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Extraction methods and applications of curcumin: A review

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Abstract
Turmeric contains curcumin, a bioactive compound. It has properties like anti-oxidant, anti-inflammatory, antiviral, antibacterial, antifungal, and antimicrobial effects. Curcumin has a wide range of applications in the health, food, and pharmaceutical industries due to those properties. Soxhlet extraction, maceration, hydro distillation, microwave aided extraction, enzyme assisted extraction, ionic liquid based extraction, and supercritical fluid extraction are all used to extract curcumin, which is employed in a variety of sectors. This review focuses on the applications of curcumin, their mode of action in the treatment of various diseases, comparing different methods of curcumin extraction in terms of the kind of solvent employed, extraction time and efficiency, and the future scope of investigation.

Keywords: Turmeric, curcumin, applications of curcumin, curative actions of curcumin, extraction of curcumin

Introduction

In today's era, the population is getting affected by numerous health-related and metabolic disorders. For these, natural and household remedies are given much more consideration. And herb, spices and condiments contribute more or less to this. Even in COVID-19 pandemic, where almost every individual life is affected in one or the other way and vaccines are formulated a little later. Herbs, spices and condiments have given support in boosting the metabolic process of the body (Rattis *et al*., 2021) [44]. Turmeric is one such spice. It is a flowering plant of the family, Zingiberaceae with scientific name *Curcuma longa* (Heffernan *et al*., 2017) [14]. Commonly it is known as the golden spice because of the golden yellow color produced by the curcumin. Curcumin is the primary bioactive compound present in turmeric. It possesses properties like anti-oxidative, anti-inflammatory, anti-viral, anti-bacterial, anti-fungal, and anti-microbial (Altunay *et al*., 2020) [4] that help to prevent cancer, viral- infection, cough, cuts, and wounds, and neurological disorders (Nair, 2019) [30]. These properties allow its use in the food, medicinal and pharmaceutical industries. The economic part of turmeric is the rhizome, that grows under the soil. A friable well-drained and loamy red soil condition in the period of May to June is needed for its proper growth and production (Akter *et al*., 2019) [3]. The various significant varieties of turmeric according to the availability and state of production are Lakadong, Suvarna, Suguna, IISR Pragati, IISR Kedaram, Prabha, Erode turmeric (IISR, 2015) [19].

India is a major producer, consumer, and exporter of turmeric producing around 389 thousand tonnes of turmeric in 246 thousand hectares of land with a productivity rate of 5646.34 kg per hectare (2018-19). Whereas USA is the major importer of Indian turmeric followed by countries like UAE, UK, Iran, Bangladesh and Malaysia (MOFPI, 2021) [28].

The present paper is a review-based study based on the extraction methods, and nutritional composition of the bioactive compounds of turmeric and its further utilization in industries along with future prospects.

Historical background

Turmeric has long been in use by humans for a variety of purposes. The use of turmeric as an ointment to cure the symptoms of poisoned foods is already mentioned in Susruta's Ayurvedic Compendium, by Marco Polo since 250 B.C and in Chinese book by Pent-Sao in the 7th century. He has referred to turmeric, an Indian saffron that can be used for coloring white or faded fabrics (Rathaur *et al*., 2012) [43]. In Ayurveda, Siddha, and Unani it has been known by different names as Jayanti (victorious over ailments), Matrimanika (as beautiful as moonlight), Haldi in north and manjal in south (Kaur, 2019) [21].

Nutritional and phytochemical composition of turmeric:

Turmeric is known for its medicinal value because of the presence of curcuminoids. It is the major bioactive compound present in turmeric. Three most important constituents of curcuminoids are curcumin (75-80%), demethoxycurcumin (10-25%), bisdemethoxycurcumin (3-5%) (Horosanskaia *et al*., 2020) [16]. Phytochemicals like alkaloids (0.76%), saponins (0.45%), tannins (1.08%), sterols (0.03%), phytic acid (0.82%), flavonoids (0.40%) and phenols (0.08%) (Nisar *et al*., 2015) [32] are also present in it. These are known to exhibit properties like anti-oxidative, anti-inflammatory, and anti-microbial.

