Temperature Dependent Curcumin Extraction and Valorization of Turmeric Biomass

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***Abstract*—Turmeric (Curcuma longa L.) is a valuable medicinal and industrial crop widely recognized for its bioactive compound, curcumin, which possesses antioxidant, anti-inflammatory, antimicrobial, and anticancer properties. The increasing demand for natural therapeutics and food additives has intensified research on efficient extraction, characterization, and utilization of curcumin. This review summarizes recent advances in curcumin extraction technologies, analytical techniques, and process optimization strategies Conventional solvent extraction methods using ethanol Methanol and Acetone have demonstrated curcumin yields ranging from 2% to 12.9%, with extraction efficiency significantly influenced by temperature, particle size, extraction time, and solvent-to-solid ratio. Modern approaches, including ultrasound-assisted extraction, pulsed electric field (PEF), high hydrostatic pressure (HPP), ohmic heating and supercritical fluid extraction, have shown potential to enhance curcuminoid recovery while preserving product quality. Advanced analytical tools such as UPLC-MS/MS, FT-NIR spectroscopy, PCA, OPLS-DA, HPCL, UV-Spectroscopy and hierarchical cluster analysis have enabled rapid quantification, quality assessment, and geographical discrimination of turmeric samples based on curcuminoid profiles. Furthermore, turmeric processing residues rich in starch and biomass present opportunities for value-added applications in food, pharmaceutical, and bioenergy industries. The reviewed studies demonstrate that integrating optimized extraction processes with modern analytical and biotechnological approaches can improve curcumin recovery, product standardization, and economic returns for turmeric producers. These developments support the sustainable utilization of turmeric as a high-value agricultural and industrial resource.**

***Index Terms*—Curcumin, Turmeric (Curcuma Longa), Extraction Techniques, Curcuminoids, Process Optimization, solvent, Color pigment and Industrial applications.**

I. INTRODUCTION

Curcumin, the principal bioactive compound of turmeric (Curcuma longa L.), has received considerable attention from researchers and industry because of its wide range of pharmacological and functional properties. It is recognized for antioxidant, anti-inflammatory, antimicrobial, and anticancer activities, which have made it an important natural compound in food, pharmaceutical, and nutraceutical applications. Curcumin is one of the major curcuminoids found in turmeric rhizomes, together with demethoxycurcumin and bisdemethoxycurcumin, and it contributes largely to the intense yellow-orange pigmentation that characterizes turmeric powder and extracts. The amount of curcumin recovered during extraction depends greatly on the conditions used in processing, especially temperature, extraction duration, particle size, and the type of solvent employed. Among these factors, temperature plays a particularly important role because moderate heating can weaken plant cell walls, improve mass transfer, and increase the diffusion of curcumin into the extraction medium. At the same time, temperatures that are too high or applied for too long may accelerate the breakdown of curcuminoids, reduce purity, and diminish biological activity. For this reason, careful control of extraction temperature is necessary to achieve high yield while preserving compound quality. A clear understanding of how temperature affects curcumin recovery is therefore essential for designing efficient and scalable extraction systems for industrial use. Beyond the recovery of curcumin itself, the solid residue remaining after extraction should also be considered a valuable resource rather than a waste product. This turmeric biomass still contains carbohydrates, dietary fiber, proteins, minerals, and other residual phytochemicals that can be further processed or reused in different applications. It may serve as a raw material for bioenergy generation, livestock feed, compost and organic fertilizer production, or the development of other value-added products. Using both the extracted curcumin and the remaining biomass in a coordinated manner supports sustainable processing, reduces environmental burden, and aligns with circular economy principles by promoting resource efficiency and waste minimization in turmeric-based industries.

