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Review

Valorizations of Marigold Waste for High-Value Products and Their Industrial Importance: A Comprehensive Review

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Abstract: The municipal authorities in developing nations face serious challenges in marigold flower garbage management. The primary issue is that they never are reused after prayers. Flower waste of *Tagetes erecta*, *T. patula*, and *Calendula officinalis* L. are commonly used for carotenoid and flavonoid extractions and, subsequently, used for incense stick and biogas production. Marigold plants are also used for phytoremediation during their growth stage. The lutein industry is booming due to its increasing market demand, expected to reach ~2121.2 billion tons by 2022, where marigolds are a major contributor globally. The process of isolating lutein from saponified marigold oleoresin yields a product with 70–85% purity. Lutein is a major xanthophyll (70–88%) of marigold petals, and a maximum of 21.23 mg/g of lutein was extracted. This review discusses the properties of selective marigold species, their compositions, and the extraction of different flavonoids and carotenoids, especially lutein. Moreover, different extraction methods of marigold lutein, the collection of marigold waste, and their subsequent utilization to derive several value-added products are discussed. Among physical treatments, ultrasonic-assisted extraction and enzymatic treatment with 5% solids loading were the maximum-yielding methods.

Keywords: marigold; *Tagetes*; carotenoids; flavonoids; value-added product; lutein; extractions

1. Introduction

Marigolds are cultivated widely in the Asian and African regions with higher adaptability and are used as cut flowers, loose flowers, and pot flowers. However, the most preferable type is loose flowers in many countries. Especially in India, they are extensively used for social and religious functions in the form of gajra and a variety of garlands. India began as the land of deities, and offering flowers has great value in worshiping the deities; this, in turn, generates a lot of floral waste. During the festive season, marigold flowers are specifically offered to many deities as offerings in favor of blessings [1]. After offering the florals to the deities, the flowers complete the purpose of worshiping but lose their value and are then treated as waste, collected with other waste before finding their way to be dumped in water bodies or with other waste and pollute the environment. Numerous beneficial, small-scale products can be manufactured with these flowers [2].

The African marigold is a medicinal plant cultivated almost everywhere; for example, one of the species of marigold is *Tagetes erecta*, grown in Africa. There are 33 different species of *Tagetes*, whereas, among the 2 most common types, the French marigold is the name given to *Tagetes patula*, and the African marigold to *Tagetes erecta* [3]. *Tagetes patula*, a species of flowering plant, is a native of Mexico and Guatemala with a wide naturalized population in various countries. The cultivation of marigolds depends mostly on many factors, including crop management, seed and soil quality, time of year, latitudes, etc. [4]. *Tagetes* spp. contain some phytochemicals and nutraceuticals that can be used to cure eye-related diseases (such as cataracts and age-related macular degeneration (AMD)), cardiovascular diseases, cancer, etc. The petals of marigolds contain a high level of lutein content (oxygenated carotenoid xanthophyll) and are used as coloring agents in the food and feed industries, as well as being used for antioxidants [5].

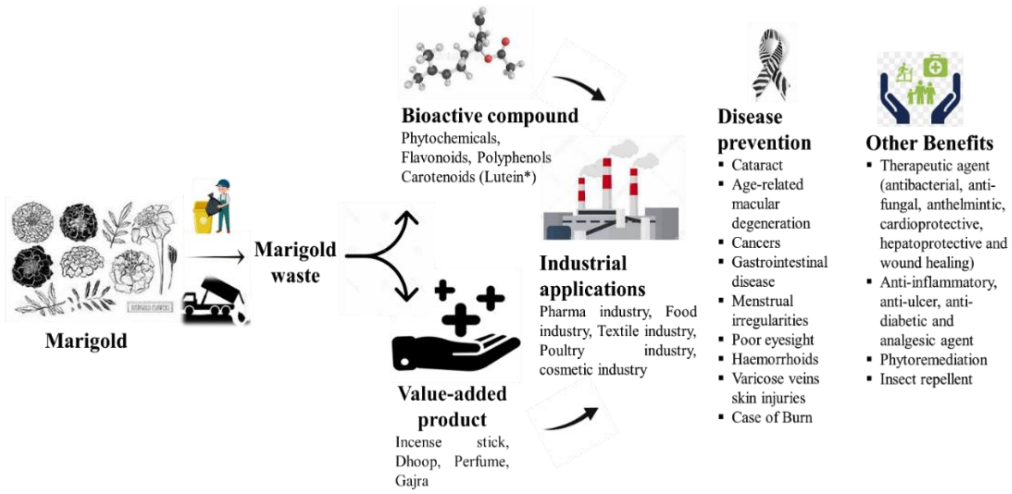
Carotenoids and polyphenols are considerably found in marigold flower petals, where lutein esters are a major component, which accounts for 70–79% of the total carotenoids [6,7]. Researchers are paying more attention to this ornamental plant due to the presence of bioactive compounds and its enormous therapeutic potential, especially in reducing the probability of macular degeneration [8]. Carotenoids are the most abundant and re-occurring pigments found in all families of plants, as well as animals. There are about 1100 known carotenoids, and various studies have provided proof that about 50–60 available carotenoids from different sources of consumption are beneficial for the human body. Khachik et al. [9] isolated, studied, and characterized three carotenoids, namely lutein, zeaxanthin, and lycopene. There are many sources for lutein and zeaxanthin, but the most economical sources are marigold flowers and *lycium chinense* mill berries. In marigold flowers, lutein is a major carotenoid accompanied by 3 to 6% zeaxanthin and is present in esterified form with fatty acids such as palmitic acid, myristic acid, and lauric acids.

Major lutein-rich foods are spinach, grapes, egg yolks, kiwi fruits, zucchini, squash, kale, and corn. Lutein is a major xanthophyll (70–88%) that occurs in marigold petals [10], and a maximum 21.23 mg/g of lutein was reported using ultrasonic intensity in 12.5 min of extraction time [8]. Lutein, along with zeaxanthin, illustrates suitable consumption of the product and helps to stop or ameliorate the effects of deteriorating human diseases [11]. Along with the extraction of lutein, the extraction of flavonoids from marigolds has attracted significant attention with respect to anti-inflammatory, antioxidant, and chelating properties. After extraction, the toxicity of flavonoids is also important. Therefore, it is necessary to assess their safety by using standard procedures of trials for the harmless use of herbal drugs and further novel antioxidant development. Marigold flavonoids are significant therapeutic products for herbal medicines and represent further progress in novel antioxidants [12].

On the other hand, several microalgal strains, such as *Chlorella sorokiniana* Kh12, among others, are renowned for being extremely productive lutein producers, with typical lutein contents up to 13.69 mg/g [13]. However, adequate biomass production requires over a month of bioprocessing, along with chemicals, facility, and labor, and the lutein obtained is in the range of 1–1.37 g/100 g biomass compared to 17–570 mg/100 g produced conventionally from available marigold waste. Although microalgae are a potential and alternative source of lutein accumulation, there are plenty of challenges in the growth of microorganisms, such as strain selection, cultivation, harvesting, extraction, and purification [14]. Currently, marigold petals assist as the main source of lutein in industries and researchers are developing a different extraction method to enhance the lutein content from marigolds [15].

