcumin has been thoroughly investigated as a chemopreventive drug for a number of malignancies (Galano et al., 2009). Furthermore, it's been proposed that curcumin could help explain why colon cancer rates are lower in Asian nations than in other nations.

It has been noted that the amount of curcumin in different batches of turmeric powder varies. According to various commercially available turmeric samples, the proportion ranges from 1.06% to 5.70% (Haq et al., 2021). Numerous studies have demonstrated that the amount of curcumin in plants that produce turmeric may be influenced by soil characteristics such as nutrients, pH, and genus diversity (Srinivasan et al., 2016).

2.3 Significance of Curing in Turmeric Processing

Turmeric (*Curcuma longa L.*), often referred to as the "golden spice," has been an integral part of culinary traditions, particularly in South Asia, for centuries. Known for its bright yellow color, distinct flavor, and numerous health benefits, turmeric is widely used in cooking, medicine, and even cosmetics. However, the full potential of turmeric is unlocked through its careful post-harvest processing, one of the most critical steps of which is curing (Gagare et al., 2015). This process, essential for enhancing the spice's flavor, color, and shelf-life, plays a significant role in both the preservation and nutritional value of turmeric.

Curing, in the context of turmeric, refers to the process of treating freshly harvested rhizomes to prepare them for drying, grinding, and storage. The curing process involves two key steps: boiling or steaming the turmeric rhizomes and then drying them, typically under the sun or using controlled drying techniques. The purpose of curing is to deactivate enzymes that could otherwise degrade the quality of turmeric, improve the color of the rhizomes, and reduce the moisture content, making the turmeric suitable for long-term storage (Bezbaruah & Hazarika, 2014).

Curcumin was extracted using a variety of methods, including hydro-distillation, low pressure solvent extraction, Soxhlet, and supercritical extraction. It was discovered that the Soxhlet extraction (ethanol) produced the highest yield (27%, weight), while the hydro-distillation process produced the lowest yield (2.1%). Soxhlet extraction (ethanol/isopropyl alcohol) produced the highest concentration of curcuminoids (8.43%). The extracts with the highest antioxidant activity were the Soxhlet and low-pressure extracts (Srinivasan et al., 2016).

A central composite rotatable design based study reveals the effects of temperature (50–90°C), particle size (0.42–0.85 mm), mixing time (10–50 min), and solvent (ethanol) to meal ratio (10–50) on the experimental value of curcumin yield from turmeric (Curcuma longa L). The results showed that the experimental value of curcumin yield may vary between 4.49 and 12.89% (Shirsath et al., 2017).

A study of turmeric's dielectric characteristics revealed that they diminish as frequency increases (Aziz et al., 2019). Ionic losses cause the dielectric loss factor to drop quickly at frequencies lower than 1 GHz, while dipolar polarization causes it to rise at frequencies 1.5 GHz and higher. The trend of the deionized water is followed by the dielectric characteristics. The moisture content in the low frequency zone determines the penetration depth.

The impact of heat treatment on the fresh turmeric rhizome's total phenolic content (TPC), color value (yellowish-ness and brightness), polyphenol oxidase (PPO) activity, and curcuminoid was investigated. It was discovered that PPO's activity was also reduced during heat treatment, and that PPO was nearly inactivated after 30 minutes of heating at 80°C. Compared to fresh turmeric, the TPC of heat-treated turmeric after drying (powder) is noticeably higher.

When fresh turmeric rhizomes were heated to varying temperatures (60–100ºC) for varying lengths of time (10–60min), the browning was reduced, as seen by the increased brightness and yellowish-ness. High performance thin layer chromatography (HPTLC) was used to quantify the curcuminoids in the turmeric sample, which led to a decrease in the curcuminoid concentration of the sun-dried samples (Govindarajan & Stahl, 1980).

The total percentages of curcuminoids in commercially available turmeric powders were reported to range from 2.34 to 9.18 using an enhanced HPLC method for the detection of curcumin, demethoxycurcumin, and bisdemethoxycurcumin (Jayaprakasha et al., 2002).

