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Research Article

Evaluation of Leaves, Flowers, and Seeds of Coriander (*Coriandrum sativum* L.) through Microwave Drying and Ultrasonic-Assisted Extraction, for Biologically Active Components

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The coriander plant (*Coriandrum sativum* L.) is well known for its antibacterial and antioxidant properties since it contains a considerable number of bioactive compounds. This property encourages the use of coriander in food because it has many health benefits and preserves food longer. The current study's objective was to demonstrate the extraction of coriander's three fractions (leaves, flowers, and seeds) using microwave drying and ultrasonic assistance, in order to identify its distinct functional components. After microwave drying, the highest amounts of ash, fat, fiber, and protein with values 6.39 ± 0.04, 10.10 ± 0.05, 10.14 ± 0.06, and $13.10 \pm 0.03\%$, respectively, were observed in coriander seeds. Among macro- and microminerals analyzed, contents of Ca and Mg were found highest in coriander leaves, with values 689 ± 0.14 and 412 ± 0.04 mg/100 g, respectively, whereas Fe, Zn, and Mn were found highest in seeds with values 15.46 ± 0.02, 3.92 ± 0.02, and 1.29 ± 0.02 mg/100 g. Ultrasonic-assisted ethanolic extracts of microwave-dried coriander leaves presented significantly high ($p < 0.05$) total phenolic contents (253.45 ± 0.12 mg gallic acid equivalent/100 g), total flavonoid contents (98.15 ± 0.09 mg quercetin equivalent/100 g), and total antioxidant activity (47.32 ± 0.04 mg trolox/100 g), followed by seeds, while flowers presented lowest values. Significantly high ($p < 0.05$) antimicrobial activities were exhibited from extracts of coriander seeds, followed by leaves. It was concluded that leaves, flowers, and seeds of coriander all were rich source of nutritional components and bioactives, and microwave drying and ultrasonic-assisted extraction were proved useful techniques for maximum retention of these contents in powders and ethanolic extracts, respectively.

1. Introduction

Particularly, plant-derived foods like fruits, vegetables, cereals, spices, and herbs have a greater antioxidant content, which makes them potentially therapeutic in addition to being a vital source of nutrition. Spices can be used to promote health in a variety of ways, including by helping people lose weight and preventing diseases including hypercholesterolemia, hyperglycemia, allergies, and obesity caused by food. The inclusion of numerous active phytochemicals, such as phenolics, flavonoids, carotenoids, vitamins, and minerals, is what gives spices their antioxidant potential [1–3]. Recently, there has been a resurgence of interest in using more natural items to improve fitness and health. The human diet includes a lot of herbs and spices. For thousands of years, people have used them to improve the flavor, color, and aroma of their food. Herbs and spices are known for their preservation and therapeutic properties in addition to flavor-enhancing ones [4, 5].

The herb coriander (*Coriandrum sativum* L.), a member of the *Apiaceae* family, is utilized extensively in both culinary and therapeutic contexts. It is indigenous to the Mediterranean and Middle Eastern areas, and Asian countries also have high knowledge and use of it [6, 7]. This spice is mostly grown for its fruits and/or leaves, which are used as a spice, food additive, and medication. The leaves can also be dried and used as an herb [8]. The leaves have a lanceolate shape; are lobed, green, or dark green; and are hairless on both surfaces. Little asymmetrical umbels of white or light pink flowers with petals pointing away from the center are produced by the blossoms. The coriander seed is a dry, globular, almost oval schizocarp with two mericarps and several longitudinal ridges on the surface. It tastes sweet, citrusy, and mildly spicy, with a sage undertone [9, 10].

Coriander is a staple in home cooking because of its high content of fiber, protein, iron, zinc, calcium, phosphorus, and vitamins A and C. These nutrients are important for human nutrition [11]. The role of iron, zinc, calcium, and magnesium in maintaining the different body functions and growth and metabolism is quite clear [12, 13]. Though they have quite different tastes and applications, coriander leaves, flowers, and seeds are all edible. The herb itself has a light, fresh flavor; it can be used whole or processed to make the ripe seeds more palatable before using them as a flavoring in various dishes [14]. Drying is one of the best ways to enjoy coriander, which has a significant role and advantage in human nutrition, throughout the years. Drying makes packing, storing, and transporting the item easier because it greatly reduces the amount of water that is present in it [15]. According to experimental tests, it is not only possible but also effective to dry specific coriander leaves, flowers, and seeds in a microwave oven without significantly changing their sensory qualities [16].

High quantities of bioactive components with antioxidant activity can be found in plants, in addition to fruits and vegetables, which are now suggested as the best sources of these components [17, 18]. Dietary phytochemicals are thought to be a useful treatment for a number of physiological conditions affecting humans [19]. The food industry's increased interest is a result of the benefits that come with using natural goods rich in bioactive compounds. Because the general public believes that dietary and natural antioxidants are safer than their synthetic counterparts, there is an increasing interest in the quest for natural antioxidants [7, 20, 21].

