REVIEW ARTICLE

Chilli Oleoresin: A Review of Phytochemistry, Green Extraction Technologies, Biological Activities and Industrial Applications

K. Nirmal Kumar[1], H. Usha Nandhini Devi[2], A. Sankari[3], P. Sudha[4], K. Gurusamy[4]

[1]Department of Vegetable Science, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India, [2]Centre for Post-Harvest Technology, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India, [3]Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India, [4]Department of Food Process Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Abstract

Capsicum oleoresin, a lipophilic concentrated extract standardized for capsaicinoids and carotenoids, has emerged as a superior alternative to raw spices for food, nutraceutical formulation, and biomedical applications. This review critically synthesizes of the phytochemistry, extraction techniques, and health effects of oleoresin from chilli, based on the *in vivo*, *in vitro,* and clinical evidence. The principal bioactive components (capsaicinoids, carotenoids, polyphenols, and polyunsaturated fatty acids) exhibit analgesic, anti-inflammatory, antioxidant, and anticancer activities through transient receptor potential vanilloid 1, Nuclear factor kappa B, and Nrf2/ARE pathways. The extraction technologies developed from low-efficient conventional methods to selective sustainable alternatives, namely, microwave, ultrasound, and enzyme-assisted, supercritical fluid, and pressurized fluid extraction, each involving trade-offs among bioactive recovery, solvent use, scalability, and regulatory compliance. This review integrates phytochemistry, extraction technologies, biological activities, industrial applications, and future perspectives within a single critical framework, clarifying how extraction method selection governs bioactive recovery and downstream applicability. Prevailing limitations, namely extraction standardization, bioavailability data, and large-scale clinical evidence, constrain its full validation; addressing these through green extraction optimization, nanocarrier-based delivery systems, and randomized controlled trials will be key to translating its substantial nutraceutical and pharmacological potential into practice.

Key words: Capsaicinoids, carotenoids, chilli oleoresin, extraction technologies, pharmaceutical applications

INTRODUCTION

Chilli (*Capsicum* spp., Family: Solanaceae) is one of the most economically important spice crops across the world, widely cultivated in subtropical and tropical countries and indispensable in human culinary, nutrition, traditional medicine, and industrial processing.[1,2] Their characteristic pungency, color, and array of phytochemicals, including the capsaicinoids and carotenoids, have sustained considerable scientific interest and stimulate the production of concentrated, standardized chilli-based products that have improved functional properties in food industries, nutraceutical, and therapeutic applications.[3,4]

Chilli oleoresin, a concentrated viscous extract prepared from dried Capsicum fruits, is the most industrially important value-added product. Oleoresin form of raw chilli offers the benefits of all the bioactive components in a protected,

Address for correspondence:
H. Usha Nandhini Devi, Centre for Post-Harvest Technology, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.
E-mail: ushanandhini@tnau.ac.in

Received: 08-04-2026
Revised: 27-05-2026
Accepted: 12-06-2026

uniform and stable form, resulting in consistent pungency, improved color intensity and excellent storage stability, particularly suited to precision formulation processes.[5] This compositional richness has stimulated increasing research on the biological activities of its main components, with capsaicin being well documented for its analgesic, anti-inflammation inhibitory, antioxidant, and anti-cancer effects.[6,7] However, this therapeutic and industrial potential is critically dependent on the extraction methodology used, which has also undergone a technological evolution, from the classical solvent-based methods to more efficient and green technologies, such as supercritical CO_2, microwave- and ultrasound-assisted extraction.[8,9]

However, despite substantial advances, existing literature remains fragmented, focused on isolated aspects such as phytochemical characterization, optimization of extraction, and specific application studies.[5,10] Furthermore, the variability of extraction conditions, solvent system, and outcome metrics across studies renders direct comparisons and hinders the translation of laboratory findings to industrial-scale processes.[10] Thus, a comprehensive and integrative synthesis encompassing chemical composition, extraction efficiency, and functional performance is critically required. This review provides a critical and extensive evaluation of chilli oleoresin by an overview on its bioactive composition and associated health implications (section 2), comparative analysis of different extraction methods for chilli pepper with respect to their efficiency, selectivity, and scalability (section 3), and a summary of applications of chilli pepper in food, cosmetic, and pharmaceutical industries (section 4).

BIOACTIVE CONSTITUENTS OF CHILLI OLEORESIN: CHEMICAL CHARACTERISTICS AND HEALTH SIGNIFICANCE

Phytochemical profile

Oleoresins derived from *Capsicum* spp. are a rich source of several bioactive compounds with various functional and health-promoting attributes [Table 1]. The primary constituents of the oleoresin fraction are capsaicinoids (0.1–1.5% dry weight), which collectively include 80–90% capsaicin and dihydrocapsaicin [Figure 1], with potent transient receptor potential vanilloid 1 (TRPV1) agonist properties (half-maximal inhibitory concentration [IC_{50}]: 0.3–0.5 μM).[4] Carotenoid pigments, especially capsanthin, which accounts for 60–70% of the total carotenoid content and capsorubin, complement the capsaicinoid profile by providing strong antioxidant capacity (oxygen radical absorbance capacity: 2,850 μmol TE/g) and imparting the red color of commercial oleoresin products.[11] Quercetin (15–22 mg/100 g), luteolin (8–13 mg/100 g) and also the derivatives of capsaicin-associated hydroxycinnamic acid exhibit strong free radical scavenging activity (2,2-Diphenyl-1-picrylhydrazyl $IC_{50:}$ 1.8–3.1 μM) by activating the Nrf2/ARE pathway, increasing the bioactive repertoire of the phenolic fraction.[12] The lipophilic matrix provided by fixed oil ingredients, primarily linoleic acid (65–72% of the fatty acid portion) and palmitic acid (12–15%), improves the solubility and delivery of fat-soluble bioactives in oleoresin formulations.[13] In addition, α and γ tocopherol (18–26 mg/100 g) function as endogenous stabilizers that protect oxidative degradation of the carotenoid and capsaicinoid fractions during processing and storage.[14] Cultivar-dependent variation has been identified in flavonoid methyl ethers and steroidal alkaloid glycosides.

Capsicum chinense varieties contain up to 35% higher total capsaicinoid content than *Capsicum annuum,* offering chemotypic diversity for targeted nutraceutical products.[15]

Evidence-based health benefits

Chilli oleoresin's bioactive constituents offer several health benefits to human health. Capsaicinoid has strong antioxidant, inflammation-modulating, pain-relieving, anticarcinogenic, anti-obesity, and cardiovascular protective properties.[6,16] Capsaicin regulates lipid metabolism through peroxisome proliferator-activated receptor α activation, with dietary supplementation (2.56 mg/day) reducing blood serum low-density lipoprotein cholesterol levels by 14–18% and triglycerides by 22% in hyperlipidemic patients after 12 weeks.[17] Reflecting these metabolic benefits, capsaicin-rich diets result in decreased waist circumference and enhanced insulin sensitivity, indicating a strong potential of capsaicin oleoresin in the metabolic syndrome regulation.[18] Capsaicin inhibits Nuclear factor kappa B activity, which decline the tumor necrosis factor-α and interleukin-6 cytokines synthesis by 35–45% in lipopolysaccharide-activated macrophages ($IC\beta_{0:}$ 12 μg/mL) in a increasing dose levels, which reflects its Prospective use in chronic inflammatory diseases.[19] The carotenoid, capsanthin, demonstrates chemopreventive potential through induction of mitochondrial apoptosis in MCF-7 human breast cancer cells.[20] For analgesic use, capsaicin formulations (0.025–0.1%) deplete substance P from nerve terminals to produce significant pain relief (visual analog scale pain score reduction: 4–57% vs. placebo, $P < 0.01$) in osteoarthritis patients in a multicenter, randomized study.[21]

EXTRACTION TECHNIQUES

Extraction techniques for chilli oleoresin have undergone substantial advancements, shifting from conventional solvent-based processes to innovative, green extraction technologies including supercritical fluid extraction (SFE), microwave-assisted extraction (MAE), and Ultrasound-assisted extraction (UAE) [Table 2]. The quality and