Sliced turmeric was subjected to drying in solar conduction dryer. The drying behaviour of sliced samples showed more uniform falling in comparison to that of whole samples. The average effective moisture diffusivity were 1.852×10^{-10} m^2 s^{-1} for slab samples and 1.456×10^{-10} m^2 s^{-1} for solid samples. Page model was fitted as the best fitted thin layer drying model for the experimental drying data (Borah et al., 2017).

When comparing microwave-vacuum drying and hot air drying of turmeric slices, it was discovered that the former had a higher drying rate (0.13-0.65 kg/kg.min) than the latter at 60°C (0.06 kg/kg.min) (Li et al., 2019). Compared to 400 mbar (vacuum), microwave-vacuum drying at 300 mbar (vac.) produced a better drying rate and drying coefficient. After grinding dried turmeric slices, a Hunter colorimeter was used to evaluate the color (L*, a*, and b*) and compare it to hot air-dried turmeric powder. The lightness (L*) and yellowness (b*) of microwave-vacuum-dried turmeric powder were noticeably higher, whereas the redness (a*) was lower (Li et al., 2019).

2.4 Swell Drying by Integration of Instant Controlled Pressure Drop (ICPD)

According to Louka et al., (2004), instant controlled pressure drop (ICPD) was created to expand partially dried food particles and give them a porous structure. They enhanced the ICPD cycle for use with unique food ingredients in their article. According to (Allaf et al., 2012), emerging economies can gain a great deal from trials for the preservation, transportation, and storage of products that meet strict standards for nutritional and organoleptic quality as well as strict hygienic requirements. Shrinkage occurs when biological material dries. The water diffusivity via the porous structure drops dramatically as a result of shrinkage. According to the study, the compact structure is not appropriate for grinding. ICPD treatment, which often amplifies the entire equation, has been suggested and tried as a texturing method for partially dried material.

Using ICPD as a texturing pre-treatment improved the extraction efficiency of phenolic components from pomegranate peel (Ranjbar et al., 2016). Compared to the untextured sample, there was an increase in the total phenolic content (TPC) and antioxidant activity as a percentage of inhibition. Scanning electron microscopy (SEM) of the treated peel revealed a striking example of textural change.

Turmeric experiments, employing sun drying, freeze drying, and hot air drying are conducted and products were compared to explore how the dried product behaves during the drying and rehydrating processes reveals decrease in curcumin to be the highest in solar drying (72%), followed by hot air drying (61%) and freeze drying (55%) (Chumroenphat et al., 2021).

Table 2.1: Applications of experimental conditions of ICPD technology of different foods

Food matrix	Application	Experimental condition	Benefits	Reference
Milk, sodium caseinates Whey protein powder	Spray-drying (spraying coupling to ICPD and final drying)	Drying: 50°C, air stream 1.2 m/s	Increased the specific surface area, Improving the kinetics of final drying	(Mounir et al., 2015)
Onion chips Apple	Puffing (Hot air drying and ICPD treatment coupling to snacking)	Hot air drying: T = 40 °C, air flow: 1 m/s, final mc: 5% db.	Greater effective diffusivity, expand the compact structure, high quality powder	(Mounir et al., 2011)
Apple	Texturation (pre-drying plus ICPD and freezing)	Freezing: - 30 °C for 600 min, after thawed at 4 °C	Improvement in drying, Good textural properties	(Li et al., 2019)
Strawberry Green Moroccan pepper	Swell-drying (coupling ICPD to standard hot air drying)	Partially hot air dried at 50 °C until 18% db., air flow: 1.2 m/s, t = 8 h	Preserve nutritional quality, Improve quality	(Mounir et al., 2012)
Bacillus stearothermophilus	Decontamination (ICPD coupling to hot air drying)	Treatment time T = 100-150 °C t = 5 - 60 s	Destruction of microorganism cell wall	(Mounir, et al., 2013)

According to Table 2.1, the primary drying method used in food processing is connective hot air drying. But air drying has serious drawbacks, including poor end product quality and low operation performance, as well as a lengthy drying period and significant energy consumption. Thermal degradation, namely the compactness of texture at the end of the drying process, is linked to the low quality of the traditionally dried product.