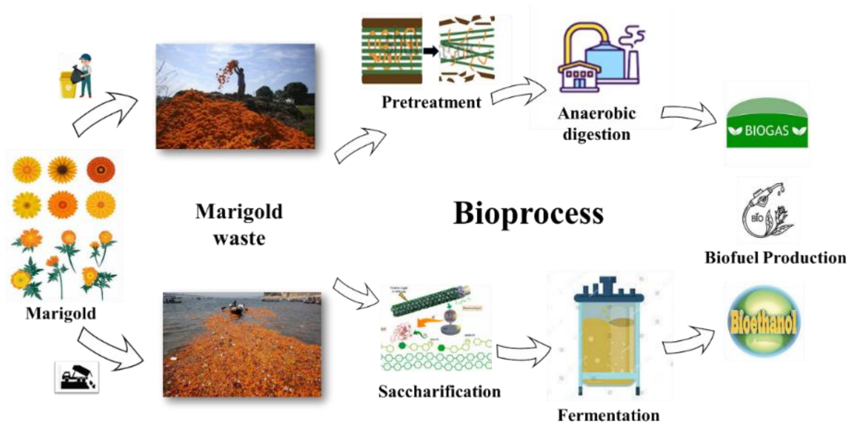
Heavy metal contamination of the land is another major environmental threat. Several physicochemical remediation techniques are generally used to deal with heavy metal contamination threats at various sites, but these methods have drawbacks, such as not being economically and commercially viable, disrupting nature, and degrading soil health. Therefore, chemical remediation is not preferred over biological methods [16]. Plant-based phytoremediation develops as a sustainable, efficient, and cost-effective potential method for the removal of several organic contaminants, such as pesticides, dyes, hydrocarbons, crude oil, chlorinated solvents, explosives, polychlorinated biphenyls, etc., as well as inorganic hazardous contaminants, such as heavy metals radionuclides, from the environment [17]. In addition to enhancing the environment's aesthetic, ornamental plants such as *Tagetes patula* L also help to clean the environment, provide extra income, and create new work opportunities [18]. Marigold flower waste contains a sufficient amount of nutrients and cellulosic fraction, making it appropriate for a variety of uses, including bioenergy production, dressing for lawn conditioners, compost preparation, and environmentally friendly incense sticks, rose water, and other goods. Hence, marigold-waste-produced cost-effective biofuels have the potential to fulfill sustainable energy demands [19]. As marigold waste offer several high-value products, it develops as a resource rather than merely a waste and exhibits great potential for contributing to a circular bioeconomy once adopted for product extraction before carrying out treatment. Products such as lutein and zeaxanthin are high-value products costing > 7500 USD/kg, depending on their purity [20].

The municipal authorities in developing nations such as India have a serious challenge managing marigold garbage. Marigold waste is typically disposed of in landfills by municipal authorities. The primary issue with the flowers is that they are never reused and are instantly wasted after being offered to deities. This article deals with the reuse of marigold waste, especially *Tagetes erecta*, *Tagetes patula*, and *Calendula officinalis* L., especially for carotenoids (lutein), along with other value-added products, such as phytochemicals and flavonoids, by direct extraction, which has several applications, as well as by manufacturing valuable products such as incense sticks, dhoop, etc., as shown in Figure 1a. On the other hand, many industries utilize marigold waste through bioprocessing and produce high-demand biofuels, such as biogas and bioethanol (shown in Figure 1b). The applications of lutein and other products are well-known to consumers. Moreover, marigold-derived flavonoids are used as good therapeutic agents and have several therapeutic effects, such as antiviral, antioxidant, cardioprotective, and wound-healing effects, as shown in Figure 1. This article also discusses the pre-treatment, drying, and filtration processes of marigold flowers, as well as an efficient methodology for the extraction of lutein from marigold waste. Marigold plants are employed for phytoremediation during the growing stages and in later stages, and they serve as a useful feedstock for lutein extraction. Due to carotenoids and other value-added products' extraction, marigolds are commercially important and, thus, have found a wide range of applications in both health and non-health sectors.



(**a**)

Figure 1. *Cont.*



(**b**)

Figure 1. Marigold waste valorization: (**a**) direct extraction of valuable products and their applications; (**b**) schematic illustration of bioprocess steps for biofuel production.

2. Marigold as a Major Source of Commercial Lutein

Lutein is an important xanthophyll (carotenoid) in marigold petals. A carotenoid is a terpenoid pigment with a backbone of 40 carbon and a strong, coupled double-bond structure. It has a major role in photosynthesis and photoprotection [21,22], with various physiological roles in human cells as blue light filters and antioxidants [23,24]. It has antioxidative and anti-inflammatory properties due to oxygenated carotenoid structures called xanthophylls, which contain carbonyl or hydroxyl groups that help in increasing their solubility and, thus, their dispersion in tissues [25]. Various forms of lutein are found in marigold petals. Free lutein ((3R, 3′R,6′R) β, ε-carotene 3,3′ diol), or yellow oxycarotenoid, has a chemical formula of $C_{40}H_{56}O_2$ with a molecular weight of 568.88 g/mol. It is yellow in color and has gained immense popularity along with zeaxanthin, the chemical structure shown in Figure 2.

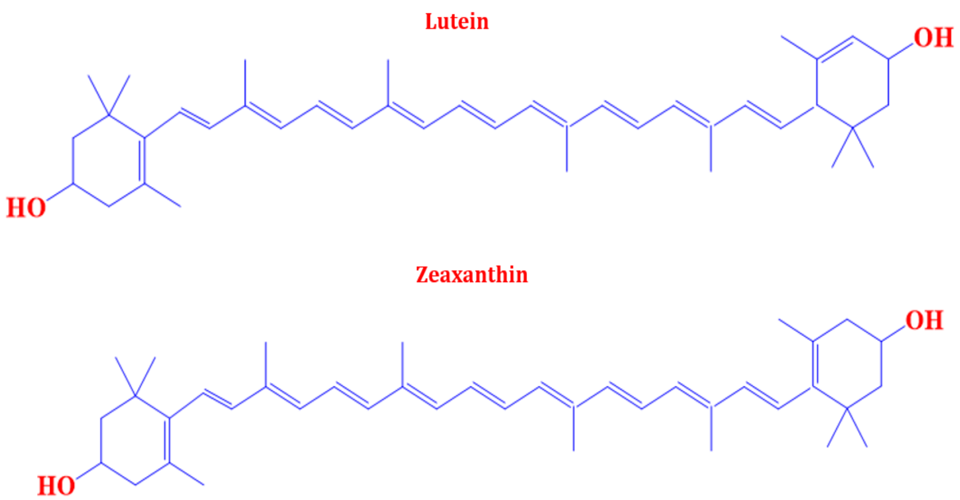


Figure 2. Structures of lutein and zeaxanthin.

Lutein (commonly known as an eye supplement) is a yellow to orange lipophilic carotenoid pigment related to Beta-carotene and Vit A found in the macula and retina of human eyes. The major function of this carotenoid in human eyes protects the eyes from rays of sunlight through light filtering [26]. Lutein has a major role in preventing eye diseases, such as vision loss due to cataracts and age-related macular degeneration. Moreover, lutein may have special effects in various clinical conditions, as it is reported that it reduces cancer risk, improves cardiovascular health, and ameliorates the function of cognitive disorders. Overall, constant lutein consumption through supplementation or diet can reduce various chronic disorders [25]. Along with its antioxidant properties, it has a major role in the anticipation of degenerative diseases and age-related macular diseases (AMDs), as well as various antibacterial, insecticidal, analgesic, and healing properties. Popular sources of lutein include marigold flowers, which yield about 5–50% oleoresin after the extraction procedure, out of which it is mostly present in the diester form with palmitic, myristic, and lauric acids, as well as two fatty acid groups occupying the place of hydroxyl groups [18]. Seven species of marigold flowers, including durango red, hero bee marigold souci, antigua orange, antigua yellow, safari scarlet marigold souci, safari yellow marigold souci, and janie primrose marigold souci, were identified for lutein content with different artificial supplements [27].