The moisture in it is present in the range of (8.92%), proteins (9.40%), carbohydrates (67.38%), fats (6.85%), crude ash (2.85%),.and crude fiber (4.60%), respectively (Hanif Mughal, 2019) [12]. Apart from this, it also contains niacin (2.3%), thiamine (0.89%), riboflavin (0.16%) and minor amounts of biotin and folate (Ikpeama *et al*., 2014) [18]. Amongst various minerals potassium is present at the highest concentration of 2374 mg, phosphorous at 276 mg, calcium at122 mg, iron at 46.08 mg, sodium at 24.41mg, zinc at 2.64 mg, and copper at 0.44 mg (Mishra & Goel, 2020) [27].

Applications of Turmeric

Medicinal Applications

The presence of curcumin in turmeric can be used as a natural source to treat a number of human ailments, including neurological disorders such as Alzheimer's and Parkinson's disease, cancer, as well as inflammatory disorders such as bowel disease, and rheumatoid arthritis. Curcumin is also useful in the treatment of non-communicable disorders such as coronary artery disease, obesity, and diabetes (Table. 1) because of its features such as apoptosis induction, anti-inflammatory, and anti-oxidative. It can also be also used in conjunction with antiretroviral (ARV) medications to treat HIV and in anti-cancerous medicines.

Table 1: Curative action of turmeric against various human diseases

Diseases	Curative Action	References
Alzheimer disease	Curcumin binds to amyloid-beta protein, deposition of which leads to plaque development	Zachariah & Leela, 2015 [53]
Parkinson's disease	Curcumin controls the abnormal buildup of a protein known as α-synuclei, which results in the production of Lewy bodies (LBs) and eventually Parkinson's disease.	Bhat *et al*., 2019 [6]
Inflammatory bowel disease (IBD)	The two most common types of IBDs are Crohn's disease (CD) and ulcerative colitis (UC). Both have an effect on the GI tract and the intestinal epithelium. Curcumin treatment improves patients outcomes because of its anti-inflammatory properties	Aguas *et al*., 2016 [1]
Coronary artery disease	Curcumin consumption lowers blood triglyceride, LDL, reducing the risk of coronary artery disease.	Ganjali *et al*., 2017 [9]
Obesity and diabetes	Obesity is caused by lifestyle changes and, in some cases, low-grade chronic inflation, which leads to insulin resistance and, eventually, diabetes. Curcumin reduces insulin resistance and hyperlipidemia, resulting in decreased chances of diabetes.	Hotamisligil, 2017 [17]
Rheumatoid Arthritis (RA)	Curcumin inhibits the expression of pro-inflammatory cytokines, and adhesion molecule genes, resulting in reduced joint inflammation in RA patients.chemokines, and adhesion molecule genes, resulting in reduced joint inflammation in RA patients.	Momtazi-Borojeni *et al*., 2018 [29]
HIV- AIDS	Antiretroviral (ARV) medications are used in the treatment of AIDS. Curcumin was given to ARV therapy patients who showed reduced side effects from the medicines, as well as enhanced lipid content and insulin sensitivity.	Prasad & Tyagi, 2015 [39]
Cancer	Turmeric has recently been employed in leukemia chemotherapies. Leading to cell death via the apoptotic autophagy pathway.	Kouhpeikar *et al*., 2019 [22]
Anxiety and depression	Curcumin works as an antidepressant by decreasing the production of mono amine oxidase-A and mono amine oxidase-B enzymes, causing a rise in norepinephrine, serotonin, and dopamine levels.	Hay *et al*., 2019 [13]
β-thalassemia major	Curcumin decreases oxidative stress and aids in disease cure by acting as an anti-oxidant and iron chelator.	Nasseri *et al*., 2017 [31]

Food Industry Applications

FAO and WHO joint association committee in the 61st summit recognized curcumin as a di-cinnamoyl methane dye that can be used as a food additive in 2004. It can be used up to a dosage range of 0-3 mg/kg of body weight (Jiang *et al*., 2021) [20]. In food products like rice, dairy products,
meat products, pastries and canned fish it can be used as a natural food coloring agent (Hewlings & Kalman, 2017) [15].
It helps to extend the shelf life of numerous food products because of its antimicrobial properties
And also acts as a preservative in cooked meat items. Pathogens, like *Escherichia coli*, *Staphylococcus aureus* and *Salmonella* sp., have shown resistance to it (Sandikci Altunatmaz *et al*., 2016) [47].