2.5 Effects of ICPD Treatment on Product Quality

The first phase in the ICPD process is a brief heating step (10–60 s) that includes injecting saturated steam at high pressure (up to 1 MPa) onto a product that was first vacuumed. The product's moisture content rises by ~0.1g H_2O/g dry basis during this step, which also includes vapor condensation and product heating. Rapid contact between the steam and the sample is ensured by the initial vacuum, which enhances heat transmission. Compressed air may occasionally be utilized as a pressured agent, such as in the multicycle ICPD treatment. After the initial heating stage, the product's water automatically evaporates due to the sudden drop in pressure (0.5 $MPa.s^{-1}$) toward a vacuum (3-5 kPa) within a few 10–60 seconds. The water's auto-evaporation guarantees quick cooling, which stops sensitive components from degrading thermally and guarantees the excellent caliber of treated products (Hamoud-Agha & Allaf, 2019). A remarkable 1500–2000 kW cooling rate is possible.

2.6 Scope of Integrating ICPD Technology in Turmeric Processing

Turmeric occupies a vital position among locally consumed spices, and its processing has evolved from traditional to mechanized methods. Rhizomes are harvested once plants wither, either manually using hoe-type hand tools or mechanically with power tillers and tractor-operated diggers. Curing is the first essential step, involving boiling, drying, and polishing. Traditionally, rhizomes were boiled in open vessels, a method that consumed excess time, fuel, and water. Modern steam-based boiling systems now offer higher efficiency and better resource use. While dryers are available, sun drying remains common for large-scale operations. Finally, rhizomes are polished using power-operated machines to achieve brighter color (Balakrishnan et al., 2023). Beyond culinary uses, turmeric finds application, curcumin extraction, and essential oil production.

The traditional method of cooking in boiling water (WC), steam cooking (SC) using a model turmeric boiler, dipping the rhizomes in boiling water (Dip) for 10 minutes, manually slicing the fresh turmeric rhizomes to 3 mm thick, and sun drying were all part of the curing treatments (Adsare & Annapure, 2021).

2.7 Refractance Window Drying for Developing Quality Product

According to Nindo & Tang (2007), refractance window drying can be utilized to turn liquid foods and other biomaterials into powdered flakes with additional value. Compared to freeze drying, this innovative drying technique is easy to use and reasonably priced. This method produces goods with outstanding color, vitamin, and antioxidant preservation by drying fruits, vegetables, or herbs for about three to five minutes during preparation.

While comparing the refractance window drying method to freeze drying asserted that the ascorbic acid retention in refractance window dried strawberry purees was higher than in freeze dried ones, and that the carotene losses in refractance window dried carrot purees were higher than in freeze dried carrot purees. Additionally, it was observed that the overall perception of aroma in strawberries was changed by refractance window drying. came to the conclusion that refractance window drying has a high potential for drying fruit slices. They have found that refractance window drying takes less time to dry than tray drying, which is done at 65 ºC (Dadhaneeya et al., 2023). When compared to refractance window drying, air drying at 90 ºC causes more thermal damage. Although it displayed higher diffusivity than those dried by air, the product's color changed the same in both drying techniques, but in certain instances it did so less in refractance window drying.

2.8 Response Surface Methodology for Development of Quality Model

It is critical to enhance system performance and boost process yield without raising costs. Optimization is the term for the technique utilized for this. The standard procedure for identifying the ideal operating conditions while maintaining the others at the same level has a parameter modification. One-variable-at-a-time is the term for this method. This technique's main drawback is that it ignores the interactive effects between the variables and, therefore, fails to show the full impact of the parameters on the process. Response surface methodology (RSM) can be used to conduct optimization studies in order to solve this issue.

RSM is a statistical method for creating experiments that provide the necessary data in the least amount of time and money. Relating product attributes to regression equations that explain the relationships between input parameters and product attributes is the fundamental idea behind RSM (Mizubuti et al., 2000). Its application results in the quick and effective creation of new and enhanced goods and procedures. The parameters (temperature, air velocity, and thickness) for the minimum color from turmeric were standardized in the current study using RSM.

The RSM is essential for creating, generating, producing, and analyzing new scientific studies and products. It also helps to improve existing studies and products. RSM's most common uses are in industrial, biological, and clinical science, social science, food science, and physical and engineering science. Because RSM has a wide range of applications in the real world, it is crucial to understand how and where it originated in history. Box and Wilson proposed a first-degree polynomial model to approximate the response variable (Box & Draper, 1959).