It is necessary to use appropriate and standardized processes in order to extract secondary metabolites from plants that have intriguing biological activity [22]. Bioactive components can be extracted in a matter of minutes, thanks to ultrasound-aided extraction, which causes damage to the plant wall through the propagation of ultrasonic waves through a liquid media. This enhances solvent penetration. Consequently, ultrasonic-aided extraction has the benefit over conventional methods in that it can reduce extraction process time and energy consumption while maintaining high efficiency [23, 24]. Ultrasound and microwave processing offer a lot of potential in food applications as green processing methods [25, 26]. Although there have been some studies upon the use of microwave and sonication for coriander, there were certain gaps which were needed to be covered. Hihat et al. [27] earlier used microwave drying for coriander leaves, but with limited analyses. Alibas and Yilmaz [15] applied microwave drying to check influence on proximate and mineral contents of coriander, but their study was limited to only coriander seeds. No authentic data about coriander flowers was found in the literature.

There is still much to learn about the comparative phytochemistry of coriander leaves, flowers, and seeds, and some of the available information is conflicting. As far as we are aware, there are not many studies on the antibacterial and antioxidant properties of coriander plants grown in Pakistan. In this study, we assessed and compared for the first time the antioxidant activity, total polyphenols, carotenoids, and ascorbic acid levels of the three fractions of coriander fruit that were microwave-dried, and then, ultrasonic-assisted ethanolic extracts were developed. The findings may shed light on coriander's potential value as a source of raw materials for the production of bioactive components used in industry.

2. Materials and Methods

2.1. Plant Materials. In the university botanical garden, coriander (*Coriandrum sativum* L.) was grown under carefully monitored circumstances without the use of pesticides or fertilizers. Following the harvesting process, the plant materials were quickly transported to the laboratory where they were kept damp pillows enclosed in a humidity-controlled refrigerator at +4°C until the drying process, which prevented them from losing their original moisture content. Currently, the plants were identified botanically with the assistance of pertinent specialists. The entire drying process was finished in a single day. Additionally, 500 ± 0.5 g samples were utilized in the drying process, and healthy and average-looking leaves, flowers, and seeds were chosen. Leaves and flowers of uniform size, shape, color, maturity, and free from any defects were collected for analysis. Seeds of uniform shape and color, with an average size of 4 ± 0.05 mm, of fully mature plants were taken. More importantly, same plants were used to obtain the leaves, flowers, and seeds, to avoid any variation in the experimental results.

2.2. Chemical Reagents. The analytical grade chemicals and reagents utilized in the current experimental studies were all acquired from Sigma Chemicals Co. in Germany. We bought genuine phenolic compound standards from Fluka and Sigma. These chemicals were produced as stock solutions in methanol of HPLC grade. These solutions were kept at 4°C after being covered in aluminium foil. Chem Tech Pvt. Ltd. provided drugs for reference in antimicrobial investigations and strains of bacteria and fungi.

2.3. Preparation of Coriander Three Fractions' Powders by Microwave Drying. As previously described by Chatzilia et al. [28], the three coriander fractions were dried in a microwave oven (Model R-3556M, 2450 MHz, Sharp Electronics Ltd., UK) at 800 W power. First of all, before drying, moisture content of each fraction was determined; after that, 500 g of each fraction was processed until the leaves, flowers, and seeds were totally dried, spreading them uniformly on a glass microwave oven plate. By determining the continuous moisture level, the ideal amount of time needed for drying each part was determined. Spread out on a paper plate, the dried fractions were given ten minutes to cool. Samples of microwave-dried coriander were finely ground using a mortar and pestle and ceramic knives in a manual grinder. We did not use any metal tools to reduce the possibility of contamination. A 0.5 mm diameter plastic sieve with a mesh bottom was used to strain the samples, having uniform particle size of the powders.

2.4. Proximate Analysis. The AACC [29] provided technique nos. 44-15A, 08-01, 30-25, 46-30, and 32-10 which were used to analyze the moisture, ash, crude fat, crude protein, and crude fiber contents, respectively, of the powdered samples of coriander flowers, seeds, and leaves.

2.5. Macro- and Micromineral Analysis. The analysis of mineral composition was conducted using the previous protocol provided by Beyzi et al. [30] as a guide. To determine certain minerals, around 0.5 g of each fraction powder was extracted, and 10 mL of a nitric+perchloric acid mixture was applied to the sample. After that, the samples were wet-ashed until just 1 milliliter of sample was left. The samples were diluted with distilled water once the ashing process was finished, and an atomic absorption spectrophotometer (PerkinElmer, Optima 4300, USA) was used for analysis. Amounts of macro- and microminerals were calculated as mg/100 g DW.

2.6. Ultrasonic-Assisted Extraction. In order to investigate the polyphenol contents and antimicrobial and antioxidant activities of three fractions of coriander, first of all, ethanolic extracts were developed with the assistance of ultrasound technology. Briefly explaining, 250 mL glass flasks were used for the extractions, and the sample to solvent ratio was 1 : 10 (w/v). For this purpose, 20 g powder of each fraction was dissolved separately in each 200 mL of 80% ethanol. In a sonication water bath (EUP540A, Euinstruments, France), ultrasonic-assisted extraction was carried out for 40 minutes at a fixed frequency of 40 kHz, 30°C, and 140 W of ultrasonic power, as was earlier reported by Zekovic et al. [31]. Glass flasks were never moved from their constant distance from the transducer, and no extra stirring was done. Following extractions, the extracts were quickly vacuum-filtered through filter paper, put into glass flasks, and kept at 4°C until analysis.