Other Applications

The pharmaceutical and cosmetic industries are two other areas where turmeric is gaining popularity.
Turmeric is considered as the earliest cosmetic used by the humans. It is used to protect the skin from ageing, wrinkles, sun damage, and moisture loss, as well as in treating nails, and lips against UV rays, inflammation, and other external influences in shampoos, oil serums, foundations, masques, and conditioning lip balms (Gopinath & Karthikeyan, 2018) and (Rafiee *et al*., 2019) [11, 41].

Purification of Curcumin

Curcumin as extracted from turmeric can be used in various industries. There are two extraction methods of curcumin, which include conventional and modern ways. The conventional extraction method is based on the extraction using solvents which includes soxhlet extraction, maceration, and hydro-distillation.

Soxhlet extraction was first designed in 1879 for the purpose of extracting lipid, however, it serves as the most popular method to extract a wide range of bioactive compounds from natural plants with higher extraction efficiency **(**Dutta *et al*., 2015**)** [7]. In case of curcumin, the extraction using soxhlet was done by using solvents like aqueous, ethanol and methanol. In a report by (Patil *et al.*, 2019) [37] ethanolic extracted curcumin showed a yield of 88.96 mg/g and (Sahne *et al.*, 2016) [45] reported a yield of 6.9% of acetone extracted curcumin.

Maceration extraction is the process of extraction of compounds using continuous stirring. Acetonic extraction yields around 50% of curcumin (Nurhadi *et al.*, 2020) [33].

Hydrodistillation is also one of the conventional approach in extracting of bioactive compounds and essential oils. Turmeric because of its pungent flavor cannot be directly added to the food products. So hydrodistillation is done to obtain deodorized or flavor less turmeric and embedded in food products (Silva *et al.*, 2005) [50].
These traditional methods are still in use but due to the limitation of high temperature usage, consumption and evaporation of higher amounts of solvents, long hours of extraction time, and lower yield limits their use. This further promotes the use of high extraction efficiency and eco-friendly methods (Zhang *et al*., 2019) [54]. Advanced methods use less dangerous volatile organic solvents. These solvents are capable enough to be renewed, are a source of energy-saving and maintains pollution free environment. The commonly used advance extraction methods include: microwave-assisted extraction, ultrasound-assisted extraction, enzyme-assisted extraction, ionic liquid based extraction and supercritical fluid extraction (Sahne *et al*., 2017**)** [46].

Ultrasound-assisted extraction is the new approach to green technologies and has many advantages including higher yield, short extraction times, and low temperature usage. The principle of this technique involves acoustic cavitation that is promoted by the system. Due to the waves produced from the ultrasound source, pressure changes occur that lead to the formation and collapse of microbubbles in the medium which finally causes micro jetting. The effects of micro jetting on the system include surface peeling, erosion, and particle breakdown. This effect promotes various applications such as extraction of different compounds, microbial and enzymatic inactivation, and physical modifications (Martins Strieder *et al*., 2019) [26]. Studies of (Shirsath *et al*., 2017) [48] shows that ultrasonic power of 250 W and ultrasound frequency of 22 kHz with ethanol as the solvent yields (72%) of curcumin. The yield obtained is higher compared to other conventional methods with lower extraction time of 1 hour.

Microwave-assisted extraction (MAE): Electromagnetic waves with a wavelength of 1meter to 1mm along with a frequency range of 0.3GHz to 300 GHz are referred as microwaves. The principle of this extraction is microwave heating which is caused by the dispersion of electromagnetic waves, and results in accelerated mass and heat transfer, allowing for improved transport of solutes from the interior of plant materials to the extraction solvent medium (Praveen *et al*., 2019) [40]. (Laolkuldilok *et al*., 2015) [24] states that the microwave power of 900 watts with ethanol solvent yields curcumin of about 163-183.77 mg/g with a lower extraction time of about 1 min.

Enzyme assisted extraction: A much greener approach of curcumin extraction from turmeric is enzyme assisted extraction. It involved the breakdown of cell wall of plants along with the help of enzymes (α-amylase, glucoamylase, amyloglocosidase, pectinases, cellulases, and hemicellulases) secreted by microorganisms (Marathe *et al*., 2017) [25]. Selection of specific enzyme depends upon various factors namely temperature, time, pH and enzyme concentration. (Kurmudle *et al*., 2013) [23] showed that 3% α-amylase when used at the pH 5.0 and 2% glucoamylase at a pH of 4.5 with an incubation period of 5 h with 8 h with acetone as a solvent led to an increased yield of curcumin by 26.04% and 31.83%.