RSM has been effectively used to optimize conditions in food and pharmaceutical research. The fundamental advantage of RSM is that it reduces the number of experimental trials required to assess various variables and their interactions. As a result, it is less arduous and time-consuming than other methodologies for process optimization (Manasa et al., 2023). Typically, it uses an experimental design, such as Box-Behnken (BBD), Central composite (CCD), or Doehlert designs (DD), to fit a second order polynomial using a least squares technique. An equation describes how the test factors influence the response and identifies the interrelationships between the variables.

RSM is useful for designing, developing, and formulating new products, as well as improving existing product design. It defines how the independent variables affect the processes, either alone or in combination (Lamidi et al., 2022). In addition to examining the impact of the independent variables, this experimental methodology creates a mathematical model that defines the chemical or biological processes.

RSM is a collection of mathematical and statistical approaches that can be used to define the relationships between the response and its independent factors. RSM specifies the impact of independent variables, either alone or in combination, on processes. In addition to examining the impact of the independent variables, this experimental methodology creates a mathematical model. The graphical perspective of the mathematical model has resulted in the term Response Surface Methodology.

It is feasible to divide the optimization research using RSM into three sections. The first stage is the preliminary work, which involves determining the independent parameters and their respective levels. The second stage involves selecting an experimental design, as well as predicting and verifying the model equation. The next step is to obtain the response surface and contour plots as a function of the independent parameters, as well as to determine the optimum spots.

RSM has been widely used to optimize processes in the food sector, such as drying and dehydration, biotechnological processes, biochemical analysis, which includes determining kinetic constants and investigating enzyme stability and kinetics, extraction procedures (Z. Chen et al., 2014).

The response surface methodology was used to explore the effects of temperature, air velocity, and loading density on the drying of infused apples and to establish the best conditions for hot air drying. Infused apple cubes dried at varying temperatures, air velocities, and loading densities in a manner similar to fresh and osmotically pre-treated apples. The hot air drying of infused apple cubes comprised of a very short constant rate period followed by two dropping rate periods. Temperature had the greatest influence on the samples' drying, followed by air velocity and loading density.

The optimal conditions for drying the infused apple cubes were a drying temperature of 80°C, air velocities of 1.50 to 1.85 m/s, and loading densities of 6.35 to 7.08 kg/m^2, resulting in short drying periods of 99-104 minutes. They also discovered that the equilibrium moisture content of the samples is unaffected by air velocity or loading density, but decreases with temperature. The utilization of the highest temperature (80°C) and moderate to medium air velocity and loading density might result in reduced drying durations for the infused apple cubes (Li et al., 2021).

Experiments were conducted to investigate the impact of pressure and temperature on the freeze drying kinetics of thick layers of apple slices. Using RSM, the optimal processing conditions for producing the highest quality freeze dried apple slices were discovered to be an operating pressure of 50 Pa and a heating temperature of 55°C (Hammami et al., 2021).

The performance of pectolytic enzymes during hydrolysis of a pectic substrate under test conditions was examined using RSM. The physical (temperature and pH) and chemical (volume of substrate and enzyme solution) factors were tuned utilizing a central composite design (Rodríguez et al 2007). In addition to substrate and enzyme concentrations as independent variables, quantities of substrate and enzyme solutions were employed

RSM was used to analyze simple enzyme kinetics by measuring two parameters (pH and cyclohexanone concentration), and 11 trials were carried out using a central composite circumscribed design (CCCD). A second order equation was derived from coded pH values, a coded-logarithmic transformation of substrate concentration, and the actual reaction rate (Baş & Boyaci, 2007).

2.9 Enumeration of Drying Process Effectiveness by Diffusivity

The drying of damp porous solids is a complex process involving linked heat and mass transfer phenomena. As a result, a wide range of parameters can influence drying behaviour, including drying temperature, air velocity, and relative humidity, as well as solid qualities like density, permeability, and porosity. Extensive characterization of drying behaviour using a strictly experimental method is a significant problem due to the enormous number of variables that must be considered. As a result, it is required to create a tool that can model product drying behavior and so expand on the findings of experimental drying studies.