2.7. Total Phenolic Contents (TPC). Following the instructions provided by Mouhoubi et al. [32], the Folin-Ciocalteu reagent-based analysis was used to measure the total phenolic contents (TPC) of extracts of coriander leaves, seeds, and flowers. In summary, 0.5 mL of extract was combined with 2.5 mL of the Folin-Ciocalteu reagent that had been diluted in water (1/10). After two minutes of room temperature incubation, the mixture was added to 2 mL of sodium carbonate (75 g/L), incubated for fifteen minutes at 50°C, and then cooled in a water ice bath. A UV-Vis spectrophotometer (Shimadzu, Model UV-1800, Germany) was used to detect the specific absorbance at 760 nm right away. On a dry weight (DW) basis, the TPC was given as mg of gallic acid equivalents (GAE) per 100 g of each fraction powder.

2.8. Total Flavonoid Contents (TFC). According to Zekovic et al. [31], the aluminium chloride colorimetric assay was used to assess the total flavonoid content (TFC). The absorbance was measured at 510 nm, and a standard diagram was prepared using quercetin. As milligrams of quercetin equivalents (QE) per 100 grams of coriander seeds, flowers, and leaves (mg QE/100 g DW), the results were reported. Every experiment was run three times, to find out the mean values.

2.9. Total Antioxidant Activity (TAA). Using the methods previously outlined by Mouhoubi et al. [32], the ability of the coriander extracts to scavenge DPPH free radical was estimated. In short, the test involves adding 250 μL of DPPH to each well and mixing 50 μL of the sample at various concentrations. The absorbance reading at 517 nm is then obtained after the microplate has been in the dark for 30 minutes. TAA was given for each portion as mg trolox/100 g DW.

2.10. Total Carotenoids. To calculate the total carotenoids, three fractions of coriander were employed to the spectrophotometric technique. Total carotenoids were extracted using Priyadarshi et al.'s [33] methodology. To summarize, two grams of each sample was pulverized, 2 mM of α-tocopherol and 2 g of anhydrous sodium sulfate were added, and ice-cold acetone was used to extract the pigments. The residue was extracted again and again until it lost all color. In a rotavapor, the solvent was extracted at 40°C with a low pressure of 40 m bar. After diluting the concentrated extract samples appropriately with 50 mL of methanol, absorbance was measured at 450 nm. The dry weight basis total carotenoid contents were given as mg/100 g DW.

2.11. β-Carotene Test. The approach outlined by Hussain et al. [34] was utilized to ascertain the amount of β-carotene present in coriander leaf, flower, and seed samples. β-Carotene was measured with UV/visible photodiode and HPLC.

An internal diameter of 4.6 mm was employed in a 250 mm reversed-phase carbon-30 column, with a mobile phase consisting of 80% methanol and 20% tertiary butyl methyl ether. A sample size of 25 μL (ether extract) was injected, and the mobile phase flow rate was adjusted to 0.8 mL/min. The analysis took 60 minutes to complete at 30°C. Using HPLC grade reagents, all of these studies were carried out in triplicate, and mean results were computed.

2.12. Ascorbic Acid Test. As was previously reported by Nath et al. [35], the coriander leaf, flower, and seed samples were titrated against the indophenol dye (2,6-dichloroindophenol, sodium salt) to assess the amount of ascorbic acid located in these parts. According to the evanescent description, 10 g of crushed each sample was combined with 25 mL of the extraction solution (15 g of metaphosphoric acid, 40 mL of acetic acid, 3.7 mL of concentrated sulfuric acid, and 450 mL of water) and homogenized before being placed in a water bath, supported with a shaker, for at least an hour at 22°C. The leftovers were extracted two times with the 10 mL extraction solution, and then, the mixture was centrifuged vertically (10000 g for 5 min) until the pink color did not last for at least 15 s. The supernatants from each treatment were then titrated against the dye solution, which contained 50 mg dye, 42 mg $NaHCO_3$, and 200 mL water. The dye factor was estimated after each assay by titrating against dye using fresh ascorbic acid solution as the reference. Per 100 grams of material, ascorbic acid was determined in milligrams.

2.13. Antimicrobial Activity. Following the guidelines provided by Farah et al. [36], the antibacterial and antifungal properties of the chosen coriander extracts were investigated using the disc diffusion method. In the case of bacteria, Petri plates with 20 mL of nutritional agar were taken, whereas for fungi, Petri plates with 20 mL of potato dextrose agar were taken. Every Petri dish was planted with a set number of selected fungal and bacterial cultures. A sterile filter paper was used to develop small discs with a diameter of 6.0 mm. Then, these discs were dipped in 50 μL of each fraction extract and were placed on the media at prominent differences. Each plate was also placed with a reference drug disc, nominated as control, to compare the antimicrobial activities of the extracts with the reference drug. Every plate was incubated at 28°C for fungi and 30°C for bacteria. Then, in the case of bacteria, the inhibition zones were meticulously measured after 48 hours, and in the case of fungi, the inhibition zones were obtained after 10 days. Three replicates' mean values were noted.