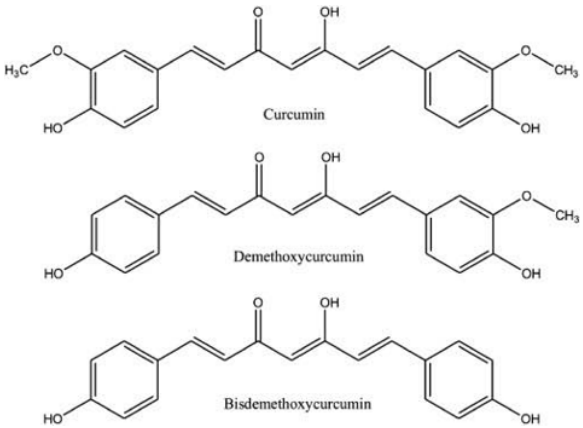

Fig 1: Chemical structure of Curcumin

II. MATERIAL AND METHADOLOGY

The extraction of curcumin from turmeric (Curcuma longa L.) has been the focus of numerous studies aimed at improving yield, efficiency, and sustainability. Conventional extraction methods, including maceration and Soxhlet extraction, have traditionally been used with solvents such as ethanol, methanol, acetone, and hexane. Although these techniques can effectively recover curcumin, they often require extended extraction times, large quantities of solvent, and considerable energy input. To address these limitations, researchers have increasingly adopted advanced extraction technologies such as ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE). These approaches enhance mass transfer, shorten extraction time, and often result in higher curcumin recovery. The efficiency of extraction is influenced by several operational factors, including solvent selection, extraction temperature, extraction duration, particle size of the turmeric powder, solvent-to-solid ratio, and the number of extraction cycles. Quantification and characterization of curcumin are commonly performed using analytical techniques such as high-performance liquid chromatography (HPLC), UV–Visible spectrophotometry, and thin-layer chromatography (TLC). In recent years, greater emphasis has been placed on the development of environmentally sustainable extraction processes that utilize safer solvents, enzymatic treatments, and eco-friendly additives. Beyond its extraction, curcumin has attracted significant interest because of its antioxidant, antimicrobial, and coloring properties, leading to applications in pharmaceutical, food, and textile industries. Overall, the available literature indicates that careful optimization of extraction conditions is essential for achieving high curcumin yields while maintaining process efficiency and environmental sustainability.

Fig: 2 Setup of extraction And Curcumin Sample

III. RESULT AND DISCUSSION

The findings reported across the literature demonstrate that curcumin extraction efficiency is governed by a complex interplay of extraction conditions and pretreatment strategies. Temperature is consistently identified as one of the most influential parameters, affecting both mass transfer and compound stability. Moderate extraction temperatures generally enhance curcumin solubility and diffusion from the turmeric matrix, whereas excessively high temperatures may accelerate degradation reactions. Nevertheless, several studies have shown that extraction at temperatures close to the boiling point of water can substantially increase curcumin release, particularly under acidic conditions, due to enhanced solvent penetration and diffusivity. The extraction medium pH also plays a critical role in determining curcumin recovery. Although alkaline conditions improve curcumin solubility and facilitate rapid release into the extraction medium, they simultaneously promote molecular instability and degradation. In contrast, acidic environments provide greater protection against degradation and support higher curcumin retention during prolonged extraction periods, making them more favourable for maintaining extract quality.

Extraction duration has been reported to exert both positive and negative effects on curcumin yield. Short extraction periods are generally sufficient to achieve substantial recovery, while prolonged processing may result in oxidative, thermal, or hydrolytic degradation of curcuminoids. Similarly, reducing particle size improves extraction performance by increasing the available surface area for solvent interaction and facilitating mass transfer. However, excessively fine particles may alter extraction dynamics and provide limited additional benefits. Solvent selection remains another important determinant of extraction efficiency. Among the commonly used solvents, ethanol frequently demonstrates superior performance because of its compatibility with curcumin polarity, extraction efficiency, and suitability for food and pharmaceutical applications. Optimization studies further indicate that intermediate temperatures, moderate extraction times, smaller particle sizes, and higher solvent-to-solid ratios generally contribute to improved curcumin recovery.

Variety	Solvent	% of Curcumin
AGR Rehydrate Salem turmeric	Ethanol	04.68%
Pure Yellow Turmeric	Ethanol	2.65%
Pure white Turmeric	Ethanol	00.08%

