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# Antioxidant and Antimicrobial Activity of Plant Hydrosol and Its Potential Application in Cosmeceutical Products

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**Abstract**

**Context:** Hydrosol is a residual product from the steam or hydro distillation process of abundant types of plants. It can be separated from the essential oil mixture by the liquid-liquid extraction process. Hydrosols from a variety of plants are becoming increasingly popular in cosmetology, aromatherapy, traditional pharmacy, and food sector; thus, their prospective applications should be further explored.
**Evidence Acquisition:** Hydrosol may generally contain chemicals such as alcohol, ketone, and ester. Based on the previous studies using gas chromatography-mass spectroscopy (GC-MS) analysis, linalool, carvacrol, and $\alpha$-terpineol are the major chemicals present in plant hydrosol.
**Results:** The chemical composition is either showing antimicrobial or antioxidant properties. The antioxidant properties are important in cosmeceutical products to prevent oxidation of the cosmetic ingredients, while the antimicrobial properties maintain the quality of the cosmetics. Hitherto, hydrosol usage is still unfamiliar in the market, but several cosmetic products have been formulated using hydrosol, such as shampoo, soap, and conditioner.
**Conclusions:** This work will review the hydrosol compound from plants, extraction methods, chemical composition, antioxidant and antimicrobial activities, and the potential of hydrosol in cosmeceutical application.

*Keywords:* Antimicrobial, Antioxidant, Cosmeceutical, Hydrosol

## 1. Context

In recent years, we can see biomass usage keeps increasing, leading to the high formation of waste. According to Saha and Basak (1), any biological substance not intentionally produced in a manufacturing process will form residual biomass produced as a by-product that may or may not be a waste. However, there is potential for dual usage of leftover biomass regenerated from medicinal and aromatic plants (MAPs), which are phytochemical extraction and subsequent conversion into value-added products. Hydrosol is one example of a biomass by-product formed during the steam or hydrodistillation process, where it is produced as liquid waste due to a large amount of water spent (1). Liu et al. (2) stated that plant essential oil's by-product is hydrosol, also referred to as flower water, distillate water, and aromatic water. Hydrosol is a complex mixture containing traces of essential oils and other water-soluble compounds. Shen et al. (3) proposed that the hydrosols are produced from the waters acquired during the hydrodistillation of plant material, and they might be secondary products of essential oil (EO) extraction or the sole output of plant material distillation. The steam distillation or hydrodistillation of aromatic plants yields two immiscible phases which are the essential oil phase (containing the majority of the volatile compounds) and the hydrosol phase, which is made up of condensed water and a small amount of dissolved EO (usually less than 1 g/L) and confers organoleptic properties (4).

Even though hydrosols are the by-products of the essential oil distillation process, they could have valuable aromatic or biological properties due to polar or partially miscible water volatiles (5). Hydrosol primarily contains oxygenated compounds that are significant as antioxidant or antimicrobial properties. Based on Jakubczyk et al. (6), plant hydrosols appear to have high antioxidant potential, depending on not only the plant species but also its origin, the section of the plant from which the hydrosol was extracted, and the technique of preservation used in the completed product. Hamedi et al. (7) stated that in contrast to pure EOs, hydrosol is moderated and balanced by water and its water-soluble volatile components. Hydrosol is gentler than EOs and does not need to be diluted with any carrier oil before being applied to the skin. Hence, hydrosol is one of the effective substances that can be used in the cosmetic industry and can be the alternative for cosmetic ingredients instead of essential oil that is harsh and might cause irritation to the skin. Shen et al. (3) also stated that hydrosol was widely used in the cosmetics industry and aromatherapy for its antibacterial, anti-infectious, antioxidant, anticoagulant, and anti-inflammatory therapeutic properties.