Table 1: Major bioactive phytochemicals present in Chilli Oleoresin: Composition, therapeutic properties and applications

Compound	Functional class	Range in chilli oleoresin	Health effects and applications	References
Capsaicinoids				
Capsaicin	Vanillylamide alkaloid	~60 mg/g; 70% of total capsaicinoids	Analgesic, anti-inflammatory, thermogenic, anticancer, TRPV1 agonist	[22,23]
Dihydrocapsaicin	Saturated vanillylamide alkaloid	~12 mg/g; 20% of total capsaicinoids	Analgesic, anti-obesity, antioxidant, neuroprotective	[22,24]
Nordihydrocapsaicin	Vanillylamide alkaloid	~4.2 mg/g; 7.4% of total capsaicinoids	Anti-inflammatory, mild pungency, antioxidant	[22]
Homocapsaicin	Vanillylamide alkaloid	≤2% of total capsaicinoids	TRPV1 agonist, pungency mediator, antimicrobial	[24]
Homodihydrocapsaicin	Saturated vanillylamide alkaloid	≤1% of total capsaicinoids	TRPV1 agonist, thermogenic, appetite suppression	
Carotenoid pigments				
Capsanthin	Xanthophyll (ketocarotenoid)	Primary red pigment; ~31.7% of total carotenoids	Antioxidant, anti-inflammatory, anticancer; Red colorant (E160c)	[25,26]
Capsorubin	Xanthophyll (diketo-carotenoid)	~7.5% of total carotenoids	Antioxidant, skin photoprotection	[26]
β-Carotene	Carotene (provitamin A)	~12.3% of total carotenoids	Antioxidant, vitamin- A precursor, anticarcinogenic, immunostimulant	[27]
Zeaxanthin	Xanthophyll	Trace amount (0.5–3%) of total carotenoids	Macular protection, antioxidant, anti-inflammatory, highest bioavailability	[28]
β-Cryptoxanthin	Xanthophyll (provitamin A)	0.1–2% of total carotenoids	Antioxidant, anticancer, bone metabolism support	[29]
Lutein and violaxanthin	Xanthophyll	Only found in yellow pepper oleoresin	Eye health, antioxidant, ophthalmic supplement	[30]
Fatty acids and esters				
Linoleic acid	Polyunsaturated fatty acid (ω-6)	20.3–64.8% of total fatty acid	Anti-inflammatory, cardiovascular protective	[22,31]
Oleic acid	Monounsaturated fatty acid (ω-9)	10.4–18.1% of total fatty acid	Cardiovascular protection,	[31,32]
Palmitic acid	Saturated fatty acid (C16:0)	8.96–15.57% in oleoresin by GC-MS	Bioavailability-enhancer	[22]
Flavonoid and phenolic compounds				
Chlorogenic acid	Hydroxycinnamic acid (phenolic acid)	Trace amount (<0.01%)	Antioxidant, anti-inflammatory, antidiabetic, cardioprotective	[26,33]
Ferulic acid	Hydroxycinnamic acid (phenolic acid)	Trace amount (<0.005%)	Antioxidant, antimicrobial, UV photoprotection	
Quercetin	Flavonoid (flavonol)	trace amount	Antioxidant, anti-inflammatory, antiviral, antiallergic	[24]
Luteolin	Flavonoid (flavone)	Trace amount	Anti-inflammatory, anticancer, neuroprotective	
Volatile and minor aroma compounds				
Branched- and straight-chain alkyl vanillylamide; Aldehydes; alcohols; Ketones	Volatile compounds	>100 compounds identified in oleoresin mixture	Contributes odor, and flavor of oleoresin.	[23]

TRPV1: Transient receptor potential vanilloid 1, UV: Ultraviolet, GC-MS: Gas chromatography-mass spectrometry

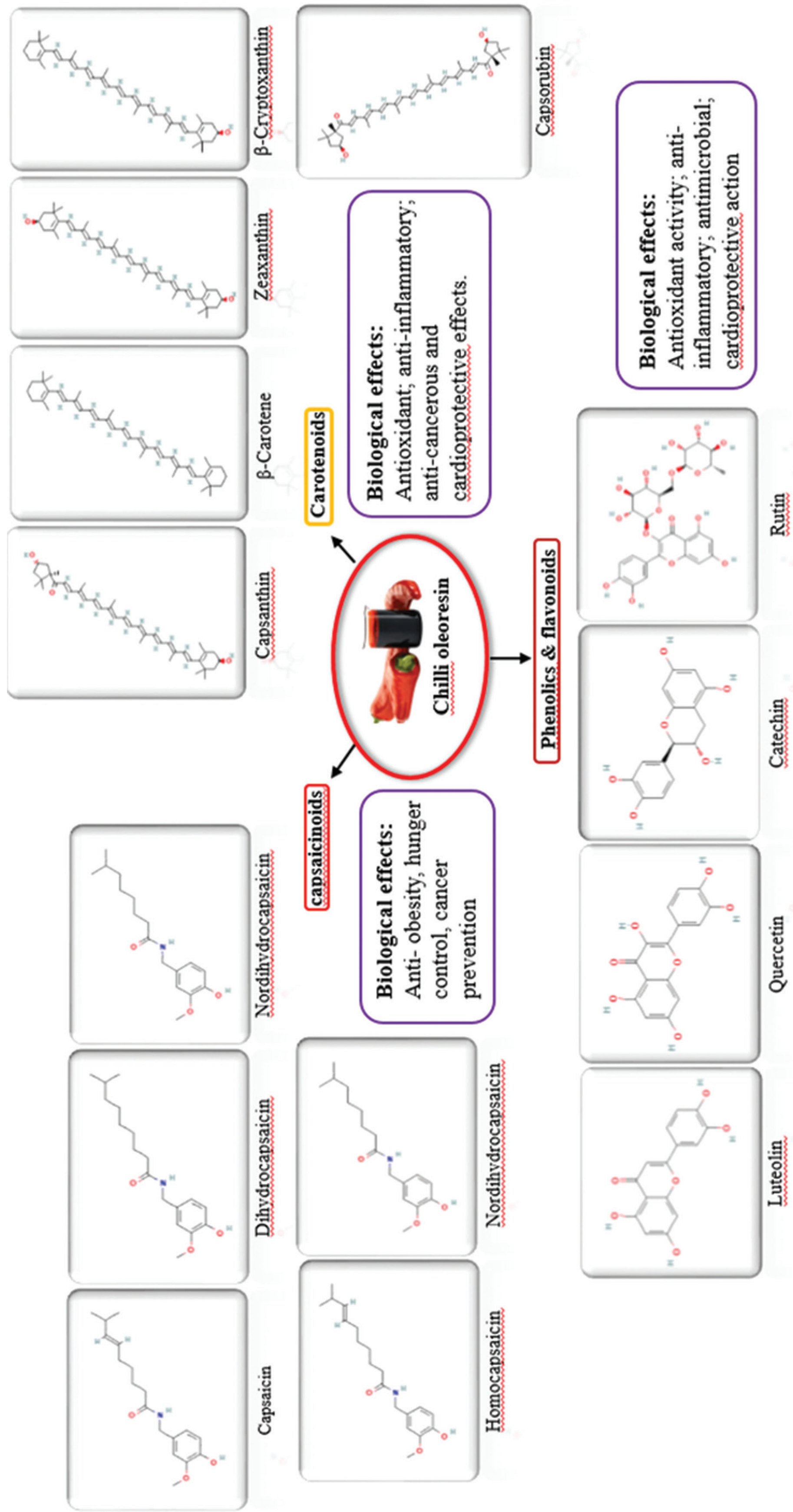

Figure 1: Major chemical compounds present in chilli oleoresin and its structure

Table 2: Comparative assessment of extraction techniques for chilli oleoresin: Solvent, optimized parameters, yield, scalability, advantages, and limitations