Lutein shares the C 40 isoprenoid with other carotenoids and also has an extended double bond where the polyene chain exists in either trans- or cis-configurations, making possibilities of multiple trans- and cis-isomers of lutein [28]. Lutein also plays an important role in light-harvesting photosystem II (PS-II) and is involved in photoprotection, accumulation in the retina to light reception, blue light filtration, and additives in poultry feed to improve the nutrition quotient. Lutein and xanthophyll have almost similar structures with the only difference in the position of the double bond. Lutein contains allylic double bonds (one ε-ionone ring and one β-ionone ring), whereas zeaxanthin structures have two rings of the β-ionone ring with conjugated double bonds. Generally, lutein is present in the esterified fatty acid form mostly with palmitic acid. The esterification considerably slows the process of degradation and is difficult for extraction, and it can be extracted in bulk from oleoresin. However, oleoresin has been used as a traditional folk medicine for several years. Prior to formulation, lutein should be saponified to obtain free lutein because lutein is present in marigolds as a diesterified element with fatty acid [29]. The first attempt at the extraction of free lutein produced poor yields from marigold flowers, it was extremely time-consuming, and it utilized a lot of harmful organic solvents—thus, it was not commercially feasible [30]. The lutein industry is booming, and its worth was estimated to reach USD 263.8 million by 2017, and then USD 357.7 million by 2022, with a compound annual growth rate (CAGR) of 6.3%. The increasing demand for lutein in the market was estimated to reach about 2121.2 billion tons by 2022, with the major contributors to lutein production across the globe including China, Germany, Denmark, India, the US, etc. Moreover, a list of some major producers of lutein include Indiisre Synthite Industries, Omni-Active, and E.I.D. Parry [31]. Various patents have been filed for the extraction, recrystallization, and purification of lutein from marigold saponified oleoresin. Philip [32] described a procedure for lutein extraction using hot isopropanol (75 °C) for lutein ester recrystallization from marigold oleoresin, whereas Khachik et al. [33] explained a complete procedure for the isolation, extraction, and recrystallization of lutein from saponified marigold oleoresin obtained from the hexane-extracted fraction of marigold flowers. The recrystallization involved dissolving lutein crystals in a binary solvent system and thereafter lowering the temperature to recrystallize lutein in a substantially pure form that was free from other carotenoids and chemical impurities. It was the final purification process for highly pure lutein crystals using a mixture of dichloromethane (containing 1% triethylamine) and hexane. The purity of the resulting lutein was usually over 90% and most often greater than 97%. The major drawback faced in the last purification step was the use of dichlone-hexane and n–hexane as recrystallization solvents, which needed thorough removal of solvent residues under a high-vacuum condition.

To obtain a purity range of 70–85% for lutein from saponified marigold oleoresin, a process used propylene glycol and an aqueous alkali to improve solubility for saponification at 70 °C for 10 h. However, the disadvantage of this procedure was the use of high temperature at multiple steps and prolonged exposure of the saponified product to high temperatures of 70–85 °C [34]. Hexane was used for lutein extraction from marigold flowers at 25 °C, followed by its evaporation at 60 °C with an additional step of alcohol mixing with oleoresin for the removal of impurities. Later, parting and drying of the carotenoid ester was carried out, which contained about 10% isomerized diester [35]. Simultaneous extraction and saponification procedures were reported at 25 °C using alcoholic potassium or sodium hydroxide and tetrahydrofuran. After completion of the reaction, free acid-crystallized lutein was obtained, and recrystallization was carried out for further purification. The main purpose of this procedure was to create an economical and convenient procedure for the separation of lutein, along with zeaxanthin. The results revealed that the lutein extracted had no byproducts and offered a purity of about 97%, which is suitable for human consumption [36].

2.1. Methodology for Lutein Extraction

The conventional method for the lutein extraction process involves a few basic steps, which include the pretreatment of fresh marigold flowers, filtration, drying, the extraction of lutein ester, the vacuum drying of oleoresin, the saponification of lutein ester, the purification of free lutein, crystallization, etc. [37].

2.2. Pretreatment, Filtration, and Drying of Waste Marigold Flowers

The process of pretreatment of marigolds was demonstrated in freshly picked flower petals from experimental cultivation fields, which were placed in sunlight for 10 days to remove ~80% of the moisture and then, finally, dried in a hot-air oven at 50–60 °C before they were ground and stored in a dark place at 25–27 °C [38]. In another study, greenhouse-grown fresh marigold flowers were collected and prepared as samples by washing and air-drying in the dark for 8 h at 45 °C to attain a moisture content of 8% prior to being ground, sieved, and stored [39]. Another approach also ground the obtained marigold flowers and sieved them for particle size determination, and the minimum heating of ground sample was ensured, and moisture content was determined [40]. The extraction of lutein ester from marigold flowers was achieved by drying petals and grinding them with anhydrous Na_2SO_4 before extracting with hexane [41]. Abdel-Aal and Rabalski [27] used seven cultivars of marigold flowers from the *Tagetes erecta* and *patula* families, including durango red, hero bee marigold souci, antigua orange, antigua yellow, safari scarlet marigold souci, safari yellow marigold souci, and janie primrose marigold souci. These marigold flower cultivars were collected, pooled, and frozen prior to use for analyzing lutein content, as well as different edible supplements and potable teas present in the market. Various pretreatment procedures utilize different approaches, such as chemical, physical, and enzymatic processes, for lutein extraction. Some past research utilized marigolds from the local market and determined about a 93% moisture content. For pretreatment, four batches were carried out, with first batch used as the control and the remaining batches as references treated with sodium hydroxide (0.125 M, pH 8.5), citric acid (0.05 M, pH 4.0), and a commercial enzyme (viscozyme) at different concentrations, ranging between 0.05% and 2.0%, for 48 h at a controlled temperature and pH [42]. Viscozyme is a mixture of protease, cellulase, hemicellulase, xylanase, and arabinase enzymes showing pectin-solubilizing and β-glucanase activities. After pretreatment steps, the pretreated flowers were drained and dried using a hydraulic press and hot-air drier respectively, and moisture content was determined at regular intervals. The obtained dried mass was ground, and the powder was used for experimentation, storage, and lutein extraction, as well as other purposes. One study reported a unique pre-treatment procedure that involved ensilage spray (anaerobic fermentation) on marigold flowers, which added an additional artificial competition with addition of lactobacillus to ensure the preservation of lutein and lutein ester, followed by saponification and fine extraction to obtain "free lutein" as the final product [28]. Another study focused on improving xanthophyll extraction using marigold flower ensilage, in which the addition of lactobacillus helped to preserve the carotenoid content from degradation. This approach yielded 24.9 g of xanthophyll per kg flowers, complementing the endogenous microorganisms of *Flavobacterium* IIb, *Acinetobacter anitratus*, and *Rhizopus nigricans* and showcasing high cellulase activity. This method proved more cost-effective and time-efficient, as onsite enzyme production offers economic viability and process-time reduction, which are the major characteristics in any experiment design [43].