Ionic liquid-based extraction: The concept of “greener solvents” is the emerging trend to the conventional solvents in the aspect of environmental protection. Ionic liquids posseses unique properties like low volatility, thermal stability, and preserving of various biological activities (Passos *et al*., 2014) [36]. Thus are combined with other extraction methods of curcumin, such as ultrasound, microwave and enzyme assisted extraction with improved extraction efficiencies. (Xu *et al*., 2015) [52] used the ionic liquids [Bmim]Br, [Him]Br, [Omim] Br, and [Omin][BF4] as solvents for Ultrasound Assisted Extraction of curcuminoids and discovered that the yield was 6.14 percent, which was greater than utilizing 85 percent ethanol-based Ultrasound Assisted Extraction (4.40 percent). The carbamate ionic liquid-based Enzyme Assisted Extraction (EAE) was used in the work of (Sahne *et al*., 2017) [46] to extract curcumin from enzyme-pretreated turmeric. Under the same operating circumstances (25°C and 2 hours), the extraction yield was 5.73 percent, which is higher than the extraction yield achieved with acetone (3.11 percent).

Supercritical fluid extraction (SFE): The supercritical fluids are used as extraction solvents in this technique. Supercritical carbon dioxide (CO2) is a popular extraction solvent since it is non-toxic and environmentally friendly. When the temperature and pressure of a gas or liquid reach their critical values, supercritical fluid is formed. SFE has advantages over traditional procedures in that it uses less solvent, takes less time to extract, is easier to automate, and enhances selectivity. (Garavand *et al*., 2019) [10]. Because the amount of curcumin extracted with pure supercritical CO2 was insufficient, it was mixed with other solvents such as ethanol, methanol, and acetone. (Belwal *et al*., 2020) [5] developed a methodology to extract curcumin using supercritical CO_2 with 10% ethanol and obtained 1.46% curcumin yield. Following the SFE procedure, the Pressurised Liquid Extraction (PLE) method was used to recover curcumin, according to (Osorio-Tobón *et al*., 2016). The study also claims that combining the SFE, PLE, and supercritical antisolvent procedures resulted in a high curcumin output (7.6 percent*)*.

Table 2: Comparing various types of extraction

Extraction methods	Type of extraction	Curcumin yield	References
Soxhlet extraction	Ethanol as solvent With extraction time of 12 hours maintained at temperature of 60^0C	88.96 mg/g (100%)	Patil *et al*., 2019 [37]
	Acetone as solvent with extraction time of 8 hours maintained at 60^0C	6.9%	Sahne *et al*., 2016 [45]
Ultrasound Assisted Extraction (UAE)	Ethanol as solvent, maintained at 35^0C for 1hour. Ultrasonic power of 250 W and frequency of 22 kHz applied.	9.18 mg/g (72%)	Shirsath *et al*., 2017 [48]
	Ethanol as solvent, maintaining at 40^0C for 2 hours. Ultrasonic power of 240 W and frequency of 22 kHz was applied.	3.22 mg/g (73.18%)	S.S. Patil *et al*., 2021 [38]
Microwave Assisted Extraction	Microwave power of 900 W applied for 1min with ethanol as solvent.	163-183.77 mg/g	Laokuldilok *et al*., 2015
	Microwave power of 140 W applied for 4 min with acetone as solvent	4.98%	Jiang *et al*., 2021 [20]
	Ethanolic extraction using microwave power of 160W for 30 min	10.32%	Marin *et al*., 2021
Enzyme Assisted Extraction	Acetone extraction pretreated with 3% α-amylase at the pH 5.0, incubation period of 5h with total extraction time of 8h	26.04%	Kurmudle *et al*., 2013 [23]
	Acetone extraction pretreated with 2% glucoamylase at pH 4.5, incubation period of 5h with total extraction time of 8h	31.83%	
Ionic liquid based extraction	Using of ionic liquid [Omim]Br as solvent for Ultrasound Assisted Extraction with ultrasonic power of 250W for duaration of 90 min	6.14%	Xu *et al*., 2015
	Using of carbamate ionic liquids along with enzyme pretreated turmeric	5.73%	Sahne *et al*., 2017 [46]
Supercritical Fluid Extraction (SFE)	Maintaining of super critical CO_2 at a pressure of 30 MPa , temperature of 50^0C along with 10%ethanol for 300 min	1.46%	Wakte *et al*., 2011 [51]
	Essential oils are removed using SFE techniques and Pressurized Liquid Extraction(PLE) with ethanol as solvent is used to recover curcumin	4.3%	Osorio-Tobon *et al*., 2014 [35]
	Integration of SFE, PLE and super critical anti solvent process	7.6%	Osorio-Tobon *et al*., 2016 [34]