Extraction technique	Solvent used	optimized parameters	Oleoresin yield (%)	Scalability	Key advantages	Limitations	References
Soxhlet extraction	99.8% ethanol	80°C, 4 h, 1:10 g/mL SSR	33	Low	Higher oleoresin yield than SFE	Better yield than Sc-CO_2 but poor bio active compound recovery	[80]
Solvent extraction	Acetone and hexane 70:30 ratio	25°C, 24 h, 1:10 g/mL SSR	3.3–8.8	High	Lowest equipment cost, simplest protocol	Solvent residues, environmental concerns	[81]
UAE	96% ethanol	25°C, 8 min, APD–0.87 W/mL, 1:20 g/mL SSR	26	Moderate-High	Energy-efficient (~95%), higher antioxidants recovery than soxhlet	Equipment fouling at high intensity, risk of emulsification	[82]
MAE	100% methanol	800W, 60°C, 5 min, pH 8, SSR 0.2:15 g/mL	26.2	Moderate	Enhanced capsaicin recovery, reduced time/solvent, energy efficient	Volatile compound loss, small batch size, high capital cost	[54]
SFE	Sc-$CO_{2,}$ co-solvent 99.9% ethanol	FR- 5 mL/min, 60°C, 73 min, and 207 bar	11.3	Low	Solvent-free GRAS product, easy solvent removal by depressurisation, eco-friendly	High capital cost, high-pressure equipment, lower yield for polar compounds	2021 [70]
PLE	Acetone	78°C, 2 cycles, 28 min, 100 bar	Not reported	Low-Moderate	Better carotenoid (850 ASTA) and capsaicinoid recovery (3560 µg/g) by Dry wt.	High equipment cost, risk of co-extracting unwanted compounds	[41]
EAE	Water	2,500 UI/L - Celuzyme conc., 60°C for 150 min	Yield increment (73.5)	Moderate	Environmental friendliness, preserves bio active compounds	Enzyme cost, longer processing time	[73]
SFE+PLE	75% ethanol, Sc-CO_2	65°C, 10 MPa, 10 min	4.75	Low	Sequential approach maximizes yield/selectivity	High combined equipment cost, complex two-step optimization	[83]
SFE+UAE	Sc-CO_2 Rate of flow-1.7569× 10^{-4} kg/s	40°C, 15MPa, 60 min, ultrasound power (360 W)	7.3	Low	Enhances mass transfer, reduced time	Very high equipment cost, complex scale-up	[84]

MAE: Microwave-assisted extraction, SFE: Supercritical fluid extraction, PLE: Pressurized liquid extraction, EAE: Enzyme-assisted extraction, APD: Absorbed power density, SSR: Solvent-to-sample ratio, ASTA: American Spice Trade Association suitability of chilli oleoresin for the food and pharmaceutical sector are greatly influenced by the recovering techniques; advanced sustainable technologies preserve the health-beneficial compounds and reduced environmental impacts.

Traditional extraction techniques

Solvent extraction of chilli oleoresin

Solvent isolation, currently the most widely adopted traditional methodology to separate chilli oleoresin, due to its user-friendly operation, scalability, and cost-effective at an industrial scale.[34] This methodology comprises the utility of organic solvents, commonly hexane, ethyl alcohol, acetone, or petroleum ether. The low boiling point (69°C), non-polarity, and high affinity of hexane make it a preferred commercial solvent, but the solvent-contamination remnants are a regulatory and health issue, requiring aggressive post-extraction desolventization. Although less effective with non-polar constituents, ethanol is a safer and greener solvent, especially when coupled with acetone – binary mixtures have shown higher yields of oleoresin by up to 27% than using single solvent systems.[35,36] Major drawbacks of solvent extraction are the residual solvent contamination, thermal degradation of heat-sensitive capsaicinoids, environmental impact, and regulatory concerns limits in food-grade products.[34,37]

Soxhlet method

Soxhlet technique is an exhaustive solid-to-liquid method of extraction where the solid matrix undergoes a series of constant reflux condensation on fresh hot solvent. It is both time-consuming (6–24 h, depending on particle size and solvent used) and guarantees a near-full exhaustion of target compounds with high-purity oleoresins that can be easily standardized analytically.[38,39] Comparative exploration of *C. chinense* waste showed that Soxhlet extraction produced 3.82% oleoresin, which was significantly more than both the maceration and ultrasound-assisted extraction of 2.41% and 3.17% respectively, demonstrating that it was thermodynamically complete irrespective of its energy inefficiency.[40] Nevertheless, prolonged heat treatment is associated with oxidative decomposition of heat-sensitive carotenoids like capsanthin, whose concentration could decrease by up to 18 % under high reflux periods (>12 h at 70°C), and consequently decrease the antioxidant potential and American Spice Trade Association (ASTA) color values.[41,42]

Steam distillation

Steam distillation is widely used extraction in isolation of essential oils, but it contributes insignificantly to chilli oleoresin production since oleoresins are not volatile terpenoids and are not extracted in the aqueous distillate phase. Rather, solvent extraction is sometimes performed after a pretreatment phase like steam distillation to eliminate volatile interfering compounds before solvent extraction or to recover essential oil and oleoresin at the same time with solvent techniques.[43,44] Sequential steam distillation followed by ethanol-based soxhlet extraction allowed simultaneous recovery of volatile monoterpenes (e.g., limonene, β-phellandrene) and oleoresin-rich capsaicinoid-carotenoid complexes to enhance overall valorization efficiency in calabrian chilli waste derivatives.[45]

Limitation of conventional extraction

Traditional processes used to extract chilli oleoresin, including solvent separation and steam hydrodistillation have the limitations of thermodynamic ineffectiveness, regulation violation, thermal deterioration, and environmental issues. Volatile organic solvents like hexane are hazardous to health and can leave a trace that is beyond the required contaminations of regulation, which requires expensive purification.[44] Elevated temperatures (>60°C) can degrade heat-sensitive capsaicinoids and carotenoids reduces the product quality.[46] In addition, co-extracted lipids interfere with analytical accuracy, making it difficult to quantify the bioactive compounds.[35] These limitations highlight the poor capability of conventional techniques with oleoresin chemistry, which has prompted the use of cutting-edge techniques for standard extraction, such as microwave, ultrasound, and supercritical liquid extraction.

Advanced methods

MAE

MAE is a quick and energy-saving alternative to the traditional solvent-based extraction of chilli oleoresin [Figure 2]. The working principle of MAE is dielectric heating, which uses microwave irradiation at 2450 MHz to induce rotational oscillation of polar solvent molecules and generate localized superheating that disrupts cell wall integrity and accelerates the diffusion of capsaicinoids and carotenoids into the solvent.[47,48] Ethanol and acetone were recognized as the most efficacious extraction solvents due to their elevated dielectric loss tangents, which enhance efficient microwave energy absorption, better solubility for both polar capsaicinoids and non-polar carotenoid pigments.[49] 400–600 W microwave irradiation power, 4–10 min of exposure duration, 10–15 mL/g of a solvent-sample ratio, and 60–80°C extraction temperature were the optimal conditions for higher capsaicinoid concentrations (1.8–3.2%).[50,51] MAE has yielded similar oleoresin content of 12–18% (w/w dry basis) in shorter processing time of 4–10 min and has used 50–60% less solvent and up to 80% less energy than Soxhlet's.[49] Reduced thermal exposure in MAE protects capsanthin and capsorubin from oxidative degradation, thereby increased ASTA color values were recorded than soxhlet method.[48,52]

Ultrasonic-assisted extraction

Ultrasound-enhanced extraction (UAE) is a non-thermal, innovative technique increasingly used in food and nutraceutical processing for its fast, greener, and more efficient alternative to conventional extractions.[53,54] UAE creates acoustic cavitation-the creation, expansion, and violent explosion of microbubbles in a liquid under ultrasonic radiation, by transmitting ultrasonic waves (>20 kHz).[55,56] This phenomenon generates localized extreme conditions, including transient temperature of approximately 5000 K and pressure of around 1000 atm, coupled with intense micro-jets and shear forces[53] which disrupt plant cell walls, increase mass transfer, and enhance the release of bioactives such as capsaicinoids and carotenoids from chilli matrices into the solvent [Figure 3].