2.3. Different Approaches for Extraction of Lutein Esters

There are several methods for the extraction of lutein ester from pretreated and dried marigold flowers (shown in Figure 3). Some techniques that are frequently used are (a) solvent-based extraction, (b) enzyme-based extraction, (c) supercritical fluid extraction, and (d) high-speed counter-current chromatography.

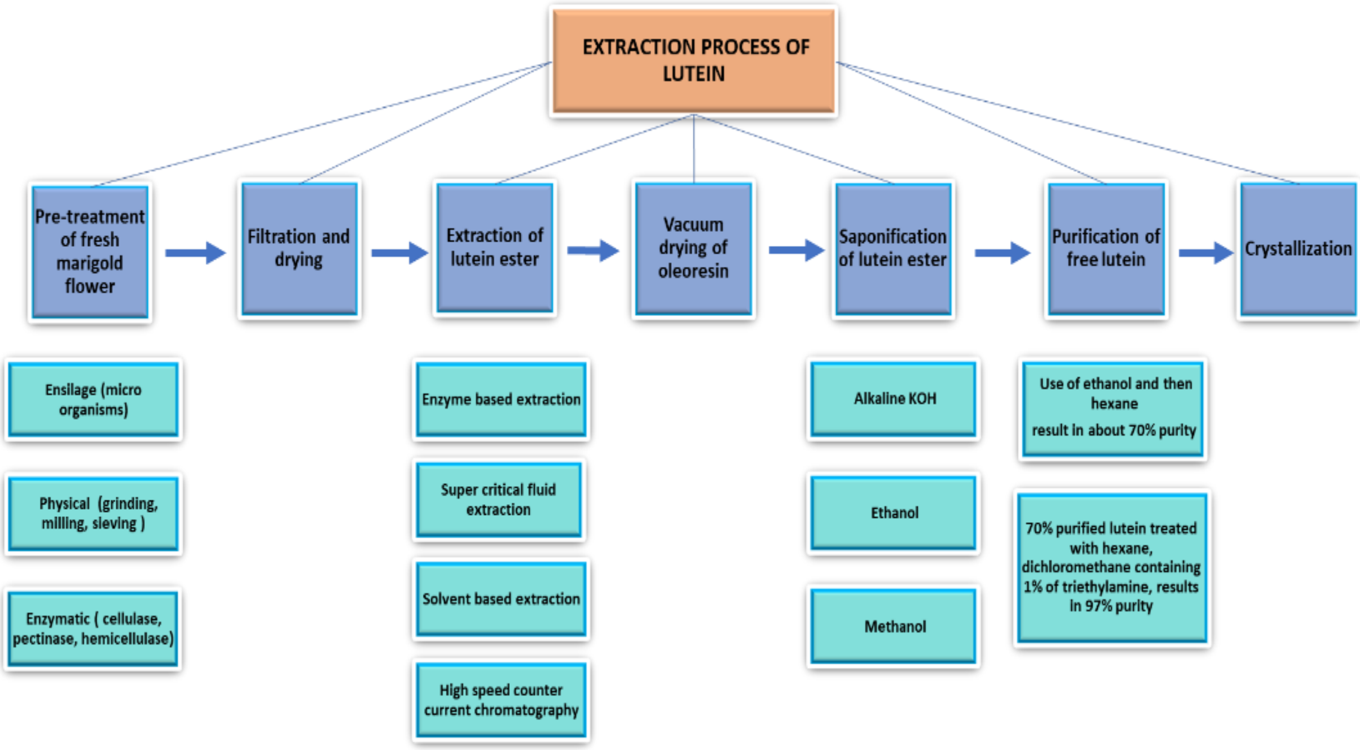


Figure 3. Various extraction processes of lutein from marigold flower waste.

(a) **Solvent-Based Extraction**

Solvent-based extraction is one of the conventional methods and is a widely used method for the extraction of many plant-based valuable products from raw material. Extraction involves various stages, such as (i) penetration of a solvent into the solid matrix, (ii) disbanding of the solute in the solvent, (iii) diffusing out of the solute, and (iv) collection of extracted solutes. Many factors affect the extraction process, such as properties of the extraction solvent, size of the raw material, the ratios of the solute and solvent, temperature, and extraction time, as well as solubility, cost-effectiveness, safety, environmental effect, solute dissolution, concentration, and timing, as these factors play an important role in the selection of a solvent [44].

Moreover, lutein extraction from marigold flowers uses different solvent systems to figure out the organic solvent best-suited for the extraction of free lutein. Previous studies have reported the use of numerous organic solvents for lutein extraction from marigold flowers, including hexane, ethyl acetate, ethanol, chloroform, propanol, benzene, diethyl ether, isopropanol, isobutanol, acetone, and xylene, among others [40,45]. Different solvents have different extraction efficiencies of lutein, which are summarized in Table 1. Some studies have suggested mixing of solvent extraction method with slight modifications, such as supercritical fluid (SCF) extraction, microwave-assisted extraction (MAE), and aqueous two-phase separation, for the generation of better yields, along with spectrometry, UV-vis spectrophotometry, and chromatographic analysis for lutein estimation [38]. Solvent-based extraction utilizes various phases of collection, extraction for an extended period of time of about 9 h, concentration of the extract, storage with light protection, and an extremely low temperature to safeguard the extracted lutein from degradation [46].

Table 1. Extraction methods of lutein, along with used organic solvents and their efficiencies.

Marigold	Extraction Method	Organic Solvent Used	Recovery/Efficiency	References
Tagetes patula	Solvent-based extraction	Acetone	78.26 ± 0.66 ppm lutein	[47]
Tagetes patula	Solvent-based extraction	Acetone, ethanol, and water	25.13 ± 1.02 g/100 g flavonoids	[48]
Calendula officinalis	Solvent-based extraction	n- hexane and acetone	0.7 to 2.7% total carotenoids	[49]
Calendula officinalis L.	Solvent-based extraction	n- hexane and acetone	0.8% to 1.7% flavonoids	[49]
Tagetes erecta	Solvent-based extraction	Hexane	99.12% free lutein	[50]
Tagetes erecta	Supercritical carbon dioxide extraction method	Hexane, palm oil, and CO_2	157.2 ± 4.4 mg free lutein/g oleoresin	[51]
Tagetes erecta	Solvent-based extraction	Hexane	65% free lutein	[52]
Tagetes erecta	Green method	2-methyltetrahydrofuran	97.64%	[53]
Tagetes erecta	Dimethyl ether extraction	Liquefied dimethyl ether	20.71 mg/g	[7]
Tagetes erecta	Solvent-based extraction	n-hexane, acetone, and ethanol	8.95 mg/g (dw) lutein	[54]
Tagetes erecta	Solvent-based extraction	n-hexane, acetone, and ethanol	14.55 mg/g (dw) zeaxanthin	[54]

There are many advantages to the solvent extraction method, but it also is accompanied by many concerns, such as affecting our environment with hazardous chemicals and solvents. To overcome this drawback, ecofriendly green solvents produced from renewable resources of biomass feedstock (e.g., wood, starch, fruits, and vegetable oils) or from petrochemical products that are nontoxic and biodegradable are being used for marigold product extraction [55]. Some of these evaluated green solvents are cyclopentyl methyl ether (CPME), dimethyl carbonate (DMC), dimethyl ether, ethyl acetate (EA), isopropyl alcohol (IPA), and 2 methyl tetrahydrofuran (2-MeTHF) [52,56]. During extraction using dimethyl ether (a green solvent) researchers reported about 20.65 mg of total xanthophyll per gram of dried marigold flowers, which was further de-esterified to obtain free lutein [52].