One of the segments of cosmetics is "cosmeceuticals," containing items with benefits linked to cosmetics and health. Dhawan et al. (8) claimed cosmeceutical items treat problems such as wrinkles, photo-aging, hair damage, hyperpigmentation, and acne. The neglected parts of medicinal plants, as well as the residual of aromatic plants, have been discovered to be extremely promising for extracting phytochemicals for the cosmetic and perfumery industries and phenolics-antioxidants (1). According to D'Amato et al. (9), the application of hydrosol in the cosmetic field is already applied. These hydrosols have become popular as a natural and inexpensive flavoring or cosmetic ingredient. Other than that, using hydrosol in the cosmetic industry as a raw material reduces wastewater treatment costs and the environmental burden as they are no longer discarded into the environment. Therefore, this review will focus on the antioxidant and antimicrobial activity of plant hydrosol and the potential of both properties to be applied in cosmeceutical.

## 2. Evidence Acquisition

### 2.1. Hydrosol from Plant

Hydrosol is a term used in the literature to describe the distillation of water containing dissolved essential oil components created during the distillation of aromatic plants. Oliveira et al. (10) stated that hydrosol is an extremely dilute aqueous solution of the most hydrophilic volatile components extracted after distillation. This fraction is high in organoleptically valuable oxygenated molecules contributing to hydrosol's flavor value (11). Hydrosol has been used in cosmetic applications, such as shampoo, conditioner, and room spray, while fragrance has been used in soap or toiletry, and aromatherapy has been used for spray and steam baths due to its biological and organoleptic capabilities (12). For instance, the organoleptic properties of hydrosol are moderate or pleasant-scented colloids or emulsions that are highly dilute acidic (pH 3.5 - 6.5).

Depending on the moment of collection during distillation, the hydrosol odor can range from light to intense, pleasant to unpleasant, and comparable to or distinct to the essential oil extracted. Hydrosols should be collected, sealed, and stored in a cool place in aseptic containers to prevent any impurities. One year is an approximation of the shelf life of adequately processed hydrosols. Hydrosol is also called aromatic water as it is extracted from an aromatic plant containing aromatic compounds, which are essentially volatile at room temperature (13). Flowers, buds, seeds, leaves, twigs, bark, fruits, and roots are all sources of hydrosol that can be extracted in several methods, but the most common and simplest method is liquid-liquid extraction. Tables 1 and 2 below show the source of hydrosol found by some of the past researchers and the characteristics of plant hydrosol, respectively.

### 2.2. Extraction Methods for Plant Hydrosol

The method used to extract hydrosol is the same as an EO because hydrosols are by-products of the steam distillation or hydrodistillation of aromatic plants (4). Hydrosol can only be obtained by the removal of EO (15). The distillate water or hydrosol, which contains a little amount of the EO remaining in the water fraction, is usually strongly aromatic, and its composition differs from the primary EO, which appears as a separate and distinct layer. Many factors, including the distillation technique and the plant species, influence the amount of EO remaining in the distillate water (19). de Elguea-Culebras et al. (23) stated that the amount of hydro distillate produced is determined by the distillation system. Compared to steam distillation, many hydrodistillation procedures use the cohobation mechanism to optimize water consumption and lower the volume of hydro distillate generated. During the extraction, the scent and chemical composition of hydrosol obtained differs on early or later in the process based on the boiling point of the plant extracted (9). According to Rajeswara Rao (11), hydrosol's extraction methods are redistillation or cohobation, liquid-liquid or solvent extraction, solid-phase extraction, and others. Figure 1 shows the product from the extraction process.

Liquid-liquid extraction or also known as solvent extraction, is a technique that should be done after steam or hydrodistillation, where it is the process of separating substances with the presence of solvent where the extraction is based on their relative solubilities. On the other hand, the cohobation method is the process of recycling the hydrosol and reusing it to perform another steam or

Table 1. Source of Plant Hydrosol

| Scope of Research | Source of Hydrosol | References |
|---|---|---|
| **Production of essential oil and hydrosol from black spruce** | Bark | (14) |
| **Preparation of bamboo plant hydrosol** | Leaf | (2) |
| **Relationship between essential oil and hydrosol of bitter orange** | Flower | (15) |
| **Properties of hydrosol from coconut and arecanut plant** | Flower and root | (3) |
| **Properties of rosemary plant hydrosol** | Leaf | (16) |
| **Properties of essential oil and hydrosol from eucalyptus plant** | Leaf and stem | (17) |
| **Properties of essential oil and hydrosol from lemon plant** | Flower, leaf, and stem | (18) |