The most popular solvents for chilli oleoresin in the UAE are methanol and ethanol due to their high polarity, which fits in well with the amphiphilic nature of capsaicinoids, their GRAS designation for food applications, and their ease of removal after extraction.[57,58] Optimized UAE parameters for chilli oleoresin extraction (with high capsaicinoids and carotenoid) were the frequencies of 20–40 kHz, solvent-solid ratio of 10–20 mL/g, 40–50°C temperature, and 10–30 min of extraction time.[50,53,59] It reduces 75% of the processing time and the use of solvents by 30–50% by operating at lower temperatures that safeguard heat-sensitive phytochemicals.[55,60]

Pressurized liquid extraction (PLE) or pressurized fluid extraction

PLE or accelerated solvent extraction (ASE) is an automated process of extraction carried out at high temperatures (60–200°C) and elevated pressures (~100 bar).[61-63]

PLE operates on the principle that extreme pressure keeps the solvent in a mobile state at its maximum point of boiling, whereas elevated temperature enhances solute solubility and diffusion of analytes. Under such subcritical conditions, the solvent exhibits a lower viscosity, relatively high diffusion coefficient, and strong solvent properties, enhancing solute-plant matrix disruption and mass transfer of capsaicinoids and other oleoresin constituents from the chilli pods.[64,65]

An ideal ASE condition for paprika oleoresin was 78°C temperature, 28 min static interval, and two cycles. This resulted in an ASTA color value of 847 and 57,200 Scoville heat unit (SHU), which is much higher than maceration extraction (ASTA: 607; SHU: 42,800) and ultrasound-assisted extraction (ASTA: 750; SHU: 50,500).[41] The maximum amount of capsaicinoids was obtained using methanol (450 µmol/kg) and ethanol (400 µmol/kg), making methanol the optimum choice due to its stronger polarity and superior solvating power.[66] PLE functions in dark and anaerobic condition, which is a unique advantage over all other extraction techniques, significantly lessens the oxidative degradation of antioxidants and natural carotenoids.

SFE

SFE (supercritical CO_2) is an advanced, clean, and non-toxic technique that uses CO_2 above its critical temperature and pressure to recover capsaicinoid and carotenoid-rich chilli oleoresin with high purity [Figure 4].[67] In this supercritical condition, CO_2 has gas-like diffusivity, liquid-like solvating power with improved solvent density and selectivity, and capable of dissolving non-polar to moderately polar oleoresin components efficiently.[64,68,69] Supercritical CO_2 (sc-CO_2; $T = 31.1°C$, $P = 73.8$ bar) is a widely employed solvent for chilli oleoresin extraction due to its non-flammable nature and strong affinity to the lipophilic capsaicinoids

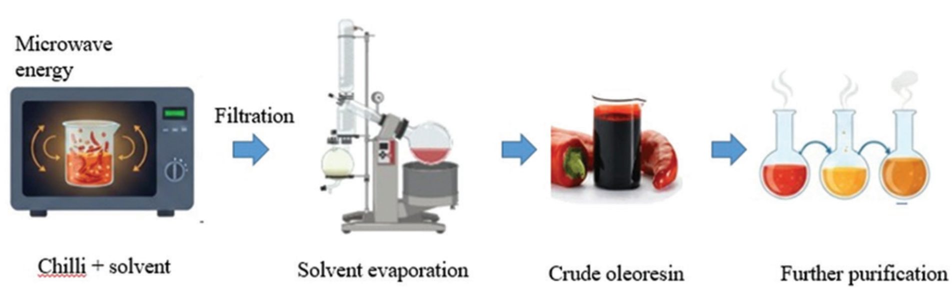

Figure 2: Process flow of microwave-assisted extraction of chilli oleoresin

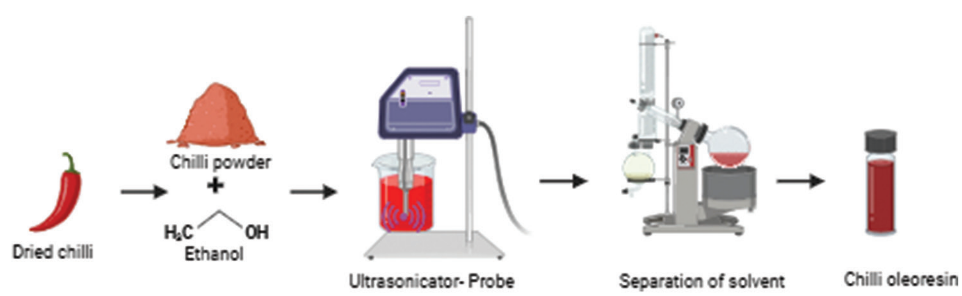

Figure 3: Process flow of ultrasound-assisted extraction of chilli oleoresin

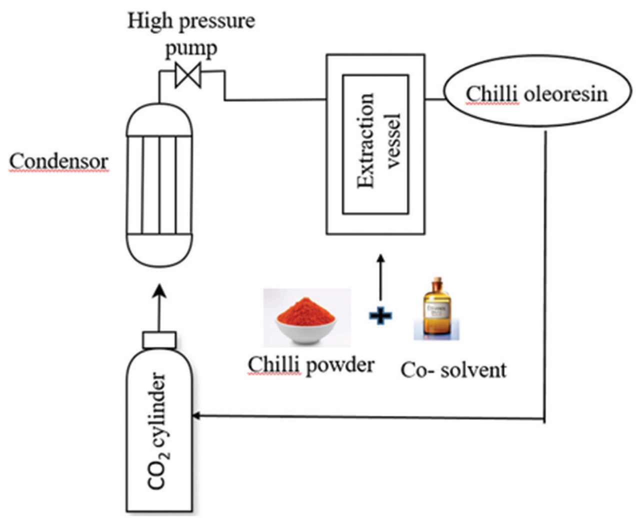

Figure 4: Process flow diagram of supercritical CO_2 extraction of chilli oleoresin

and carotenoid pigments present in chilli.[70] The addition of co-solvent (ethanol) greatly enhances oleoresin and target alkaloid recovery.[62,68,71] Reported the highest extraction yield at 40°C, 400bar pressure with 96% of capsaicinoids, 80% of carotenoids. Under ideal extraction conditions of 68.31°C, 347.98 bar, and 102.50 min; *C. chinense* cv. Bhut Jolokia produced an oleoresin yield of 7.23 ± 2.15% and a maximum capsaicin concentration of 367.14 ± 1.12 mg/g in <2 h.[72] SFE offers a clear advantage over classical extraction techniques by using little or solvent-free extraction, thereby eliminating the need for downstream solvent removal steps and producing clean, residue-free oleoresin for pharmaceutical, nutraceutical, and food-grade applications.[64]

Enzyme-assisted extraction (EAE)

Using cellular wall-breaking enzymes to improve the extraction of chilli oleoresin

EAE is a highly selective, efficient, and eco-friendly technique which employs cell wall-breaking enzymes to improve the extraction of chilli oleoresin.[73-75] The Working principle relies on the breakdown of glycosidic linkage by the cell wall degrading enzymes (Cellulases, pectinases, and multi-enzyme complexes- Celluclast, Viscozyme, and Pectinex Ultra).[76] Cellulose, hemicellulose, pectin, and lignin were the major cell wall composition of Capsicum fruits.[77] The enzymatic breakdown of these structural elements greatly increased the permeability of the cell wall, allowing for more effective mass transfer of target bioactives.[78]

The ideal extraction conditions for oleoresin extraction were 0.3–1% enzyme concentration, 30–60°C, pH 5–7, and 2–24 h, with viscozyme or cellulase.[76,78,79] Reported that enzyme treatment increases the oleoresin yield from 12.83% to 14.15%, color by ~15,000 color units, and capsaicin from 0.79% to 0.82% under 1% enzyme and ~14 h incubation in Byadgi red chilli. High selectivity for bioactive compounds is the key advantage of EAE, and moderate temperature levels prevent the degradation of heat-sensitive bioactives.[73] (Carotenoids, polyphenols, capsaicinoids, anthocyanins), preserves color, flavor, and nutritional properties.