(b) **Enzyme-Assisted Extraction**

Hydrolytic enzymes are used in enzyme-assisted extraction to break down the cell wall's structural integrity for the exposure of intracellular materials for improved extraction. Carotenoids extracted from plant samples with enzyme-assisted extraction seem to have a lot of potential and are promising for commercial and industrial applications. Typically, pectinase and cellulase are utilized in the pretreatment stage prior to the extraction process. While pectinase works to breakdown the pectin compounds and pectin found in the middle lamella and primary cell walls, cellulase hydrolyzes the 1,4-D-glycosidic bonds of the cellulose present in the primary cell wall of plant cells [42]. Other than cellulase, pectinase, and hemicellulase, several commercial enzymes are also utilized in enzyme-assisted extractions, such as viscozyme, pectinex, neutrase, corolase, and HT-proteolytic enzymes. These enzymes are commercially manufactured and show higher activities than pectinase, cellulase, and hemicellulose and, subsequently, better conversion to oleoresin by evaporation under vacuum conditions [56]. According to Barzana et al. [57], hydrolytic enzymes served as a better alternative for lutein extraction due to their ability to act in an organic solvent with a smaller amount of water, could be utilized for the simultaneous breakdown of marigold flowers and extraction of lutein or carotenoids in less time, and provided better yields compared to other processes.

Various commercial enzymes have been used in lutein extraction from marigold petals, such as Econase-CEP (having glucosidase activity) and Pectinase-CEP (having mixed activity of pectinase, cellulase, and hemicellulose). Fresh marigold flowers were separated from receptacles and processed fresh with dehydration and milling through a sieve. After a series of slurries, they were treated with enzymes and antibiotics to prevent contamination, and the pH was adjusted according to the nature of the sample for high recovery. Enzymatic treatment with a 5% solids slurry produced the marigold meal with the highest all-trans-lutein content, reported as up to 25.1 g/kg dry weight at the end of the experiment [58].

(c) **Super Critical Fluid Extraction**

Supercritical CO_2 (SC-CO_2) is used as an extracting solvent in supercritical fluid extraction (SFE), making it a successful technique for removing carotenoids from both solid and liquid matrices. In comparison to traditional approaches, it has many advantages over conventional methods, such as rapid penetration into the pores of complex matrices, and it is made possible by an SC-enhanced CO_2 diffusion coefficient and reduced viscosity, which improve the extraction efficiency. SFE-produced extracts are also highly concentrated since process depressurization easily separates CO_2, removing all traces of harmful organic solvents from the final product. Additionally, SC-CO_2 extraction is thought of as a green extraction method because the CO_2 gas stream may be recycled. SFE often involves drying and grinding processes. Dimethyl ether (subcritical), a water-miscible solvent, can be used to remove the need for sample dehydration, cell disruption, and solvent evaporation [59]. In addition to ethanol, various organic modifiers can be utilized in supercritical fluid extraction, including acetone, methanol, propane, methylene chloride, and ethyl acetate [60]. Several conventional and non-conventional techniques of extracting carotenoids have led researchers to the conclusion that SC-CO_2 is the most efficient approach under ideal conditions, producing the largest yields and purest carotenoids without using any solvents that are harmful to the environment. It has several advantages, such as easy product isolation, low critical-point temperature, low toxicity, and simply depressurization. Moreover, a cosolvent (ethanol and vegetable oils) is used for improving the extraction efficiency, whereas palm oil is the most efficient (enhance lutein by 16%) cosolvent with ethanol, olive oil, soyabean oil, etc. Generally, a cosolvent interacts with a solute and sample matrix, but SC-CO_2 provides higher solubility due to leading solubility with lutein fatty acid esters, resulting in a higher extraction of lutein [51]. Supercritical CO_2 (SC-CO_2) extraction is a novel technique to enhance the extraction of lutein from marigolds using ultrasound. Extraction efficiency depends on different parameters, including flow rate of CO_2, temperature, pressure, particle size of the matrix, and ultrasonic conditions, such as frequency, power, and irradiation time or interval on lutein yield. Some results demonstrated that the presence of ultrasound considerably improved the output of lutein esters (p 0.05) due to the higher mass-transfer coefficient in the solid phase. A particle size fraction of 0.245–0.350 mm, a temperature of 55 °C, an extraction pressure of 32.5 MPa, and a CO_2 flow rate of 10 kg/h with an ultrasonic frequency of 25 kHz, an ultrasonic power of 400 W, and an ultrasonic irradiation time/interval of 6/9 s were used to achieve the highest yield of lutein esters, up to 690 mg per 100 g. Many organizations have improved lutein amount significantly by increasing the mass-transfer coefficient in the solid phase with the presence of ultrasound at lower temperatures and pressures [61].

2.4. High-Speed Counter-Current Chromatography as a Lutein Separation Method

High-speed counter-current chromatography (HSCCC) is a modern technique for the separation of bioactive compounds; it involves a support-free liquid–liquid partition method for product separation that eliminates the possibility of sample adsorption onto the solid support while carrying out extraction This method is widely utilized for the preparative separation of plant-based natural products, as it provides a larger separation capacity in comparison to high-pressure liquid chromatography (HPLC), and it also has an excellent recovery rate for analyses with the direct application of crude extracts [62].

The separation of lutein was performed with the HSCCC method using a two-phase solvent composed of n-heptane, chloroform, and acetonitrile in the ratio of 10:3:7, respectively. Some other solvents were reported for the homogenization and separation of lutein, such as isopropyl alcohol, acetone, hexane, methanol, toluene, etc. [63]. Lutein separation using HSCCC has a high success rate and was reported about at 7.6% lutein determined in the HPLC peak of an extraction sample obtained from marigold petals [64]. HSCCC does not utilize any solid support for extraction; hence, the retention of the stationary phase in the column is mandatory for obtaining a high peak resolution.

2.5. Saponification

The oleoresin obtained from marigold petals was subjected to hydrolysis by stirring one unit of oleoresin with three units of isopropanol at 60 °C until a flowy liquid solution was obtained. To the obtained solution, 50% aqueous potassium hydroxide was added slowly at a temperature of 60–65 °C with constant mixing and observation. After the completion of saponification, the mixture was allowed to cool down and was diluted with deionized water and left to stand still for an hour, and then diluted four times with deionized water and centrifuged to obtain an orange-colored precipitate, which was collected, washed, dried until 5% moisture was obtained, and preserved for further studies [38]. Another method for determining the best conditions for extracting lutein ester from dried marigold petals was to grind them with anhydrous Na_2SO_4, extract the hexane, and then perform saponification on the purified lutein ester by treating it with various concentrations of methanolic KOH at various temperatures for various reaction times. The extract was excavated with hexane until it turned colorless after being diluted with water. The saponified extract was evaporated to dryness and redissolved in methanol after being washed with excess water to remove alkali from the hexane extract. Then, using HPLC, the lutein content was estimated. However, the optimum efficient saponification conditions were reported at 50 °C with 0.5 M KOH for 30 min [64].