2.14. Statistical Analysis. All results in this investigation are presented as means ± SD, and every extraction trial and analysis was done in triplicate. Influence of ultrasonic-assisted extraction and microwave drying on various coriander leaf, flower, and seed parameters was noted, and the data from the experiments were statistically evaluated using Tukey's post hoc test and ANOVA with a 95% confidence level, using JMP software (version 10.0, SAS). p values were employed to evaluate the importance of the parameters under study's influence.

3. Results and Discussion

3.1. Proximate Composition of Coriander Three Fractions. Proximate analysis results of coriander three fractions are shown in Table 1, presenting the significantly high amounts of ash, fat, fiber, and protein contents in seeds, followed by flowers, except for ash, which was found high in leaves. Jayasuriya et al. [3] stated that moisture content is a very accurate indicator of the growth of microorganisms and the deterioration of dry spice products, as well as the preservation of spices. High microwave power used in current study was proved useful in lowering the moisture content of leaves, flowers, and seeds of the coriander. The traditional hot air dying procedure has a lot of drawbacks. Microwave drying has provided a different approach in recent decades to enhance the quality of dried goods [28]. Present results were found in accordance with the earlier results of Shahwar et al. [37], when they compared coriander seeds and leaves for proximate analysis and reported significantly high amounts of ash, fat, fiber, and protein contents in seeds. Findings of current trials were also supported by the analysis performed by Bhat et al. [14], comparing coriander leaves and seeds for proximate composition.

Biologically active chemicals are typically lost during the thermal processing of plant materials. But it is generally known that a quick procedure like microwave improves bioactives by releasing them from constrained shapes [27]. The moisture content of leaves was determined to be 87% after being oven-dried at 70°C for a whole night, whereas after drying in the microwave at 850 W for 90 seconds, it was discovered that the moisture content of the dried coriander leaves was the same as that of oven-dried coriander [38]. Findings in line with current ones were observed when Alibas and Yilmaz [15] dried coriander leaves through microwave and reported high amount of protein.

El Hadidy and Rizk [39] developed coriander seed powder to incorporate in wheat flour for development of breads and reported higher concentrations of protein, ash, and fiber, as compared to present result, which might be due to cultivar difference and agroclimatic variations. Bhat et al. [14] compared leaves and seeds of coriander for moisture, ash, fat, fiber, and protein contents and reported higher parameters in seeds as compared to leaves, giving findings in line with the current study. The findings of Pirbalouti et al.'s [8] research showed that the drying process and temperature had an impact on the changes in chemical composition of coriander aerial components, with microwave drying turning out to be the most effective way.

3.2. Mineral Composition of Coriander Three Fractions. Mineral analysis data shown in Table 2 reveals that all coriander fractions are good sources of important minerals with significantly high ($p < 0.05$) values presented by leaves, followed by seeds, while coriander flowers are found lowest in these selected minerals. Among macrominerals, Mg and Ca were found in high amounts in leaves, and among microminerals,

Table 1: Proximate composition of coriander three fractions.

Microwaved powder of coriander three fractions	Proximate composition (%) Moisture	Ash	Fat	Fiber	Protein
Leaves	6.38 ± 0.03c	4.92 ± 0.03b	3.82 ± 0.01c	6.28 ± 0.02c	10.47 ± 0.06c
Flowers	7.23 ± 0.04b	3.52 ± 0.02c	6.19 ± 0.04b	8.41 ± 0.03b	11.94 ± 0.03b
Seeds	8.12 ± 0.02a	6.39 ± 0.04a	10.10 ± 0.05a	10.14 ± 0.06a	13.10 ± 0.03a

Each value is the mean ± SD. Different alphabetical letters in a column indicate significant results ($p < 0.05$).

Table 2: Mineral composition of coriander three fractions.

Microwaved powder of coriander three fractions	Minerals (mg/100 g) Mg	Fe	Zn	Ca	Mn
Leaves	412 ± 0.04a	14.62 ± 0.03b	3.56 ± 0.03b	689 ± 0.14a	1.07 ± 0.02b
Flowers	198 ± 0.02c	6.72 ± 0.01c	1.92 ± 0.01c	348 ± 0.30c	0.38 ± 0.01c
Seeds	349 ± 0.06b	15.46 ± 0.02a	3.92 ± 0.02a	534 ± 0.12b	1.29 ± 0.02a

Each value is the mean ± SD. Different alphabetical letters in a column indicate significant results ($p < 0.05$).