Comparative evaluation and sources of variability across extraction techniques

The extraction techniques summarized in Table 2 present clear trade-offs between bioactive recovery, processing time, solvent consumption, scalability, and cost. Conventional solvent and Soxhlet extraction remain attractive for large-scale industrial application due to low equipment cost and simple operation, but this scalability advantage is offset by higher solvent residues, longer processing times, and greater thermal degradation of capsaicinoids and carotenoids.[34,38] In contrast, MAE and UAE substantially shorten processing time and reduce solvent and energy consumption while achieving oleoresin yields comparable to conventional methods, making them attractive for moderate-scale operations, although their industrial uptake is currently limited by the higher capital cost of microwave and ultrasound reactors relative to simple solvent tanks.[54,56] SFE offers the highest product purity and eliminates downstream desolventization, and is therefore best suited to high-value pharmaceutical and food-grade applications, but its very high equipment and operating costs restrict economic feasibility to premium product lines rather than bulk commodity oleoresin.[64,70] Hybrid approaches such as SFE combined with UAE or PLE further improve mass transfer and yield but compound equipment costs and process-optimization complexity, presently limiting them to pilot – rather than industrial-scale application.[83,84]

Beyond the extraction technology, oleoresin yield and bioactive content vary considerably due to differences in Capsicum cultivar, fruit maturity and pretreatment, extraction solvent polarity and ratio, temperature, and time. For instance, capsaicinoid content differs markedly between *C. chinense* and *C. annuum* genotypes,[15] while oleoresin yield for a single raw material can range from 3% to 7% depending solely on whether maceration, ultrasound, or supercritical extraction is applied.[40,72]

APPLICATIONS OF CHILLI OLEORESIN

Pharmaceutical and therapeutic applications

Chilli extract capsaicin cream is utilized to treat an array of pain which include nerve pain, inflammatory arthritis, rheumatism, post-surgical neuralgia, diabetic neuropathy, osteoarthritis,[16,85] and musculoskeletal pain by activating TRPV1 receptors, depleting substance P, and causing the desensitization of nociceptive fibers.[86,87] Capsaicin-loaded topical gels based on carbopol show improved antifungal and antibacterial properties and sustained drug release (52 h for 50% release), suggesting its use in inflammatory

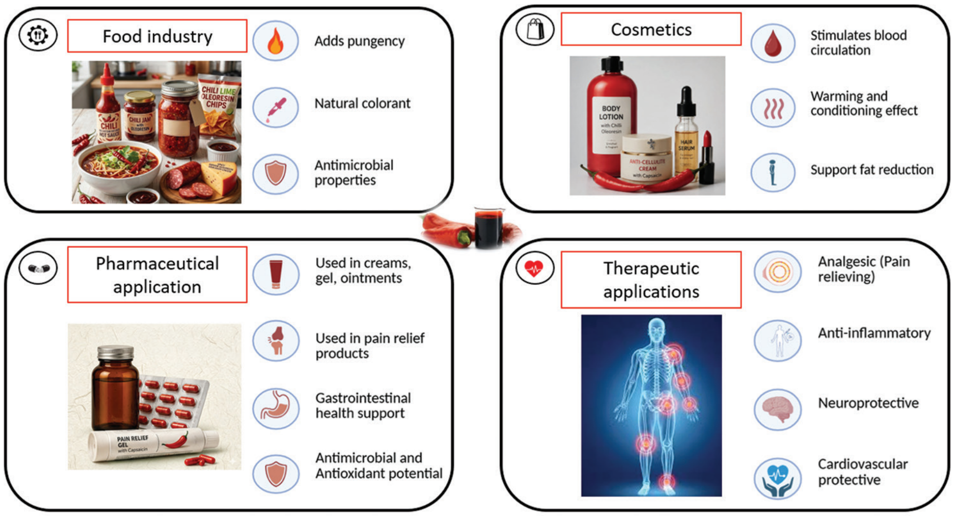

Figure 5: Multifaceted applications of chilli oleoresin across food, cosmetic, therapeutic, and pharmaceutical industries

dermatosis.[88] Formulation of capsaicin derived from oleoresin into nanostructured lipid carriers and nano/microemulsions facilitates transdermal delivery with enhanced dermal penetration, sustained release, stability, and decreased skin irritation, thus allowing the application of higher active doses in chronic pain.[16,89] Beyond analgesia, capsaicinoids possess antioxidant and anti-inflammatory effects, cardioprotective, anticancer, and anti-obesity activities, and being explored in oral and nanoencapsulated systems as adjuncts for metabolic disorders and cancer therapy, where sustained-release formulations improve bioavailability and reduce gastrointestinal adverse effects.[6,90] Chilli extracts and capsaicin-containing creams are also reported as counterirritants, antiseptics, and adjuvants in dentistry and internal medicine, including orofacial neuropathic pain management.[24]

Food industry

Chilli oleoresin has become one of the most multifunctional and essential natural ingredients in the current food processing sector, serving simultaneously as a food flavoring agent, natural colorant, preservative, and functional ingredient [Figure 5]. The vibrant red hue of chilli oleoresin provides a stable, heat-resistant alternative to artificial colors like Red 40 in a range of items, including sauces, snacks, dairy products, and processed meats, satisfying consumer desire for clean-label formulations.[5] It is a non-solid flavoring agent that provides consistent pungency and typical aroma and is important in providing consistent sensory profiles in spice blends, marinades, and ready-to-eat meals.[91] Moreover, chilli oleoresin has vital antimicrobial properties against *Listeria monocytogenes* and *Staphylococcus aureus*, prolongs the shelf life of meat analogs and low-water-activity foods.[92] Chilli oleoresin has been deemed safe to consume by a number of international food safety agencies, including the Food and Drug Administration, European Food Safety Authority, and Food Safety and Standards Authority of India, and can be included in a variety of food matrices at the concentration of 50–500 ppm, depending on the intended use and sensory impacts.[5,93] The use of advanced delivery methods, including Pickering emulsions prepared with chickpea Aquafina or microencapsulation were used, to increase stability, bioavailability, and targeted delivery of its active capsaicinoids and capsanthin.[94,95]

Cosmetics

In cosmetics, Capsicum-derived ingredients (extracts, powders, resins, oleoresins, and tinctures) are primarily used as skin-conditioning agents, external analgesics, fragrances, and rubefacients. Their primary cosmetic role is to induce a mild warming or irritating effect on the skin, which can help increase blood flow and provide a temporary invigorating or stinging feeling.[96] A few cosmetic items, including hair care, bath products, cleansers, and body care, contain these ingredients in concentrations ranging from 0.003% in shampoo to up to 5% in bath powder. For enhanced safety and efficacy, new delivery systems like nanoparticle-based hydrogels containing hyaluronic acid or emulgels containing capsaicin and anti-inflammatory agents (e.g. dexibuprofen) have also been developed to improve skin tolerance, reduce toxicity to keratinocytes (e.g. HaCaT cells) and enhance transdermal delivery.[97,98]

CONCLUSION

Chilli oleoresin is a powerful bioactive complex consisting of capsaicinoids, carotenoids, and polyphenols with well-documented analgesic, anti-inflammatory, antioxidant, and antimicrobial properties. Although operationally defined, traditional extraction approaches have critical limitations, namely, solvent toxicity and degradation of bioactive compounds. The adoption of advanced methods, namely, MAE, UAE, EAE and supercritical CO_2 extraction improve the sustainability, effectiveness, and selectivity. Vast use of chilli oleoresin in food processing, pharmaceutical, and cosmetic sectors further underscores the immense commercial and nutraceutical potential of chilli oleoresin. Nevertheless, issues of high cost of production, standardization of bioactive profiling, and limited large-scale clinical validation remain a hurdle to its full exploitation. Future research should prioritize green extraction process optimization, development of nanoparticle – and lipid-based delivery systems to improve bioavailability, application of multi-omics approaches to elucidate cultivar-specific biosynthesis, artificial intelligence-assisted modeling for extraction process optimization, and confirmatory multi-center randomized controlled clinical trials. Equally, commercialization of chilli oleoresin will depend on harmonized extraction and quality-control standards, reliable bioavailability data, clear regulatory approval pathways, and validated large-scale production protocols, which together remain key priorities for translating its laboratory-demonstrated therapeutic and nutraceutical potential into clinical and industrial practice.