3. Other Value-Added Products from Marigold and Their Roles

The marigold flower is the most popular offering at temples in India. These flower wastes, like other waste offerings, become an environmental threat after serving their purpose. Such flower trash can be utilized in various ways to create useful products, which may also help to protect the environment from pollution brought on by the improper disposal of flowers dedicated to the gods. The literature has reported on various methods, such as the extraction of pigments and flavonoids, dye extraction, essential oil extraction, incense stick production, Holi color, biogas generation, and vermicomposting [65–69]. The details of a few of these value-added items obtained from marigold waste and their advantages are explained below and shown in Table 2.

Table 2. Flavonoids and value-added products from marigold species.

Marigold Species	Chemical/Flavonoid Composition	Value-Added Product	Reference
Tagetes patula	piperitone, trans-β-ocimene, terpinolene, and β-caryophyllene	Essential oil	[65]
Calendula officinalis	lupeol, taraxasterol, erythrodiol, calenduloside, quercetin, isorhamnetin, cubenol, α-casino, and oplopanonec	Medicines (treatment for inflammation of the skin and wound healing)	[66]
Tagetes minuta L.	β-phelandrene, limonene, β-ocimene, dihydrotagetone, tagetone, and tagetenone	Essential oil	[67]
Tagetes erecta	β-caryophyllene, limonene, methyleugenol, E-ocimene, piperetone, piperitenone, and terpinolene	Essential oil	[65]
Tagetes nelsonii Greenm.	α and β-pinene, trans-β-ocimene, limonene, linalool, (E) and (Z)-tagetones, dihydrotagetone, and cis- and trans-tagetenone	Perfume and incense sticks for pest control	[68]
Tagetes terniflora	cis-tagetone and cis-ocimene	Essential oil	[65]
Tagetes laxa	trans-tagetenone, cis-tagetenone, cis-β-ocimene, and trans-β-ocimene	Essential oil	[65]
Tagetes filifolia	trans-ocimenone, cis-tagetone, and cis-ocimenone	Native teas of Mexico and insect repellent	[17,69]

3.1. Incense Stick Production from Marigold Waste

According to TERI (Tata Energy Research Institute), waste generation in developing countries, such as India, is growing at a rate of 1.0 to 1.33 percent per year, where floral waste generally arises during festivals, ceremonies, and largely worships from temples, mosques, flower markets, and wedding halls, which causes environment pollution [70]. The CSIR-CIMAP (Council of Scientific and Industrial Research-Central Institute Medicinal and Aromatic Plants), Lucknow, India, has established an innovative technology using waste flowers and leaves for fragrant cone and incense stick production, which reduces environmental pollution. This innovative technology significantly decreased problems associated with the toxicity of smoke from typical, charcoal-based incense sticks by using a massive amount of waste flower [71].

Lighting incense sticks, agarbatti, and dhoop is a daily practice in the majority of Indian households, as it symbolizes many religious practices in worshiping. As well as having spirit-uplifting effects and benefits in aromatherapy, it is said to contain some essential oils that help in healing the blockage of nasal passages and give other health benefits, while burning in the home has great spiritual and religious value in the Hinduism practice [72]. Dried marigold flower samples were used to reduce poisonous smoke and harmful gases and help in combustion. Makko powder, arabic gum, and refined charcoal are basic ingredients in incense sticks, in which makko powder and arabic gum act as binding agents and refined charcoal helps in combustion [73]. Along with incense sticks, various value-added products, such as essential oils, medicinal benefits, dye extraction from carotenoids, vermicomposting, and the generation of other value-added products such as biofuel, can also be achieved [74].

The project named Mission Sakshama conducted by CSIR-CIAMP, Lucknow, Uttar Pradesh, focused on utilizing waste floral waste from spiritual grounds for incense stick preparation, and on average, 1500 incense sticks could be made from 1 kg of raw material [75]. Temple waste consisting of different flowers, along with marigolds, was collected in separate bins, segregated, and dried. The dried flowers were then mixed with binding agents (gum Arabic and Makko powder), along with a small amount of charcoal to make them combustible. The mixture was kneaded slowly to prepare a dough, and then the dough was rolled over bamboo sticks to make incense sticks [26]. Marigold is known to possess some insecticidal properties; the flower part of the marigold is generally used for various purposes, though other parts of *Tagetes erecta* were utilized by crushing the *Tagetes erecta* to powder to convert it into incense sticks for an economical commercial product with low to no side effects [76].

3.2. Marigolds to Biogas

The marigold is an alternative method for the production of chemical compounds and biogas through the integral valorization of leaves, stems, and exhausted flowers of marigolds. Anaerobic microorganisms allow the production of high-calorific-value energy carriers through carbohydrate biodegradation, such as biomethane or biogas [77]. Anaerobic digestion is an effective process to achieve biogas. Researchers have developed methods to increase the production of biogas from marigold waste, such as innovative alkaline pretreatment, solar digester heating, and codigestion with food waste. When compared to conventional sodium hydroxide pretreatment, a unique alkaline pretreatment of floral waste utilizing sodium carbonate and sodium bicarbonate resulted in a 106% increase in biogas generation while saving up to 96% on chemical pretreatment costs. Additionally, compared to digesters operating in ambient settings, solar heating of a digester boosted biogas output by 122%. Additionally, biogas generation was increased by 32.6% when floral waste and food waste were codigested. The methane content in raw biogas made from floral waste was over 57% which was higher than in other studies. Society could profit when these techniques are used on a large scale [78].

Pretreatment with alkaline agents, such as NaOH, Na_2CO_3, and $NaHCO_3$, at 60 °C for 24 h for various ADs of flower waste (marigold flowers, basil leaves, and aster flowers) under solar heating exhibited yields of biogas of 84.6, 100.1, and 101.8 mL/g of total volatile solids, respectively [78]. In comparison, anaerobic digestion (AD) of *Ocimum sanctum* (Tulsi) basil leaves using cow manure sludge at 27–30 °C achieved 77.2 mL/g of biogas from the total volatile solids [79]. The rest of the liquid and solid-part digestate could be used as potential fuel precursors, compost material, and soil amendments [80,81]. Moreover, the biodegradation ability of substrates could be improved by performing different pretreatments, such as thermal, physical, and chemical pretreatments [82]. In AD, the volatile solids content (VS) and total solids content (TS) are essential parameters to calculate the loads of substrate and sludge. The biodegradable content of a substrate is high (biogas productivity) in the high VS content of marigold samples, whereas the composition of organic compounds present in samples affects the yield of biogas. A maximum yield of biogas of 1624.3 mL/g VS (theoretically 70.4%) through fermentation of the solid fraction was found despite a low ratio of VS and TS in the AD stage. After upgrading stages for electricity generation in a sustainable energy economy, biogas residues can supply energy for industry or communities by direct combustion and methane consumption [79].

3.3. Marigold as a Therapeutic Agent

Since time immemorial, plants have been an important source to cure many diseases. Herbal medicines obtained from plants are used as traditional therapy to treat a wide range of diseases. These therapies are free from side effects and very cost-effective [83]. In India, 8000 medicinal plant species are used by several communities across different ecosystems. Interestingly, only 880 species (10%) are active in the market or trade [84]. Therefore, there is a need to explore efficient plants to promote herbal and cost-effective medicine.