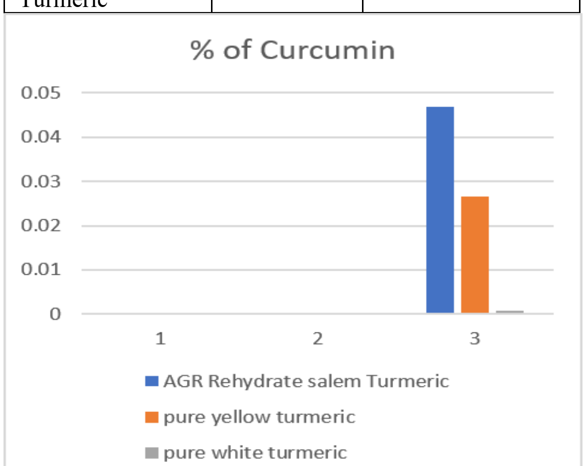

Fig: 3 graph of % of Curcumin

The application of emerging extraction technologies has attracted considerable interest as a means of enhancing extraction efficiency while reducing processing intensity. Ultrasound-assisted extraction promotes cavitation-induced disruption of plant tissues and improves solvent penetration. However, the literature indicates that excessive ultrasound energy may generate reactive species and localized high-energy conditions that contribute to curcumin degradation, thereby limiting overall extraction efficiency. In contrast, pulsed electric field treatment has shown greater potential for preserving curcumin while enhancing extraction. By inducing electroporation and increasing cell membrane permeability, PEF facilitates the release of intracellular compounds without causing extensive structural damage to the plant material. Consequently, significant improvements in curcumin recovery have been reported following PEF pretreatment, particularly under acidic extraction conditions. Similar benefits have also been observed with high-pressure processing and ohmic heating, which improve cell disruption and mass transfer while maintaining the integrity of thermally sensitive compounds.

The observed improvements in extraction efficiency can be explained by the structural characteristics of turmeric. Curcuminoids are embedded within a complex matrix composed of starch, polysaccharides, proteins, fats, and oleoresins. Effective extraction therefore requires disruption of this matrix to increase solvent accessibility and facilitate the release of bioactive compounds. Physical, thermal, chemical, and electrical pretreatments contribute to matrix disintegration through different mechanisms, ultimately enhancing curcumin availability. Analytical techniques including high-performance liquid chromatography (HPLC), Fourier-transform infrared spectroscopy (FTIR), ultraviolet-visible spectroscopy (UV–Vis), and thin-layer chromatography (TLC) have been widely employed to evaluate extraction performance and characterize curcuminoid composition. These studies also reveal substantial variability in curcumin content among turmeric cultivars, highlighting the influence of botanical origin on extraction outcomes. Overall, the evidence suggests that maximizing curcumin recovery requires careful optimization of extraction parameters to enhance mass transfer while minimizing degradation, with emerging non-thermal technologies offering promising opportunities for improving extraction efficiency and product quality.

IV. CONCLUSION

Curcumin, the major bioactive compound of turmeric (Curcuma longa L.), has gained significant attention because of its wide-ranging applications in food, pharmaceutical, cosmetic, and textile industries. The reviewed literature highlights that turmeric processing, particularly turmeric powder production and curcumin extraction, holds promising economic potential. From a techno-economic perspective, turmeric powder production is comparatively less risky and more financially stable than large-scale curcumin extraction, as indicated by favourable benefit–cost ratios and a higher probability of achieving positive net present value. Adequate raw material availability among farmer producer organizations further strengthens the feasibility of both processing pathways. However, the success of curcumin production largely depends on extraction efficiency, where conventional solvent methods using acetone, ethanol, and methanol have shown satisfactory results, with acetone often performing better.

In recent years, advanced extraction techniques such as ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) have emerged as more efficient and sustainable alternatives to conventional methods. These techniques reduce processing time, enhance extraction yield, and better preserve curcuminoids and phenolic compounds, making them more suitable for industrial applications. Extraction performance is strongly influenced by parameters such as solvent type, temperature, particle size, extraction time, solvent-to-solid ratio, and pH, and proper optimization of these factors significantly improves curcumin recovery. Although aqueous extraction is environmentally friendly, its application is limited due to the poor solubility of curcumin in water; however, suitable pretreatments and acidic conditions can enhance its efficiency.

Beyond extraction, curcumin also shows strong potential as a natural colorant and bioactive compound due to its antioxidant and antimicrobial properties, which support its use in food preservation and health-related applications. It is also effective as a textile dye for both natural and synthetic fibres, producing stable yellow shades with good fastness properties. Overall, the literature indicates that UAE and MAE offer clear advantages over conventional extraction methods in terms of efficiency, sustainability, and processing time. Future research should focus on optimizing extraction conditions, improving compound stability, reducing production costs, and scaling up green extraction technologies. These advancements will enhance the industrial utilization of turmeric and support its sustainable commercialization as a valuable natural source of bioactive compounds.

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