Future scope

Being aware on all the important properties of turmeric, it's widely used in the preparation of foods in South Asian countries from early days. Whereas in other parts of world the curcumin supplements are used either in the form of powders or capsules. However, its limited solubility and absorption in the free form in the gastrointestinal tract, as well as its quick biotransformation into inactive metabolites, (Kunnumakkara *et al*., 2019) [2] severely limit its effectiveness as a health-promoting agent and dietary supplement. Recent advancements in curcumin micro- and nano-formulations with substantially improved absorption resulting in desirable blood levels of the active forms of curcumin now allow for a wide range of potential applications, including pain treatment and tissue protection (Stohs *et al*., 2020). Studies of (Hewlings and kalman 2017) [15] shows that the bioavailability can be increased by combining of curcumin with other enhancing agents. Their study shows that forming of Piperine and curcumin complex improves the bioavailability of curcim by 2000%. In comparison to unformulated conventional curcumin, a formulation containing a combination of hydrophilic carrier, cellulosic derivatives, and natural antioxidants greatly boosts curcuminoid appearance in the blood (Jager *et al*., 2014). Studies on enhancing curcumin formulations for human ingestion and boosting its bioavailability are gaining traction in the future.

Conclusion

Curcumin has a wide range of health advantages as well as uses in a variety of sectors. More research is being done in the area of encapsulation to address the constraints of curcumin's bioavailability. Traditional extraction procedures, such as soxhlet extraction, yield more curcumin but have drawbacks such as consuming more solvents and requiring longer to extract. Advanced methods such as microwave assisted extraction and ultrasonic assisted extraction, on the other hand, overcome these constraints with less extraction time and less solvent consumption while producing a good level of yield when compared to other advanced extraction methods. Green extraction method like supercritical fluid extraction have significant drawbacks in the aspect of yield. Increasing more studies in the areas of bio availability and improving the measures to improve the extraction efficiency of advanced methods are the future scope of study.

References

1. Aguas M, Del Hoyo J, Faubel R, Nos P. Use of telemedicine in inflammatory boweldisease: A real monitoring option? Expert Review of Gastroenterology & Hepatology, 2016, 1–3. https://doi.org/10.1080/17474124.2016.1200464
2. Ajaikumar Kunnumakkara B, Choudhary Harsha, Kishore Banik, Bethsebie Sailo L, Devivasha Bordoloi, *et al*. Is curcumin bioavailability a problem in humans: lessons from clinical trials, Expert Opinion on Drug Metabolism & Toxicology. Expert Opinion on Drug Metabolism & Toxicology 2019. https://doi.org/10.1080/17425255.2019.1650914
3. Akter J, Hossain Md A, Takara K, Islam Md Z, Hou DX. Antioxidant activity of different species and varieties of turmeric (Curcuma spp): Isolation of active compounds. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology. 2019;215:9-17. https://doi.org/10.1016/j.cbpc.2018.09.002
4. Altunay N, Elik A, Gürkan R. Preparation and application of alcohol based deep eutectic solvents for extraction of curcumin in food samples prior to its spectrophotometric determination. Food Chemistry. 2020;310:125933. https://doi.org/10.1016/j.foodchem.2019.125933
5. Belwal T, Chemat F, Venskutonis PR, Cravotto G, Jaiswal DK, Bhatt ID, *et al*. Recent advances in scaling-up of non-conventional extraction techniques: Learning from successes and failures. TrAC Trends in Analytical Chemistry. 2020;127:115895. https://doi.org/10.1016/j.trac.2020.115895
6. Bhat A, Mahalakshmi AM, Ray B, Tuladhar S, Hediyal TA, Manthiannem E, *et al*. Benefits of curcumin in brain