AUTHOR CONTRIBUTIONS

K. Nirmal Kumar wrote the original manuscript text; H. Usha Nandhini Devi reviewed the manuscript and prepared the table; A. Sankari, P. Sudha, and K. Gurusamy reviewed the manuscripts.

DATA AVAILABILITY

No datasets were generated or analysed. Data sharing is not applicable to this article.

REFERENCES

1. Tripodi P, Kumar S. The *capsicum* crop: An introduction. In: The *Capsicum* Genome. Germany: Springer; 2019. p. 1-8.
2. Barboza GE, García CC, De Bem Bianchetti L, Romero MV, Scaldaferro M. Monograph of wild and cultivated chili peppers (*Capsicum* L., *Solanaceae*). PhytoKeys 2022;200:1.
3. Alonso-Villegas R, González-Amaro RM, Figueroa-Hernández CY, Rodríguez-Buenfil IM. The genus capsicum: A review of bioactive properties of its polyphenolic and capsaicinoid composition. Molecules 2023;28:4239.
4. Reyes-Escogido MD, Gonzalez-Mondragon EG, Vazquez-Tzompantzi E. Chemical and pharmacological aspects of capsaicin. Molecules 2011;16:1253-70.
5. Procopio FR, Ferraz MC, Paulino BN, Do Amaral Sobral PJ, Hubinger MD. Spice oleoresins as value-added ingredient for food industry: Recent advances and perspectives. Trends Food Sci Technol 2022;122:123-39.
6. Zhang W, Zhang Y, Fan J, Feng Z, Song X. Pharmacological activity of capsaicin: Mechanisms and controversies (Review). Mol Med Rep 2024;29:38.
7. Maharjan A, Vasamsetti BM, Park JH. A comprehensive review of capsaicin: Biosynthesis, industrial productions, processing to applications, and clinical uses. Heliyon 2024;10:e39721.
8. Avilés-Betanzos KA, Scampicchio M, Ferrentino G, Ramírez-Sucre MO, Rodríguez-Buenfil IM. Evaluation of the capsaicinoid extraction conditions from Mexican *Capsicum Chinense* Var. Mayapan with supercritical fluid extraction (SFE). Processes 2023;11:2272.
9. Sricharoen P, Lamaiphan N, Patthawaro P, Limchoowong N, Techawongstien S, Chanthai S. Phytochemicals in *Capsicum* oleoresin from different varieties of hot chilli peppers with their antidiabetic and antioxidant activities due to some phenolic compounds. Ultrason Sonochem 2017;38:629-39.
10. Sowbhagya H. Value-added processing of by-products from spice industry. Food Qual Saf 2019;3:73-80.
11. Hornero-Méndez D, Costa-García J, Mínguez-Mosquera MI. Characterization of carotenoid high-producing *Capsicum annuum* cultivars selected for paprika production. J Agric Food Chem 2002;50:5711-6.
12. Materska M, Perucka I. Antioxidant activity of the main phenolic compounds isolated from hot pepper fruit (*Capsicum annuum* L). J Agric Food Chem 2005;53:1750-6.
13. Topuz A, Ozdemir F. Assessment of carotenoids, capsaicinoids and ascorbic acid composition of some selected pepper cultivars (*Capsicum annuum* L.) Grown in Turkey. J Food Compost Anal 2007;20:596-602.
14. Marín A, Ferreres F, Tomás-Barberán FA, Gil MI. Characterization and quantitation of antioxidant constituents of sweet pepper (*Capsicum annuum* L.). J Agric Food Chem 2004;52:3861-9.
15. Wahyuni Y, Ballester AR, Sudarmonowati E, Bino RJ, Bovy AG. Secondary metabolites of *Capsicum* species and their importance in the human diet. J Nat Prod 2013;76:783-93.
16. Lu M, Chen C, Lan Y, Xiao J, Li R, Huang J, *et al*. Capsaicin-the major bioactive ingredient of chili peppers: Bio-efficacy and delivery systems. Food Funct 2020;11:2848-60.
17. Ludy MJ, Moore GE, Mattes RD. The effects of capsaicin and capsiate on energy balance: Critical review and meta-analyses of studies in humans. Chem Senses 2012;37:103-21.
18. Snitker S, Fujishima Y, Shen H, Ott S, Pi-Sunyer X, Furuhata Y, *et al*. Effects of novel capsinoid treatment on fatness and energy metabolism in humans: Possible pharmacogenetic implications. Am J Clin Nutr 2009;89:45-50.
19. Kim CS, Kawada T, Kim BS, Han IS, Choe SY, Kurata T,

et al. Capsaicin exhibits anti-inflammatory property by inhibiting IkB-a degradation in LPS-stimulated peritoneal macrophages. Cell Signal 2003;15:299-306.