This allows the impact of various variables on drying behaviour to be investigated and evaluated without the need for a large number of experimental tests. In addition, a thorough understanding of heat and mass movement in food products allows for improved design and control of processing and storage conditions. As drying operations progress from basic constant drying settings to sophisticated time-varying drying schemes, understanding temperature and moisture movement in the product can aid enhance drying methods and food quality.

Although not much attention is paid to solar drying for fruit and vegetables in industrialized nations, it can constitute a cost-effective environmentally friendly form of drying, even though it is often more labor intensive than other choices for the drying of fruits and vegetables. When it comes to hot air, there are two primary types of driers to consider: cabinet and tunnel. Freeze drying is a drying method that yields high-quality food with good scent retention and rehydration capabilities. It is utilized for high-value fruits and vegetables, but the expensive cost precludes this method from being extensively adopted.

In fruit and vegetable drying studies, such as those involving apples, strawberries, kiwifruits, and a variety of tropical fruits like chempedak, salak, and litchi the drying models suggested for assessing drying behavior are described as theoretical (Fick's second law of diffusion), semi-theoretical, and empirical. The semi-theoretical model most frequently used to forecast the drying kinetics of food products is based on Fick's second law (Inyang et al., 2018). They frequently provide accurate model parameter estimations. They are less complicated and don't require mass diffusivity, conductivity, or sample geometry assumptions. While empirical models have parameters with no physical meaning because they ignore the basics of the drying process, semi-theoretical models have limits in reporting drying time for specific drying conditions.

An experimental hot-air drier was used to study the drying behavior, shrinkage, and moisture distribution within cylindrical pieces of plantain of varied thickness and air temperatures (Talukdar et al., 2025). They discovered that both air temperature and plantain piece thickness had a substantial effect on drying pace, with the former having a greater influence.

The moisture diffusivity of olive waste cake was reported to range from 2.03×10^{-9} to 1.71×10^{-9} m^2/s. Mathematical models have shown to be quite beneficial for designing and analyzing these transfer processes during dehydration (Prasad et al., 2006). Some models include mathematical assumptions about minimal shrinkage and an isothermal process. With the added assumption that a constant value of effective moisture diffusivity may be utilized to represent the internal mass transfer phenomenon, analytical solutions to this model could be produced for simpler geometries. Effective diffusivity values in food materials vary according to the type of food, moisture content, and temperature. The effective diffusivity typically ranges from 1.05×10^{-8} to 52.4×10^{-11} m^2/s (Ben Haj Said et al., 2015).

The drying behaviour of sliced turmeric slices showed more uniform falling in comparison to that of whole samples. The average effective moisture diffusivity were found as 1.852×10^{-10} $m^2\ s^{-1}$ for slab samples and 1.456×10^{-10} $m^2\ s^{-1}$ for solid samples (Bora et al., 2015).

2.10 Turmeric Based Products

Turmeric tea has gained global attention as a functional drink, driven by interest in natural wellness and plant-based nutrition. Current trends emphasize its anti-inflammatory and antioxidant benefits, largely linked to curcumin, often enhanced with piperine for better bioavailability (Rosyidah & Andrianto, 2024). Formulations increasingly blend turmeric with ingredients like ginger, cinnamon, lemon, or honey to improve flavor and synergistic health effects. Ready-to-drink turmeric teas, instant powders, and cold-brew options are expanding in retail and e-commerce markets. Consumers are drawn to organic, sustainably sourced turmeric, reflecting broader clean-label and ethical sourcing movements. Innovative processing, such as low-temperature drying and encapsulation, helps retain color, flavor, and potency. Positioned between traditional herbal remedies and modern functional drinks, turmeric tea continues to grow as a daily wellness ritual across cultures.

The main product of turmeric dried whole rhizomes: mother rhizomes (egg-shipped primary rhizomes) and finger rhizomes (cylindrical and multibranched secondary rhizomes) are often cooked separately for 40-60 minutes under slightly alkaline conditions in copper, galvanized iron, or earth vessels before being sun-dried on bamboo mats for 10-15 days to reduce moisture content to 10-11%. Ground turmeric: Powder made from dried finger rhizomes (60-80 mesh). Spice: used alone or in curry powders and pastes (Singhal et al., 2016). Dye: for food, textiles, and cosmetics. Medicine: used in Ayurveda and Chinese medicine as a nutritional supplement. Turmeric Oils: Steam distillation or supercritical CO^2 extraction can be used to extract the dried rhizomes (ground turmeric) or leaves. It's used as a spice, medication, and a nutritional supplement (Tiwari et al., 2022).