Zn and Fe were found high. The current mineral analysis of coriander leaves was well supported by the earlier latest experiments of Alibas and Yilmaz [15], using microwave drying of coriander leaves. Values of these minerals in coriander seeds were also supported by the findings of Beyzi et al. [30]. In another study, when Bhat et al. [14] compared presence of important minerals in seeds and leaves of coriander, similar outcomes were observed. In a similar study, using different drying techniques, the distribution of dietary minerals in the three components of coriander (leaf, stem, and root) was assessed. Potassium was the mineral found in the highest concentration in each section of the coriander plant, followed by calcium, magnesium, sodium, phosphorus, zinc, and iron. The rate of transpiration, as well as the growth and development of the plants, may be responsible for the different distribution of each mineral [6].

El Hadidy and Rizk [39] reported slightly higher contents of all these minerals in coriander seed powder, before inclusion in wheat flour to develop breads. Bhat et al. [14] summarized the mineral variations in coriander leaves and seeds and found equally higher contents of Fe, Zn, Ca, and Mg in both portions, with slightly higher values in leaves. During comparison of macro- and microminerals present in leaves and stems of coriander, Cao et al. [40] also provided in line results reporting that leaves contain higher mineral contents.

Calcium is a necessary mineral that influences blood clotting, some metabolic events, enzyme-related functions, and the stiffness of the skeleton. Magnesium is important in protein synthesis, energy metabolism, DNA synthesis, and the preservation of the electrical potential of nerve tissues and cell membranes in addition to being a cofactor for several enzymes. Despite its connection to neurodegenerative illnesses, magnesium is necessary for healthy cellular homeostasis, growth, and development. Zinc helps to maintain the integrity of cells by balancing the molecular structures of cell membranes and other components of the cell. It is a crucial part of numerous enzymes that are involved in the synthesis and degradation of lipids, proteins, carbohydrates, and nucleic acids. Iron is probably an oxygen-transporting component of haemoglobin. It also supports a strong immune system and is an ingredient in many enzymes that produce energy [12, 13, 41, 42].

3.3. Analysis of the Total Phenolic Contents (TPC), Total Flavonoid Contents (TFC), and Total Antioxidant Activity (TAA) in Coriander Three Fractions. Results regarding polyphenolic and antioxidant assay of coriander three part's ethanolic extracts have been presented in Table 3 from where it can be seen that leaves have significantly high amounts of TPC, TFC, and TAA, followed by seeds, whereas flowers were found lowest in all these parameters. Presence of high amount of these discussed bioactives in all three fractions of coriander may be attributed to microwave drying and ultrasonic-assisted extraction, as these implementations caused maximum retention of phytochemicals in extracts. Current findings were found in line with those of Zekovic et al. [31], when coriander seeds were extracted through ultrasonic technique to determine TPC, TFC, and TAA. Current values were much high than those of reported by Farah et al. [36], possibly due to the difference in the drying and extraction techniques adopted. Zekovic et al. [43] also reported on the ideal microwave-assisted extraction settings for maximizing polyphenol extraction and increasing the antioxidant activity of coriander seeds simultaneously while using ethanol as a solvent.

According to Divya et al. [38], both the leaves and the seeds of coriander have been demonstrated to contain antioxidants, but the leaves were shown to be more effective than the seeds, which can be ascribed to their high pigment content, particularly carotenoids, phenolics, and flavonoids. Findings of current research were also well supported by the recent work of Mouhoubi et al. [32], as microwave-assisted extraction proved effective for high phenolic contents of coriander leaves. In a similar study by Hihat et al. [27], coriander leaves' antioxidant capabilities were examined in relation to the impacts of two drying techniques. Results regarding antioxidants demonstrated that microwave-dried

Table 3: Total phenolic contents (TPC), total flavonoid contents (TFC), and total antioxidant activity (TAA) of coriander three fractions.

Ethanolic extracts of coriander three fractions	Polyphenol assessment TPC (mg GAE/100 g)	TFC (mg QE/100 g)	TAA (mg trolox/100 g)
Leaves	253.45 ± 0.12a	98.15 ± 0.09a	47.32 ± 0.04a
Flowers	188.90 ± 0.14c	59.82 ± 0.05c	21.42 ± 0.07c
Seeds	246.14 ± 0.21b	94.27 ± 0.06b	36 ± 0.05b

Each value is the mean ± SD. Different alphabetical letters in a column indicate significant results ($p < 0.05$). TPC: total phenolic contents; TFC: total flavonoid contents; TAA: total antioxidant activity; GAE: gallic acid equivalent; QE: quercetin equivalent.

leaves had higher total polyphenol and total flavonoid levels than oven-dried leaves (48.44 mg GAE/g and 20.28 mg RE/g, respectively, and 26.64 mg GAE/g and 19.60 mg RE/g, respectively). Further, at the end, it was determined that the employment of microwave technology significantly increased the scavenging action of the stable radicals ABTS and DPPH.

Presence of polyphenols in coriander flowers in rich amount was witnessed by experiments of Thakur and Nanda [44], on bee pollens of coriander leaves. DPPH radical scavenging activity, ferric reducing antioxidant power, and metal chelating activity were all significantly higher in coriander pollen, than in other samples. Strong correlations between TPC and the observed antioxidant properties were found. After moist-heat and fry-cooking procedures, the coriander leaf, stem, and root extracts under investigation significantly lost their antioxidant potential. The total phenolic and flavonoid contents of the steamed coriander leaves were between 270.13 mg/mL GAE and 795.20 mg/mL CE, respectively, showing a substantial increase in all antioxidant assays [6].