disorders. BioFactors. 2019;45(5):666–689. https://doi.org/10.1002/biof.1533
7. Dutta B. Study of secondary metabolite constituents and curcumin contents of six different species of genus Curcuma. Journal of Medicinal Plants Studies. 2015;3(5):116-119.
8. Fernández-Marín R, Fernandes SCM, Andrés MA, Labidi J. Microwave-Assisted Extraction of *Curcuma longa* L. Oil: Optimization, Chemical Structure and Composition, Antioxidant Activity and Comparison with Conventional Soxhlet Extraction. Molecules. 2021;26(6):1516. https://doi.org/10.3390/molecules26061516
9. Ganjali S, Dallinga-Thie GM, Simental-Mendía LE, Banach M, Pirro M, Sahebkar A. HDL functionality in type 1 diabetes. Atherosclerosis. 2017;267:99-109. https://doi.org/10.1016/j.atherosclerosis.2017.10.018
10. Garavand F, Rahaee S, Vahedikia N, Jafari SM. Different techniques for extraction and micro/nanoencapsulation of saffron bioactive ingredients. Trends in Food Science & Technology. 2019;89:26–44. https://doi.org/10.1016/j.tifs.2019.05.005
11. Gopinath H, Karthikeyan K. Turmeric: A condiment, cosmetic and cure. Indian Journal of Dermatology, Venereology and Leprology. 2018;84(1):16. https://doi.org/10.4103/ijdvl.IJDVL_1143_16
12. Hanif Mughal M. Turmeric polyphenols: A comprehensive review. Integrative Food, Nutrition and Metabolism. 2019;6(6). https://doi.org/10.15761/IFNM.1000269
13. Hay E, Lucariello A, Contieri M, Esposito T, De Luca A, Guerra G, *et al*. Therapeutic effects of turmeric in several diseases: An overview. Chemico-Biological Interactions. 2019;310:108729. https://doi.org/10.1016/j.cbi.2019.108729
14. Heffernan C, Ukrainczyk M, Gamidi RK, Hodnett BK, Rasmuson ÅC. Extraction and Purification of Curcuminoids from Crude Curcumin by a Combination of Crystallization and Chromatography. Organic Process Research & Development. 2017;21(6):821-826. https://doi.org/10.1021/acs.oprd.6b00347
15. Hewlings S, Kalman D. Curcumin: A Review of Its Effects on Human Health. Foods. 2017;6(10):92. https://doi.org/10.3390/foods6100092
16. Horosanskaia E, Yuan L, Seidel-Morgenstern A, Lorenz H. Purification of Curcumin from Ternary Extract-Similar Mixtures of Curcuminoids in a Single Crystallization Step. Crystals. 2020;10(3):206. https://doi.org/10.3390/cryst10030206
17. Hotamisligil GS. Inflammation, metaflammation and immunometabolic disorders. Nature. 2017;542(7640):177-185. https://doi.org/10.1038/nature21363
18. Ikpeama Ahamefula, Onwuka GI, Nwankwo Chibuzo. Nutritional Composition of Tumeric (*Curcuma longa*) and its Antimicrobial Properties. International Journal of Scientific & Engineering Research, 2014;5(10).
19. Jayashree E, Kandiannan K, Prasath D, Sasikumar B, Senthil Kumar CM, Srinivasan V, *et al*. Indian Institute of Spice Research (IISR), 2015. http://www.spices.res.in/sites/default/files/Extension%20Pamphlets/turmeric.pdf
20. Jiang T, Ghosh R, Charcosset C. Extraction, purification and applications of curcumin from plant materials-A comprehensive review. Trends in Food Science & Technology. 2021;112:419–430. https://doi.org/10.1016/j.tifs.2021.04.015