20. Erden Y. Capsanthin stimulates the mitochondrial apoptosis-mediated cell death, following DNA damage in MCF-7 Cells. Nutr Cancer 2021;73:662-70.
21. Altman RD, Aven A, Holmburg CE, Pfeifer LM, Sack M, Young GT, editors. Capsaicin cream 0.025% as monotherapy for osteoarthritis: A double-blind study. In: Seminars in Arthritis and Rheumatism. Amsterdam: Elsevier; 1994.
22. Sharma PK, Fuloria S, Alam S, Sri MV, Singh A, Sharma VK, *et al*. Chemical composition and antimicrobial activity of oleoresin of *Capsicum annuum* fruits. Mindanao J Sci Technol 2021;19(1):29-43.
23. Barceloux DG. Pepper and capsaicin (*Capsicum* and piper species). Dis Mon 2009;55:380-90.
24. Batiha GE, Alqahtani A, Ojo OA, Shaheen HM, Wasef L, Elzeiny M, *et al*. Biological properties, bioactive constituents, and pharmacokinetics of some *Capsicum* spp. And capsaicinoids. Int J Mol Sci 2020;21:5179.
25. Márkus F, Daood HG, Kapitány J, Biacs PA. Change in the carotenoid and antioxidant content of spice red pepper (paprika) as a function of ripening and some technological factors. J Agric Food Chem 1999;47:100-7.
26. Riquelme N, Matiacevich S. Characterization and evaluation of some properties of oleoresin from *Capsicum annuum* var. Cacho de cabra. CyTA-J Food 2017;15:344-51.
27. O'Sullivan L, Jiwan MA, Daly T, O'Brien NM, Aherne SA. Bioaccessibility, uptake, and transport of carotenoids from peppers (*Capsicum* spp.) Using the coupled *in vitro* digestion and human intestinal Caco-2 cell model. J Agric Food Chem 2010;58:5374-9.
28. Pérez-Gálvez A, Martin HD, Sies H, Stahl W. Incorporation of carotenoids from paprika oleoresin into human chylomicrons. Br J Nutr 2003;89:787-93.
29. Varelis P, Melton L, Shahidi F. Encyclopedia of Food Chemistry. Amsterdam: Elsevier; 2018.
30. Nisar N, Li L, Lu S, Khin NC, Pogson BJ. Carotenoid metabolism in plants. Mol Plant 2015;8:68-82.
31. Dippong T, Senila L, Muresan LE. Preparation and characterization of the composition of volatile compounds, fatty acids and thermal behavior of Paprika. Foods 2023;12:2041.
32. Varela C, Silva F, Costa G, Cabral C. Alkaloids: Their Relevance in Cancer Treatment. New Insights into Glioblastoma. Amsterdam: Elsevier; 2023. p. 361-401.
33. Estrada B, Bernal MA, Díaz J, Pomar F, Merino F. Fruit development in *Capsicum annuum*: Changes in capsaicin, lignin, free phenolics, and peroxidase patterns. J Agric Food Chem 2000;48:6234-9.
34. Schweiggert U, Carle R, Schieber A. Conventional and alternative processes for spice production-a review. Trends Food Sci Technol 2007;18:260-8.
35. Ancy A, Kanimozhi NV, Ashok Kumar S, Palpandi Raja R, Sukumar M. A review of extraction and quantification of capsaicin and its bio insecticidal activity in food grains. Prep Biochem Biotechnol 2024;54:435-43.
36. Madhusankha GD, Siow LF, Thoo YY. Efficacy of green solvents in pungent, aroma, and color extractions of spice oleoresins and impact on phytochemical and antioxidant capacities. Food Biosci 2023;56:103171.
37. Mustafa A, Turner C. Pressurized liquid extraction as a green approach in food and herbal plants extraction: A review. Anal Chim Acta 2011;703:8-18.
38. Klausen SJ, Falck-Ytter AB, Strætkvern KO, Martin C. Evaluation of the extraction of bioactive compounds and the saccharification of cellulose as a route for the valorization of spent mushroom substrate. Molecules 2023;28:5140.
39. Mokaizh AA, Nour AH, Alazaiza MY, Mustafa SE, Omer MS, Nassani DE. Extraction and characterization of biological phytoconstituents of Commiphora gileadensis leaves using Soxhlet method. Processes 2024;12:1567.
40. Olguín-Rojas JA, Vázquez-León LA, Palma M, Fernández-Ponce MT, Casas L, Fernández Barbero G, *et al*. Re-valorization of red habanero chili pepper (*Capsicum chinense* Jacq.) Waste by recovery of bioactive compounds: Effects of different extraction processes. Agronomy 2024;14:660.
41. Huang P, Yu Q, Feng X, Ma C, Kan J. Optimization of accelerated solvent extraction of paprika oleoresin and its effect on capsaicinoid and carotenoid composition. J Food Compost Anal 2022;110:104589.
42. Zhang Q, Chen Y, Geng F, Shen X. Characterization of spray-dried microcapsules of paprika oleoresin induced by ultrasound and high-pressure homogenization: Physicochemical properties and storage stability. Molecules 2023;28:7075.
43. Jiang C, Zhang L, Yu L, Fang Z, Hu B, Chen H, *et al*. Effects of Thermal Treatments on the Physicochemical and Flavor Profiles of Chili Powders and Their Derived Chili Oils. Foods 2025;14:3129.
44. Ravindran A, Jayashree E, Anees K. Recent advances in the extraction of spice essential oil and oleoresin: A review. Agric Rev 2025;46:53-61.
45. Corsetti S, Alessandroni L, Coppin JC, Tonanni V, Sagratini G. The added value of flavouring extracts from Calabrian chili peppers by-products: Characterization of bioactive and volatile compounds comparing green extraction techniques. Eur Food Res Technol 2025;251:3821-37.
46. Fabela-Morón MF, Cuevas-Bernardino JC, Ayora-Talavera T, Pacheco N. Trends in capsaicinoids extraction from Habanero chili pepper (*Capsicum chinense* Jacq.): Recent advanced techniques. Food Rev Int 2020;36:105-34.
47. Kaufmann B, Christen P. Recent extraction techniques for natural products: microwave-assisted extraction and pressurised solvent extraction. Phytochem Anal 2002;13:105-13.

48. Barbero GF, Palma M, Barroso CG. Determination of capsaicinoids in peppers by microwave-assisted extraction-high-performance liquid chromatography with fluorescence detection. Anal Chim Acta 2006;578:227-33.
49. Routray W, Orsat V. Microwave-assisted extraction of flavonoids: A review. Food Bioprocess Technol 2012;5:409-24.
50. Martínez J, Rosas J, Pérez J, Saavedra Z, Carranza V, Alonso P. Green approach to the extraction of major capsaicinoids from habanero pepper using near-infrared, microwave, ultrasound and Soxhlet methods, a comparative study. Nat Prod Res 2019;33:447-52.
51. Barbero GF, Ruiz AG, Liazid A, Palma M, Vera JC, Barroso CG. Evolution of total and individual capsaicinoids in peppers during ripening of the Cayenne pepper plant (*Capsicum annuum* L.). Food Chem 2014;153:200-6.
52. Du HY, Shen ZJ, Li Y. Microwave-assisted extraction of capsaicin from chili pepper powder. Adv Mater Res 2013;634-638:1591-4.
53. Barbero GF, Liazid A, Palma M, Barroso CG. Ultrasound-assisted extraction of capsaicinoids from peppers. Talanta 2008;75:1332-7.
54. Vázquez-Espinosa M, González De Peredo AV, Ferreiro-González M, Barroso CG, Palma M, Barbero GF, *et al*. Optimizing and comparing ultrasound-and microwave-assisted extraction methods applied to the extraction of antioxidant capsinoids in peppers. Agronomy 2019;9:633.
55. Civan M, Kumcuoglu S. Green ultrasound-assisted extraction of carotenoid and capsaicinoid from the pulp of hot pepper paste based on the bio-refinery concept. Lwt 2019;113:108320.
56. De Mello AF, Hoscheid J, Raspe DT, Stevanato N, Da Silva C. Green extraction of oleoresin from pink pepper fruits: Effect of experimental conditions and characterization. AppliedChem 2024;4:56-69.
57. Cortés-Ferré HE, La Vega D, Romero G, Antunes-Ricardo M, Gutierrez J. Ultrasound assisted extraction of capsaicinoids from by-products of chili pepper industry and effects on macrophage cells viability. SSRN Electron J 2022.
58. Hussain M, Qamar MT, Ahmed D. Microwave-and ultrasound-assisted extraction of capsaicin from *Capsicum annuum* using deep eutectic solvents. Int J Veg Sci 2022;28:312-9.
59. Keharom S, Mahachai R, Techawongstein S, Chanthai S. Optimization studies on ultrasonic assisted extraction of the capsaicinoids from sweet-to-superhot chilli samples using response surface methodology. Int Food Res J 2016;23:1676-84.
60. Peña-Alvarez A, Alvarado LA, Vera-Avila LE. Analysis of capsaicin and dihydrocapsaicin in hot peppers by ultrasound assisted extraction followed by gas chromatography-mass spectrometry. Instrum Sci Technol 2012;40:429-40.
61. Chanthai S, Juangsamoot J, Ruangviriyachai C, Techawongstien S. Determination of capsaicin and dihydrocapsaicin in some chilli varieties using accelerated solvent extraction associated with solid-phase extraction methods and RP-HPLC-fluorescence. J Chem 2012;9:1550-61.
62. Soldan AC, Arvelos S, Watanabe ÉO, Hori CE. Supercritical fluid extraction of oleoresin from *Capsicum annuum* industrial waste. J Clean Prod 2021;297:126593.
63. Liu A, Han C, Zhou X, Zhu Z, Huang F, Shen Y. Determination of three capsaicinoids in *Capsicum annuum* by pressurized liquid extraction combined with LC-MS/MS. J Sep Sci 2013;36:857-62.
64. De Aguiar AC, Viganó J, da Silva Anthero AG, Dias ALB, Hubinger MD, Martínez J. Supercritical fluids and fluid mixtures to obtain high-value compounds from *Capsicum* peppers. Food Chem X 2022;13:100228.
65. Machado TD, Portugal I, Kodel HD, Fathi A, Fathi F, Oliveira MB, *et al*. Pressurized liquid extraction as an innovative high-yield greener technique for phenolic compounds recovery from grape pomace. Sustain Chem Pharm 2024;40:101635.
66. Barbero GF, Palma M, Barroso CG. Pressurized liquid extraction of capsaicinoids from peppers. J Agric Food Chem 2006;54:3231-6.
67. Fernández-Trujillo J. Supercritical CO 2 extraction of sweet and hot paprika. Grasas Aceites 2008;59:7-15.
68. Perva-Uzunalić A, Škerget M, Weinreich B, Knez Ž. Extraction of chilli pepper (var. Byedige) with supercritical CO2: Effect of pressure and temperature on capsaicinoid and colour extraction efficiency. Food Chem 2004;87:51-8.
69. Del Valle JM, Jiménez M, De La Fuente JC. Extraction kinetics of pre-pelletized Jalapeño peppers with supercritical CO2. J Supercrit Fluids 2003;25:33-44.
70. Deka D, Swami Hulle NR. Supercritical fluid extraction of Bhut Jolokia oleoresin and its quality analysis. SN Appl Sci 2021;3:260.
71. Jarén-Galán M, Nienaber U, Schwartz SJ. Paprika (*Capsicum annuum*) oleoresin extraction with supercritical carbon dioxide. J Agric Food Chem 1999;47:3558-64.
72. Ksh V, Anand V, Rana VS, Mishra J, Varghese E, Upadhyay N, *et al*. Extraction of capsaicin from *Capsicum chinense* (cv Bhut Jolokia) using supercritical fluid technology and degradation kinetics. Chem Papers 2023;77:6747-61.
73. Cortes-Ferre HE, Antunes-Ricardo M, Gutiérrez-Uribe JA. Enzyme-assisted extraction of anti-inflammatory compounds from habanero chili pepper (*Capsicum chinense*) seeds. Front Nutr 2022;9:942805.
74. Baby KC, Ranganathan TV. Effect of enzyme pretreatment on yield and quality of fresh green chilli (*Capsicum annuum* L) oleoresin and its major capsaicinoids. Biocatalysis Agric Biotechnol 2016;7:95-101.
75. Mendoza NN, Rodríguez SA, Lima BL. Mejoramiento de la extracción de carotenoides y capsaicinoides del