According to recent studies, coriander seed extracts in ethanol and methanol were equally found exhibiting rich phytochemical profiles with high contents of phenolics and flavonoids, having high antioxidant potential. Flavonoids (quercetin and isoquercetin), polyphenols (rutin, caffeic acid derivatives, ferulic acid, gallic acid, and chlorogenic acid), carotenoids, and tannins were all present in the coriander seeds [1, 45]. Extractions through assistance of different technologies have become a desirable environmentally friendly, economically viable, and highly bioactive yielding approach by which desired bioactives are released with preserved or improved efficacy. The DPPH, FRAP, and cellular antioxidant activity experiments showed that coriander seed extracts had a significant number of polyphenols and shown increased antioxidant activity [46]. Similar outcomes were also found in the work of Palmieri et al. [24], validating the use of sonication for coriander seed extraction.

The impact of high-pressure processing and heat processing on the bioactive components and microbiological safety of coriander paste was quantified through experimentation. When treated at 400 and 600 MPa, the phenolic content increased by 0.99 and 1.10%, respectively. The sample that was processed under high pressure (400 MPa) had considerably more flavonoids than the sample that was processed thermally [35]. The varying concentrations of polyphenol chemicals could be caused by crop management techniques, climate variations, and genotypic variations. As previously stated, while the generation of secondary metabolites is mostly determined by genetics, growing conditions and environmental factors also play a major role. A dried product that weighs the same as a fresh product, according to Jayasuriya et al. [3], has six to seven times more concentrated phenol than a fresh product, since the product's water content evaporates during drying, increasing the product's concentration. The release of phenolic compounds from the matrix during the procedure may be the cause of the rise in total phenolics of the microwaved coriander fractions. Drying might have accelerated the degradation of cellular constituents and released more bound phenol chemicals [32].

3.4. Analysis of Total Carotenoids, β-Carotene, and Ascorbic Acid of the Dried Part Extracts. Clean label and environmentally friendly extraction techniques are currently well known for eliminating the need for solvents and using less energy. Within this framework, a novel method for the extraction of bioactives and nutraceuticals has emerged: microwave- and ultrasound-aided extraction. This procedure was shown to need less time and energy due to its increased extraction efficiency, and remarkably, the functioning of the bioactive chemical has not diminished [47]. The results presented in Table 4 provided the information regarding presence of total carotenoids, β-carotene, and ascorbic acid contents in ultrasonic-assisted ethanolic extracts of coriander three fractions that were dried with microwave, and it was evident that leaves were found significantly high in these contents, followed by flowers, whereas seeds presented lowest values. Aruna and Baskaran [48] reported that coriander leaves possess significant amounts of total carotenoid contents and β-carotene, supporting the current study outcomes. While comparing the seeds and leaves of coriander, Bhat et al. [14] also validated current findings. Similar findings with slightly lesser values of total carotenoids and ascorbic acid in coriander leaves were also reported by Priyadarshi et al. [33], and these lesser contents given by them might be due to the absence of ultrasonic and microwave technologies in their studies.

Foods contain carotenoids, polyphenols, vitamins, and minerals, which are antioxidants, and coriander has a lot of them too, found in different quantities in different parts [49]. All plants contain carotenoids, which are more prevalent and concentrated in reproductive organs. In green leafy vegetables, carotenoids, in particular β-carotene, are mostly found in the leaves where in addition to other functions, they serve primarily as free radical scavengers of the chlorophylls during photooxidation. Total carotenoids were found in greater concentrations in the foliage of all coriander cultivars than the seeds. The overall content of carotenoids and chlorophylls was shown to be affected by the microwave

Table 4: Analysis of total carotenoids, β-carotene, and ascorbic acid of the dried part extracts.

Ethanolic extracts of coriander three fractions	Total carotenoids (mg/100 g)	Polyphenol assessment β-carotene (mg/100 g)	Ascorbic acid (mg/100 g)
Leaves	210 ± 0.22a	82.65 ± 0.10a	65.38 ± 0.08a
Flowers	190 ± 0.13b	76 ± 0.05b	49.24 ± 0.04b
Seeds	7.64 ± 0.04c	3.29 ± 0.02c	31.28 ± 0.06c

Each value is the mean ± SD. Different alphabetical letters in a column indicate significant results ($p < 0.05$).

treatment period. Carotenoid content reduced as treatment time rose, especially when exposed to lower power levels for extended periods of time. However, as treatment time increased, chlorophyll a level dropped [38].

The ascorbic acid level of the raw coriander paste was 1.32 mg/g, but after high pressure and heat processing, it fell to 1.17 and 0.50 mg/g, respectively [35]. Analysis of carotenoids and ascorbic acid contents of coriander leaf powder that was applied with different drying techniques by Shafi et al. [50] concluded that cabinet-dried powder was found high in carotenoids and ascorbic acid contents, as compared to conventionally dried samples. According to Mierzwa and Szadzińska [51], the combined effects of microwave- and ultrasonic-aided convection improve the quality of the final product and the efficiency of drying green vegetables, retaining up to 90% more vitamin C, carotenoids, phenolics, and natural colors.