Turmeric oleoresin is extracted from dried rhizomes by solvent extraction with acetone, dichloromethane, 1,2-dichloroethane, methanol, ethanol, isopropanol, and light petroleum (hexanes), or supercritical CO^2 extraction. Graded according to curcuminoids amount or color value. It is used as a food coloring, medication, and nutritional supplement. Curcumin is extracted from pulverized turmeric rhizomes using solvents and then purified through crystallization. Acetone, carbon dioxide, ethanol, ethyl acetate, hexane, methanol, and isopropanol are all acceptable solvents (Amalraj et al., 2017). It is used as both a medication and a nutritional supplement.

2.11Turmeric Infusion and Evaluation for Curcumin Bioavailability

Infusion tea is made up of three major components: green tea, turmeric, and ginger or pepper. Turmeric tea and green tea have significant benefits for arthritis (Chavalittumrong & Jirawattanapong, 1992). Turmeric tea contains potent anti-inflammatory effects that can help reduce inflammation and swelling in arthritis patients. Turmeric tea offers therapeutic characteristics, such as antioxidants and anti-inflammatory effects, which could help prevent cancer. Turmeric's therapeutic qualities may help improve the immune system. Lowering LDL cholesterol will help lower your chances of getting major diseases including heart disease and stroke (Das et al., 2019).

The numerous formulations meant to increase curcumin bioavailability can be classified into a number of categories. Curcumin is fat soluble, therefore ingesting it with a fatty meal improves absorption (Tabanelli et al., 2021). Early attempts to improve absorption included the inclusion of turmeric oil and a tiny amount of piperine to activate the gastrointestinal system and prevent curcumin efflux. Which resulted in a minor incremental improvement in curcumin absorption (Das et al., 2019). There are three major forms of formulation that occur technically viz., lipid additives include turmeric oil, piperine, and turmeric oleoresin. Adsorption and dispersion on matrices include whey protein, rice flour, and silica dioxide, among others. A variety of curcumin micellar and nanoparticle formulations were developed using ingredients such as Tween 80, polysorbate 80, ceramic particles, polyethylene glycol (PEG), alginate, poly (lactic-co-glycolic acid) (PLGA), omega-3 fatty acids, chitosan, and others (Yakubu & Pandey, 2024). Newer formulations use curcumin adsorption and dispersion onto matrices like γ-cyclodextrin. Whey protein, rice flour, stearic acid, and other ingredients.

2.12 Summary of Chapter 2

Turmeric, often referred to as the "golden spice," has held a revered place in human history for centuries. Across Indian and Chinese traditional medicine, turmeric was valued not only for its vibrant color and culinary appeal but also for its therapeutic benefits. Modern scientific inquiry has confirmed much of this ancient wisdom, showing that curcumin, the primary bioactive compound in turmeric, carries powerful antioxidant, anti-inflammatory, anti-cancer, anti-diabetic, and neuroprotective properties. Research highlights that persistent low-grade inflammation underpins conditions such as cancer, heart disease, Alzheimer's disease, and metabolic syndrome. Curcumin, by suppressing inflammatory pathways and neutralizing free radicals, emerges as a protective agent against these ailments. Further, it has been shown to boost brain-derived neurotrophic factor, supporting memory and learning, while also displaying potential in alleviating arthritis, depression, and other chronic disorders associated with aging. An important discovery is that piperine, a compound found in black pepper, enhances curcumin absorption by nearly two thousand percent, unlocking its full therapeutic potential.

Taken together, turmeric represents a unique convergence of heritage and innovation. Its journey from traditional medicine cabinets to modern nutraceutical shelves illustrates the evolving relationship between food, health, and technology. Centuries of cultural wisdom have been validated by modern pharmacology, while technological advances in processing and formulation ensure that turmeric's benefits are preserved and amplified. From the farm fields to global markets, turmeric continues to embody resilience and adaptability, offering both scientific intrigue and tangible health benefits. The challenge moving forward lies in ensuring sustainable cultivation, standardized processing, and equitable distribution so that the golden spice can truly serve as a bridge between tradition and modern wellness.