ají nativo (*Capsicum baccatum*), asistido con enzimas celulolíticas. Rev Peruana Biol 2020;27:55-60.
76. Nath P, Kaur C, Rudra SG, Varghese E. Enzyme-assisted extraction of carotenoid-rich extract from red *Capsicum* (*Capsicum annuum*). Agric Res 2016;5:193-204.
77. Sowbhagya HB, Chitra VN. Enzyme-assisted extraction of flavorings and colorants from plant materials. Crit Rev Food Sci Nutr 2010;50:146-61.
78. Salgado-Roman M, Botello-Alvarez E, Rico-Martínez R, Jiménez-Islas H, Cárdenas-Manríquez M, Navarrete-Bolaños JL. Enzymatic treatment to improve extraction of capsaicinoids and carotenoids from chili (*Capsicum annuum*) fruits. J Agric Food Chem 2008;56:10012-8.
79. Rohit K. Effect of Enzyme Treatment on Preparation of Chili Oleoresin and its Food Application. Karnataka: CSIR-CFTRI; 2013.
80. Zampieri FG, Junior JC, Rodrigues VA, Lambert JC, De Souza TD, De Oliveira AD, *et al*. Evaluation of the chemical composition and quantification of capsaicin in oleoresin from peppers of the genus *Capsicum* spp. Rev Delos 2024;17:e1380.
81. Sarojam S, Mohan N, Paul SS, Chacko BK, Nema NK, Jacob V. A comparative study on cultivars of capsicum: critical assessment based on colour values, pungency and total capsaicinoids content. Open Food Sci J 2020;12:9-17.
82. Toscano A, Silva AFR, Ramos MP, Komora N, Silva FVM, Fradinho P. Spicy food ingredient from red habanero by-product obtained by ultrasound-assisted extraction. Foods 2025;14:1407.
83. De Aguiar AC, Osorio-Tobon JF, Vigano J, Martinez J. Economic evaluation of supercritical fluid and pressurized liquid extraction to obtain phytonutrients from biquinho pepper: Analysis of single and sequential-stage processes. J Supercrit Fluids 2020;165:104935.
84. Dos Santos P, De Aguiar AC, Rezende CA, Martínez J, editors. Supercritical Carbon Dioxide Extraction of Oleoresin from Malagueta Pepper (*Capsicum frutescens* L.) Enhanced by Ultrasound. In: Iberoamerican Conference on Supercritical Fluids Cartagena de Indias, Colombia; 2013.
85. Srinivasan K. Biological activities of red pepper (*Capsicum annuum*) and its pungent principle capsaicin: A review. Crit Rev Food Sci Nutr 2016;56:1488-500.
86. Gupta A, Joshi R, Dewangan L, Shah K, Soni D, Patil UK, *et al*. Capsaicin: Pharmacological applications and prospects for drug designing. J Pharm Pharmacol 2025;77:459-74.
87. Catalfamo LM, Marrone G, Basilicata M, Vivarini I, Paolino V, Della-Morte D, *et al*. The utility of *Capsicum annuum* L. In internal medicine and in dentistry: A comprehensive review. Int J Environ Res Public Health 2022;19:11187.
88. Goci E, Haloci E, Di Stefano A, Chiavaroli A, Angelini P, Miha A, *et al*. Evaluation of *in vitro* capsaicin release and antimicrobial properties of topical pharmaceutical formulation. Biomolecules 2021;11:432.
89. Anantaworasakul P, Anuchapreeda S, Yotsawimonwat S, Naksuriya O, Lekawanvijit S, Tovanabutra N, *et al*. Nanomaterial lipid-based carrier for non-invasive capsaicin delivery; manufacturing scale-up and human irritation assessment. Molecules 2020;25:5575.
90. Petran EM, Periferakis A, Troumpata L, Periferakis AT, Scheau AE, Badarau IA, *et al*. Capsaicin: Emerging pharmacological and therapeutic insights. Curr Issues Mol Biol 2024;46:7895-943.
91. Usmani Z, Dar AH, Altaf A, Jagdale YD. Pepper oleoresin: Properties and economic importance. In: Handbook of Oleoresins. Boca Raton: CRC Press; 2022. p. 1-9.
92. Vuerich M, Petrussa E, Filippi A, Cluzet S, Fonayet JV, Sepulcri A, *et al*. Antifungal activity of chili pepper extract with potential for the control of some major pathogens in grapevine. Pest Manag Sci 2023;79:2503-16.
93. Prasad VR. Branding of paprika oleoresin in chilli-challenges and opportunities. Int J Agric Sci 2023;19:134-7.
94. Sahin SS, Hernández-Álvarez A, Ke L, Sadeghpour A, Ho P, Goycoolea FM. Composition, characterisation and emulsifying properties of natural nanoparticles in chickpea aquafaba for the formation of chilli oleoresin-in-water Pickering emulsions. Food Hydrocoll 2024;150:109728.
95. Fernandes B, Oliveira MC, Marques AC, Dos Santos RG, Serrano C. Microencapsulation of essential oils and oleoresins: Applications in food products. Foods 2024;13:3873.
96. Baenas N, Belović M, Ilic N, Moreno DA, García-Viguera C. Industrial use of pepper (*Capsicum annum* L.) derived products: Technological benefits and biological advantages. Food Chem 2019;274:872-85.
97. Chittasupho C, Thongnopkoon T, Burapapisut S, Charoensukkho C, Shuwisitkul D, Samee W. Stability, permeation, and cytotoxicity reduction of *Capsicum* extract nanoparticles loaded hydrogel containing wax gourd extract. Saudi Pharm J 2020;28:1538-47.
98. Burki IK, Khan MK, Khan BA, Uzair B, Braga VA, Jamil QA. Formulation development, characterization, and evaluation of a novel dexibuprofen-capsaicin skin emulgel with improved *in vivo* anti-inflammatory and analgesic effects. AAPS Pharm Sci Tech 2020;21:211.

Source of Support: Nil. **Conflicts of Interest:** None declared.