21. Kaur A. Historical background of usage of turmeric: A review. Journal of Pharmacognosy and Phytochemistry. 2019;8(1):2769-2771
22. Kouhpeikar H, Butler AE, Bamian F, Barreto GE, Majeed M, Sahebkar A. Curcumin as a therapeutic agent in leukemia. Journal of Cellular Physiology. 2019;234(8):12404-12414. https://doi.org/10.1002/jcp.28072
23. Kurmudle N, Kagliwal LD, Bankar SB, Singhal RS. Enzyme-assisted extraction for enhanced yields of turmeric oleoresin and its constituents. Food Bioscience. 2013;3:36–41. https://doi.org/10.1016/j.fbio.2013.06.001
24. Laolkuldilok N, Kopermsub P, Thakeow P, Utama-ang N. Microwave assisted extraction of bioactive compounds from turmeric (*Curcuma longa*). Journal of Agricultural Technology. 2015;11(5):1185-1196.
25. Marathe SJ, Jadhav SB, Bankar SB, Singhal RS. Enzyme-Assisted Extraction of Bioactives. In M. Puri (Ed.), *Food Bioactives*. Springer International Publishing, 2017, 171-201. https://doi.org/10.1007/978-3-319-51639-4_8
26. Martins Strieder M, Keven Silva E, Angela A, Meireles M. Specific Energy: A New Approach to Ultrasound-assisted Extraction of Natural Colorants. Food and Public Health. 2019;9(2):45-52. https://doi.org/10.5923/j.fph.20190902.02
27. Mishra S, Goel B. Pharmaceutical and Nutritional Properties of Turmeric (*Curcuma longa*): A Mini Review. Advances in Zoology and Botany. 2020;8(3):83-86. https://doi.org/10.13189/azb.2020.080302
28. Ministry of Food Processing Industries. Recent Export Trends in Turmeric: Prospects and Challenge, 2022. https://www.mofpi.gov.in/pmfme/enewsaugust9/markettrends1.html
29. Momtazi-Borojeni AA, Haftcheshmeh SM, Esmaeili SA, Johnston TP, Abdollahi E, Sahebkar A. Curcumin: A natural modulator of immune cells in systemic lupus erythematosus. Autoimmunity Reviews. 2018;17(2):125-135. https://doi.org/10.1016/j.autrev.2017.11.016
30. Nair KP. Turmeric (*Curcuma longa* L.) and Ginger (*Zingiber officinale* Rosc.) - World's Invaluable Medicinal Spices: The Agronomy and Economy of Turmeric and Ginger. Springer International Publishing 2019. https://doi.org/10.1007/978-3-030-29189-1
31. Nasseri E, Mohammadi E, Tamaddoni A, Qujeq D, Zayeri F, Zand H. Benefits of Curcumin Supplementation on Antioxidant Status in β-Thalassemia Major Patients: A Double-Blind Randomized Controlled Clinical Trial. Annals of Nutrition and Metabolism. 2017;71(3-4):136-144. https://doi.org/10.1159/000479634
32. Nisar T, Iqbal M, Raza A, Safdar M, Iftikhar F, Waheed M. Estimation of Total Phenolics and Free Radical Scavenging of Turmeric (*Curcuma longa*). Environ. Sci, 2015, 6.
33. Nurhadi B, Saputra RA, Setiawati TA, Husein SN, Faressi FR, Utari CD, *et al*. Comparison of Curcuma domestica and *Curcuma xanthorrhiza* oleoresins extracted using maceration, Soxhlet, and ultrasound-assisted extraction (UAE). IOP Conference Series: Earth and Environmental Science. 2020;443(1):012074. https://doi.org/10.1088/1755-1315/443/1/012074
34. Osorio-Tobón JF, Carvalho PIN, Rostagno MA, Meireles