Some marigold plants are famous as aromatic herbs, such as *Calendula officinalis* (also called English or pot marigold), belonging to Asteraceae family and used as medicine in traditional times known as Ayurveda. Due to containing a good range of phytochemicals, including saponins, triterpenoids, triterpenes, esters, carotenoids, flavonoids, steroids, essential volatile fatty acids, polysaccharides, and amino acids, marigolds are used to treat many diseases because they possess several biological activities. They act as an anti-inflammatory, anti-ulcer, antidiabetic, and analgesic agent and have various therapeutic effects, such as antiviral, antioxidant, antibacterial, antifungal, anthelmintic, cardioprotective, hepatoprotective, and wound-healing properties [85]. Many more species of marigold have been discovered as therapeutic agents to cure several ailments, including gastrointestinal disease, menstrual irregularities, poor eyesight, hemorrhoids, varicose veins, skin injuries, and cases of burns [86,87]. *Tagetes erecta* is known as a potential healing agent for the treatment of dermal wounds by topical application (leading to earlier healing than those treated with saline), for promoting wound contraction, and for modulating inflammation [88]. Marigold extract is proved to possess a wide range of additional pharmacological properties, as well as antioxidant, anti-edematous, anti-human immunodeficiency virus (HIV), and immunostimulant activities. Moreover, other properties include hepatoprotective, anticytotoxic, and spasmolytic activities, and they also exhibit effects on the expressions of increased tumor necrosis factor (TNF-alpha), pro-inflammatory cytokines, interleukin (IL-1 beta, IL-6), interferons (IFN-gamma), and acute-phase protein (C-reactive protein). Marigold has been unambiguously used to overcome the side effects of radiotherapy, but it may have significance for cancer treatment in the future [89]. Other known plants are *Lavandula stoechas*, *Rhododendron arboreum*, and *Curcuma longa*, which are used as therapeutic agents [90–92].

3.4. Marigold Essential Oil and Its Advantages

The demand for wild marigolds in the flavor and fragrance industries is rising due to their essential oil content. Moreover, due to climate change, generally plants have elevated abiotic stresses, which result in a reduction in growth, germination, and quality of essential oil. Wild marigold has several tolerance mechanisms to cope up with such hostile effects. They occur as boosted lipid peroxidation in the cell membrane to protect cell wall structure, enhanced activity of antioxidants to maintain cellular redox homeostasis, the accumulation of osmolytes, and the production of metabolites. Therefore, marigolds can grow over a wide range of climates because of physiological changes and biochemical characteristics of stress tolerance, which enable them to manage stress-tolerant lines [93]. Synthetic herbicides have a negative impact on human health and the environment. Therefore, plant-derivative products used as natural products are gaining more attention. Mexican marigolds *Foeniculum vulgare var. azoricum*, *Satureja hortensis* L., *Tagetes minuta* L., and *Tanacetum parthenium* L. were investigated for herbicidal effects with different essential oil concentrations. The major component of *T. parthenium* was found as camphor (56.63%), and dihydro-tagetone (62.57%) was the main constituent of *T. minuta*. Moreover, γ-terpinene (59.75%) and (E)-anethole (84.32%) were the major oil component of *S. hortensis* and *F. vulgare var. azoricum*, respectively. These essential oils were examined for herbicidal effects and strongly inhibits weeds, such as *H. spontaneum* and *A. retroflexus* [94].

The bioactive compounds of the marigold plant *Tagetes minuta* show medicinal properties and a broad range of microbicidal and insecticidal potentials against a wide range of microbes, nematodes, and insects. The allelopathic potential of the volatile essential oil of *T. minuta* was investigated in invasive weeds, such as *Phalaris minor* Retz. and *Chenopodium murale* L., and *Amaranthus viridis* L. volatile essential oil from *T. minuta* significantly reduced the growth, germination, chlorophyll content, and respiratory ability of weeds in a dose-dependent manner. Due to the complete arrest of mitotic activity revealed in cells of treated root tips of *Allium cepa*, these were effective with various aberrations, such as binucleated, trinucleated, and distorted cells [95].

4. Ecological Significance of the Marigold Plant in Phytoremediation

Alternatively, bioremediation methods can overcome the drawbacks of chemical remediation, as these methods are cost-effective and environmentally friendly. Among various bioremediation techniques, hyperaccumulator plants are the most preferred for contaminated sites [96]. The marigold plant does have the ability to accumulate heavy metals, and they develop a robust root system that helps them survive in contaminated soil, thereby helping in the decontamination of soil with a source of commercially valuable products and extraction of heavy metals from biomass by incineration, etc. [97]. The hyperaccumulator nature of two marigold species (*Tagetes patula* and *Tagetes erecta*) was studied in different types of soil (red, black, alluvial, clay, sewage sludge, sewage-irrigated, and garden soil) under uniform spiked heavy metal pollution (Cd, Cr, and Ni) in potted conditions and concluded that both species of marigold were effective in the bioremediation of Cd and Ni. The Cd was more accumulated by *Tagetes erecta*, and *Tagetes patula* accumulated more of Ni. The study concluded that the marigold plant could be used as a potential plant to remediate heavy-metal-contaminated soil, but the experiment needs to be performed at the field level [98–100].

The remediation of Ni using marigold species studies in pot and greenhouse conditions revealed that, up to 30 days, the concentration of organic Ni increased (20.46 mg/kg), whereas a slight decrease was observed on the 45th day, and after that rapid increase (103.13 mg/kg) was observed up to 60th day of experimentation. The experiment demonstrated a phytoremediation strategy for Ni by integrating bio-amendments with marigold hyperaccumulator species for the remediation of contaminated soil [101].

For the remediation of contaminated wastewater (domestic as well as commercial-grade, i.e., domestic and tanneries), the adsorption capabilities of marigold leaf powder and tea waste were used for investigation. These adsorbents were affected by the pH, electrical conductivity, and turbidity of the wastewater. The distribution of adsorbents at different amounts was studied, which revealed that tea waste as a biosorbent or coagulant had a greater impact than marigold flowers and could be utilized for wastewater treatment. The study considered a small-scale experimentation level, but the commercialization of this method totally depended upon the reusability and recovery of adsorbed contaminants in an economically feasible manner, which requires further studies in the field [102].

Another experiment about using the ornamental plant *Tagetes erecta* for the phytoremediation of heavy metals such as Cadmium (Cd), Lead (Pb), Zinc (Zn) involved potted plants filled with laterite soil with varying concentrations of 20 to 160 mg/kg heavy metals. The uptake of heavy metals was monitored for about a 12-week growth period and analyzed for residual heavy metals, revealing that the ability to uptake Zn and Cd was comparably high and 13 times as much as that for Pb, which was significantly high. At lower concentrations, the uptake of Cd was slightly higher than Zn, but at higher concentrations, Zn uptake was higher. The order of accumulation could be predicted as Cd > Zn > Pb for the shoots, but for roots the Zn > Cd > Pb accumulation order changed. The study revealed that *Tagetes erecta* was tolerant of heavy metals but acted as a hyperaccumulator for Cd and Zn but not Pb. *Tagetes erecta* beginning as an ornamental flower also ensured that it did not possess any risk of contamination of the food chain and was a good choice for bioremediation purposes [103,104].

5. Industrial Applications of Lutein

Marigold flowers are used by different industries, including the textile industry, food industry, pharma industry, agriculture industry, and veterinary industry, as a source of natural colorants, dyes, phytochemicals, aromatic oils, etc. [3]. The current lutein market is majorly divided into dietary supplements, pharmaceuticals, aquaculture, and animal industries. Several research articles have proved that lutein has attractive coloring, preservation, and textural properties and, hence, it can be used in the food and animal industries, but due to its instability in food components, various optimization procedures are tested to elicit health effects. Moreover, due to the antioxidant properties of lutein, it also serves multiple pharmaceutical purposes such as wound-healing, anti-ulcer, antibacterial, antimicrobial, hepato-protective, analgesic, etc. Due to their larvicidal, insecticidal, mosquitocidal, and nematocidal properties, they are used in aquaculture [105].