3.5. Antimicrobial Activities of Coriander Three Fractions' Powder Extracts against Selected Bacterial and Fungal Species. The results of antimicrobial activities of ethanolic extracts of coriander leaves, flowers, and seeds are shown in Figures 1 and 2, from where it was observed that reference antimicrobial drug (ampicillin) exhibited significantly high ($p < 0.05$) zone of inhibitions against all bacterial and fungal species. After that, significantly high ($p < 0.05$) zone of inhibitions was exhibited by coriander seed extracts, followed by leaves, whereas flowers presented the lowest zone of inhibitions. On the other hand, standard antimicrobial drug used in the trials was also compared for the antimicrobial activities of coriander three fractions, showing that activities of extracts were very comparable to the reference drug, exploiting the potential of these extracts to be used in the food preservation and drugs. Variations in the zone of inhibitions among three extracts and six microbes possibly were due to the differences in the bioactive substances present in coriander three fractions (leaves, flowers, and seeds). These findings found close relevance with the earlier results of antimicrobial studies conducted by Farah et al. [36], on coriander seeds and leaves, reporting significantly high zone of inhibitions presented by coriander seeds, as compared to the coriander leaves, against all bacterial and fungal species.

According to Wei et al. [52], different types of coriander extracts and essential oils have variable degrees of germicidal and inhibitory activity against different types of pathogenic bacteria. Moreover, coriander seeds (fruits) and leaves (aerial portions) have more potent antibacterial components than other extracts. Shafi et al. [50] analyzed different drying techniques for coriander leaves and observed high storage

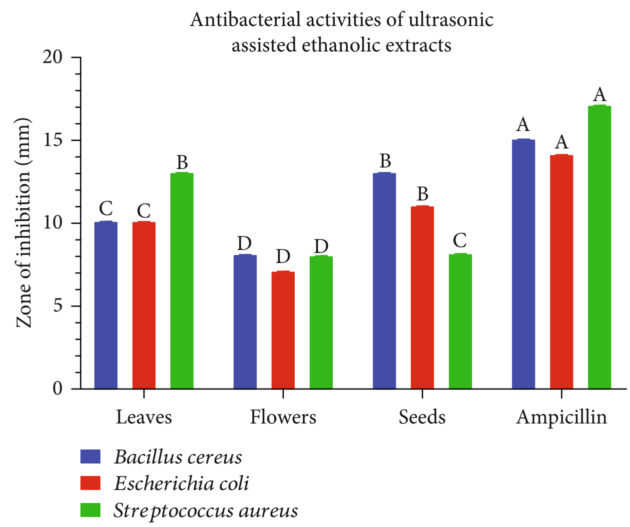

Figure 1: Antibacterial activities of ultrasonic-assisted ethanolic extracts of coriander leaves, flowers, and seeds.

stability of cabinet-dried coriander leaf powder, which was found due to lesser microbial counts.

Because of the presence of various bioactives and essential oils, this plant's seeds, leaves, flowers, and fruit all have antioxidant and antibacterial properties [49]. Coriander seeds were found rich in essential fatty acids, like oleic and linoleic, which have been well known for their vast medicinal role and antimicrobial potential of coriander might have found link with these fatty acids [39]. Findings of Yakout et al. [53] provided much similar findings for ethanolic extracts of coriander seeds against same bacterial and fungal species, witnessing the strong antimicrobial potential of coriander seeds. According to Msaada et al. [21], numerous bioactive phenolic acids, flavonoids, and carotenoids are responsible for antioxidant and antimicrobial potential of coriander. Scanning electron microscope photos demonstrated the inhibitory effect of coriander seed essential oil that was extracted through microwave assistance, against bacteria on their cell walls, supporting Ghazanfari et al.'s [54] claim that coriander seed essential oil had a stronger inhibitory effect against several bacterial species.

As a result, current findings showed that ethanol-prepared coriander seed extract has a stronger inhibitory effect on several pathogens than leaf and flower extract. We think that it would be beneficial to utilize coriander as an antibacterial food ingredient. The need of using natural items to combat resistant germs that are endangering human

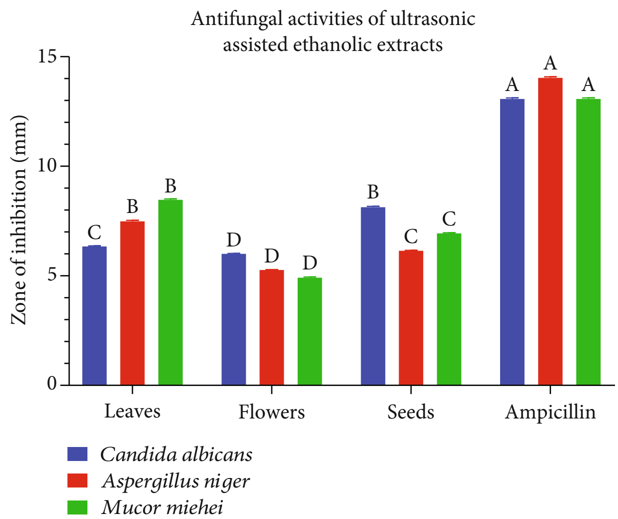

Figure 2: Antifungal activities of ultrasonic-assisted ethanolic extracts of coriander leaves, flowers, and seeds.