MAA. Process integration for turmeric products extraction using supercritical fluids and pressurized liquids: Economic evaluation. Food and Bioproducts Processing. 2016;98:227-235. https://doi.org/10.1016/j.fbp.2016.02.001
35. Osorio-Tobón, J. F., Carvalho, P. I. N., Rostagno, M. A., Petenate AJ, Meireles MAA. Extraction of curcuminoids from deflavored turmeric (*Curcuma longa* L.) using pressurized liquids: Process integration and economic evaluation. The Journal of Supercritical Fluids. 2014;95:167-174. https://doi.org/10.1016/j.supflu.2014.08.012
36. Passos H, Freire MG, Coutinho JAP. Ionic liquid solutions as extractive solvents for value-added compounds from biomass. Green Chem. 2014;16(12):4786-4815. https://doi.org/10.1039/C4GC00236A
37. Patil SS, Bhasarkar S, Rathod VK. Extraction of curcuminoids from *Curcuma longa*: Comparative study between batch extraction and novel three phase partitioning. Preparative Biochemistry and Biotechnology. 2019;49(4):407-418. https://doi.org/10.1080/10826068.2019.1575859
38. Patil SS, Pathak A, Rathod VK. Optimization and kinetic study of ultrasound assisted deep eutectic solvent based extraction: A greener route for extraction of curcuminoids from *Curcuma longa*. Ultrasonics Sonochemistry. 2021;70:105267. https://doi.org/10.1016/j.ultsonch.2020.105267
39. Prasad S, Tyagi AK. Curcumin and its analogues: A potential natural compound against HIV infection and AIDS. Food & Function. 2015;6(11):3412-3419. https://doi.org/10.1039/C5FO00485C
40. Praveen MA, Parvathy KRK, Balasubramanian P, Jayabalan R. An overview of extraction and purification techniques of seaweed dietary fibers for immunomodulation on gut microbiota. Trends in Food Science & Technology. 2019;92:46-64. https://doi.org/10.1016/j.tifs.2019.08.011
41. Rafiee Z, Nejatian M, Daeihamed M, Jafari SM. Application of curcumin-loaded nanocarriers for food, drug and cosmetic purposes. Trends in Food Science & Technology. 2019;88:445-458. https://doi.org/10.1016/j.tifs.2019.04.017
42. Ralf Jager, Ryan Lowery P, Allison Calvanese V, Jordan Joy M, Martin Purpura, *et al*. Comparative absorption of curcumin formulations. Nutrition Journal. 2014;13:11 http://www.nutritionj.com/content/13/1/11
43. Rathaur P, Raja W, Ramteke PW, John SA. Turmeric: the golden spice of life. IJPSR; 2012;3(7).
44. Rattis BAC, Ramos SG, Celes MRN. Curcumin as a Potential Treatment for COVID-19. Frontiers in Pharmacology. 2021;12:675287. https://doi.org/10.3389/fphar.2021.675287
45. Sahne F, Mohammadi M, Najafpour GD, Moghadamnia AA. Extraction of bioactive compound curcumin from turmeric (*Curcuma longa* l.) Via different routes: a comparative study. Pak. J. Biotechnol. 2016;13(3):173-180.
46. Sahne F, Mohammadi M, Najafpour GD, Moghadamnia, AA. Enzyme-assisted ionic liquid extraction of bioactive compound from turmeric (*Curcuma longa* L.): Isolation, purification and analysis of curcumin. Industrial Crops and Products. 2017;95:686–694. https://doi.org/10.1016/j.indcrop.2016.11.037
47. Sandikci Altunatmaz S, Yilmaz Aksu F, Issa G, Basaran Kahraman B, Dulger Altiner D, Buyukunal S. Antimicrobial effects of curcumin against L. monocytogenes, S. aureus, S. Typhimurium and E. coli O157:H7 pathogens in minced meat. Veterinární Medicína. 2016;61(5):256-262. https://doi.org/10.17221/8880-VETMED
48. Shirsath SR, Sable SS, Gaikwad SG, Sonawane SH, Saini DR, Gogate PR. Intensification of extraction of curcumin from Curcuma amada using ultrasound assisted approach: Effect of different operating parameters. Ultrasonics Sonochemistry. 2017;38:437–445. https://doi.org/10.1016/j.ultsonch.2017.03.040
49. Sidney Stohs J, Oliver Chen, Sidhartha Ray D, Jin Ji, Luke Bucci R, Harry Preuss G. Highly Bioavailable Forms of Curcumin and Promising Avenues for Curcumin-Based Research and Application: A Review. Molecules. 2020;25:1397. doi:10.3390/molecules25061397
50. Silva LV, Nelson DL, Drummond MFB, Dufossé L, Glória MBA. Comparison of hydrodistillation methods for the deodorization of turmeric. Food Research International. 2005;38(8–9):1087–1096. https://doi.org/10.1016/j.foodres.2005.02.025
51. Wakte PS, Sachin BS, Patil AA, Mohato DM, Band TH, Shinde DB. Optimization of microwave, ultra-sonic and supercritical carbon dioxide assisted extraction techniques for curcumin from *Curcuma longa*. Separation and Purification Technology. 2011;79(1):50-55. https://doi.org/10.1016/j.seppur.2011.03.010
52. Xu J, Wang W, Liang H, Zhang Q, Li Q. Optimization of ionic liquid based ultrasonic assisted extraction of antioxidant compounds from *Curcuma longa* L. using response surface methodology. Industrial Crops and Products. 2015;76:487-493. https://doi.org/10.1016/j.indcrop.2015.07.025
53. Zachariah TJ, Leela NK. Curcumin or Curcumnoids: Industrial and Medicinal Potential. 2015;220:10.
54. Zhang R, Li S, Zhu Z, He J. Recent advances in valorization of Chaenomeles fruit: A review of botanical profile, phytochemistry, advanced extraction technologies and bioactivities. Trends in Food Science & Technology. 2019;91:467-482. https://doi.org/10.1016/j.tifs.2019.07.012