The food industry utilizes marigolds as a natural pigment to produce the most enticing yellow cheese and butter. For a more attractive appearance, dried marigold is also put into tea. Due to the presence of natural β-carotene in marigold flowers, extracts are utilized as food additives. In addition to bringing a delicate flavor to drinks, soup, and pesto, the blooms give a splash of color to many recipes [106]. Tea made from marigold flowers can ease stomach discomfort, treat stomach ulcers, and lessen cramping. *T. erecta* leaves are used broadly in the poultry industry as coloring ingredients for the yellow skin of chickens and the orange yolk present in their eggs. Chickens employ a carotenoid to change the color of chicken skin to a certain color and play a role in the development of fertility and metabolism. In the poultry sector, marigold is frequently employed to increase the amount of xanthophyll in corn and alfalfa meal to stabilize the feed xanthophyll content [107].

Numerous *Tagetes* sp. marigolds produce *Tagetes* oil, a potent, fragrant oil utilized in the cosmetics and fragrance industries. Fresh floral oils can have a deforming effect on the spine's marrow. Extracted marigold oil is used to relieve discomfort and treat bacterial ear infections. Researchers have discovered that the marigold flower's flavonoids have anti-inflammatory, cytotoxic, and inhibitory effects on colon cancer, leukemia, and melanoma cells. Marigold is frequently used in pharma industry due to its numerous therapeutic properties [3,108,109].

Nowadays, with worldwide concern about using environmentally friendly and decaying material in fabrics, manufacturers chose to use ecofriendly and biodegradable colors. Thus, natural dyes are in high demand in the textile industry because marigold offers various shades, such as orange, yellow, brown, etc. The other purpose of extracting dye from marigolds is to reduce environmental pollution [110].

6. Economic Importance of Marigold

The floriculture industry spans more than 145 nations, and the global floriculture trade was estimated to be worth USD 70 billion [111]. According to International Association of Horticultural Producers (AIPH 2010), about 702,383 hectares of area is used for flower cultivation across the globe, out of which 48,705 hectares in are Europe; 21,067 hectares are in North America; 523,828 hectares are in Asia; 4026 hectares are in the Middle East; 7604 hectares are in Africa; and 97,153 hectares are in South America [112]. The Netherlands is the biggest importer from developing countries, along with major producers of flowers. The US, Germany, the Netherlands, and the UAE are major importing countries for Indian floriculture [113]. India, as a spiritual country, has a vast floriculture sector; marigold flowers play an important role loosely, as well as in the form of garlands, for various auspicious functions. A total of 342,000 acres are used for floriculture, which yields 769,000 MT of cut flowers and 1,760,000 MT of loose flowers per year (2017–2018 estimates). To ensure continuous growth, the innovation of novel products is essential for the floriculture sector [114]. In India since 2017, the innovative technology developed by CSIR-CIMAP, Lucknow, of using waste flowers and leaves for fragrant cone and incense stick production has given training, demonstration programs, and job opportunities to more than 4500 women and unemployed youth per year [71].

Seven different microbial and fertilizer treatments were studied for enhancement in the production of a marigold crop. These treatments included azotobacter, azospirillum, purple sulfate bacteria (PSB), city compost, vermicompost, poultry beat on production, characterization of the plants, and flower content. The results showed that poultry beat was the most successful, as the plants were healthier, offering a yield of 272.56 q/ha, which was significantly higher than the other treatments. The other recorded yields were 26.48 (vermicompost), 263.98 (city compost), 241.49 (PSB), 238.98 (FYM), 232.48 (azotobacter), 228.92 (azospirillum), and 201.04 q/ha (control). Poultry beat was the most economical option among all the treatments, and the income generated after covering all the expenses for land rent and cost of cultivation, i.e., net and gross returns, was also significantly higher at the average price per quintal of loose marigold sold on the market for INR 1200 [115].

The carotenoid market on a global scale was estimated to be approx. USD 1400 million in 2017 and USD 2000 million by 2022, with an annual growth rate of 5.7% for the tenure 2017 to 2022, and lutein constituted only about 23% of the total global carotenoids market [116–118]. The bright yellow petals of Tagetes marigold flowers, which are a major source of the current commercial supply of lutein, are to blame. The European Union approved Tagetes lutein (E161b) as a food and healthcare product colorant, with a daily intake permissible of 1 mg/kg body weight [119]. By 2024, the market for lutein, which had a value of about USD 135 million in 2015, is expected to rise at a rate of 6% annually [120]. The market for lutein in the European Union was valued at EUR 255 million and is expected to grow to EUR 405 million by 2027 [121]. Due to its medicinal properties, it is highly demanded in the pharmaceutical industry because lutein has been tested for macular aged disorder, as it helps in UV light filtration, and is an excellent ROS scavenger, thus having beneficiary effects for aged individuals, infants, and pregnant women [105].

7. Future Prospective and Conclusions

Marigolds are a rich source of several important biomolecules, such as carotenoids and flavonoids, which have major applications in various industries, such as pharmaceutics, food and beverages, therapeutics, veterinary, cosmeceuticals, textiles, etc. During growth, this plant serves for the phytoremediation of various pollutants from polluted waterbodies. Moreover, after product extraction, residual waste is utilized for biogas, compost production, and various industrial applications. This review discussed the properties of marigold species, their compositions, and the extraction of different carotenoids, flavonoids, and lutein from marigold flowers. The different procedures followed for the extraction of lutein from marigold collection to marigold waste, as well as the utilization of the collected used flowers to form different value-added products for day-to-day utilization were discussed. It also discussed the challenges faced during various procedures, the production of value-added products, and approaches to make modifications for obtaining better yields and the removal of various complications in the commercialization of extracted biomolecules and value-added products. The review also walked through a comparison among various technologies involved in lutein extraction and purification processes, as lutein extraction is highly sensitive to light (formation of low molecular compounds), pH (de-esterification or cis- and trans-isomerization), and extreme temperatures, which makes it highly unstable for extraction. Lutein extraction from marigolds also bears some disadvantages, such as the utilization of a high amount of chemicals for extraction, as well as the saponification process, the availability of the marigold flower, the presence of smaller contents of lutein, and no proper procedure for the extraction of lutein from agro-based samples. Some other challenges faced are cost ineffectiveness, the time-consuming nature of the extraction procedure, low yields, and low purity levels, which act as deterrents in the commercialization of flower- or agro-based extraction of free lutein.

However, greater investigation of these approaches' costs, environmental safety, efficacy, and reproducibility is required. The automation of these techniques could also be beneficial for extensive industrial applications. When compared to conventional solvents, carotenoid extraction utilizing non-toxic solvents has a number of benefits for the environment, as well as applications in food and cosmetics. Therefore, it would make sense to have methodological and technological breakthroughs in these areas. Based on a range of high-value products extracted from marigold waste flower, they become a resource rather than merely waste and exhibit great potential for contributing to a circular bioeconomy in the near future once adopted for product extraction before carrying out treatment. Product extraction could be designed under a biorefinery concept for one or more products from a single process that enable not only the offset of treatment costs but gains profits, as lutein and zeaxanthin are such high-value products, costing > 7500 USD/kg depending on the purity.

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