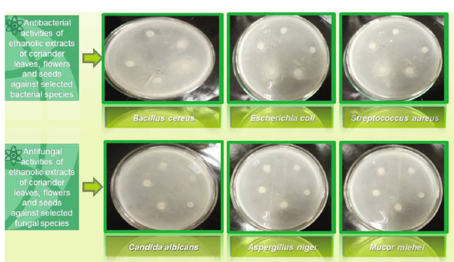

Figure 3: An overview of the antimicrobial activities of the ethanolic extracts of coriander leaves, flowers, and seeds.

health has been made clear by the current study. This scientific investigation could be a crucial starting point for the creation of low-cost, secure, and powerful natural medications. An overview of the antimicrobial studies has been presented in Figure 3.

4. Conclusion

Powdered coriander fractions that have undergone microwave processing would make excellent food and are easy to store, transport, and use, while having nutrients in condensed form. According to the current study, microwave treatment is an effective and affordable way for drying bioactive-rich coriander plant materials. The current thorough investigations of coriander three parts demonstrate that there are significant variations in the accumulation of minerals, phenolics, flavonoids, and ascorbic acid, among mature leaves, flowers, and seeds. Microwave-dried coriander leaves' ethanolic extracts with ultrasonic assistance showed considerably elevated total phenolic contents (253.45 ± 0.12 mg gallic acid equivalent/100 g), total flavonoid contents (98.15 ± 0.09 mg quercetin equivalent/100 g), and total antioxidant activity (47.32 ± 0.04 mg trolox/100 g). Seeds were also high in these contents with very comparable values to the leaves, while flowers presented lowest of these contents. Further analysis revealed that total carotenoid content, β-carotene, and ascorbic acid were also significantly high in leaves, having values 210 ± 0.22, 82.65 ± 0.10, and 65.38 ± 0.08 mg/100 g, respectively. Coriander leaf and seed extracts were very effective having high antimicrobial activities against selected fungal and bacterial species. Use of coriander, leaves, flowers, and seeds, in the form of powders and extracts, in different food formulations will not only boost the nutritional and medicinal potential of food but can also serve as natural preservatives.

4.1. Recommendations. There is not enough information about coriander three fractions currently available. Due to these findings, ongoing studies should be conducted to pinpoint the precise bioactive elements such as antioxidants that coriander leaves, flowers, and seeds contain that may be important for promoting and preserving health. Investigating the function of these substances is vital since research suggests that some of these foods, when included in a balanced diet, may be able to postpone the onset of many diseases linked to the microorganisms. Further, in order to retain the bioactive pigments in various plant materials and products, it is necessary to screen and analyze the specific processing conditions.

Data Availability

Data related to this study can be provided on request.

Additional Points

Highlights. (i) The herb coriander (*Coriandrum sativum* L.) is well known for its medicinal role. (ii) Comparison of phytochemistry of flowers, leaves, and seeds of coriander was reported. (iii) Application of microwave drying and ultrasonic-assisted extraction was used in the study. (iv) Leaves were found high in fiber, ash, polyphenols, minerals, and carotenoids. (v) Noteworthy antioxidant and antimicrobial activities of ethanolic extracts of leaves and seeds were shown. *Practical Applications.* When stored at room temperature, coriander is susceptible to postharvest yellowing or withering of its leaves and flowers, and its quality rapidly declines as a result of an increase in senescence. Food processors must constantly choose drying and extraction methods that preserve the highest quality and retain the greatest amount of bioactives, while also following extremely energy-efficient protocols. The outcomes will be helpful technologically, for the processing and preservation of coriander leaves, flowers, and seeds through microwave drying and ultrasonic-assisted extraction.

Ethical Approval

There are no animal or human experiments involved in this study. However, since there are no necessary national rules for the sensory evaluation of produced products, proper standards for safeguarding the privacy and rights of all participants were used throughout the research process.

Conflicts of Interest

The authors have declared no conflicts of interest for this article.

Authors' Contributions

Ashiq Hussain was responsible for the conceptualization. Adnan Ahmed was responsible for the data curation. Muhammad Rehan Arif and Iqra Fiaz were responsible for the formal analysis. Nabeela Zulfiqar was responsible for the funding acquisition and investigation. Muhammad Qasim Ali was responsible for the methodology and project administration. Nida Firdous was responsible for the resources. Ashiq Hussain was responsible for the software. Ashiq Hussain was responsible for the supervision. Haya Fatima and Anjum Shehzad were responsible for the validation and visualization. Ashiq Hussain and Abdeen Elsiddig Elkhedir wrote the original draft. Ashiq Hussain and Abdeen Elsiddig Elkhedir wrote, reviewed, and edited the manuscript.

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