Table 2. Characteristics of Plant Hydrosol

| Plant | Species | Part of Plant | Origin | Farming System | References |
|---|---|---|---|---|---|
| **Bamboo** | *Phyllostachys heterocycla* | Leaf | China | - | (2) |
| **Arecanut** | *Areca catechu* L. | Flower, floral axis, and root | China | - | (3) |
| **Coconut** | *Cocos nucifera* L. | | | - | |
| **Orange Blossom** | *Citrus aurantium* | Flower | Europe and around the Mediterranean basin | Commercial | (4) |
| **Rose flower** | *Rosa damascena* and *R. centifolia* | | | | |
| **Thyme** | *Thymus × citriodorus* (Pers.) Schreb. | - | Portugal | Organic | (10) |
| **Black Spruce** | *Picea mariana* (Miller) B.S.P | Bark | Canada | - | (14) |
| **Bitter Orange** | *Citrus aurantium* L. | Flower | Cyprus | Cultivation | (15) |
| **Rosemary** | *Rosmarinus officinalis* L. | Leaf | France | Cultivation | (16) |
| **Eucalyptus** | *Eucalyptus parvula*, *Eucalyptus cinerea*, and *Eucalyptus pulverulenta* | | Italy | Organic | (17) |
| **Lemon** | *Monarda Citriodora* | Leaf and stem | Italy | Cultivation | (18) |
| **Lavender** | *Lavandula x intermedia* | - | United State of America | - | (19) |
| **Oregano** | *Origanum vulgare* L. | Aerial part | Saudi Arabia | - | (20) |
| **Shrub** | *Satureja thymbra* | Leaf | Greece | Cultivation | (21) |
| **Geranium** | *Pelargonium graveolens* L'Her | Leaf and stem | Russia | Cultivation | (22) |

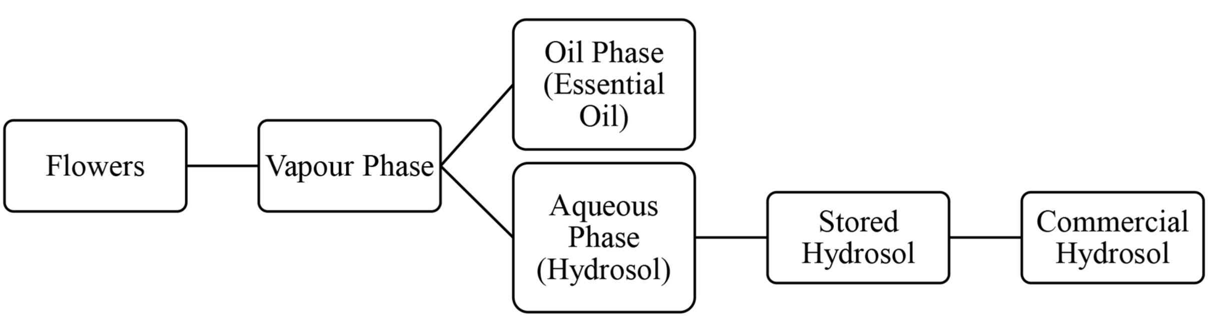


**Figure 1.** The product from the extraction process (4).

hydrodistillation (16). Furthermore, Liu et al. (2) explored the steam-distillation extraction of hydrosols from bamboo leaf and provided the data for the subsequent investigation of bamboo leaf hydrosols and their industrial uses, the best extraction features, and optimal parameters for extraction. Table 3 below shows the type of solvent used for liquid-liquid extraction.

**Table 3.** Type of Solvent Used for Liquid-Liquid Extraction

| Type of Plant Hydrosol | Type of Solvent Used | References |
|---|---|---|
| **Black spruce** | Distilled water | (14) |
| **Bamboo** | n-hexane | (2) |
| **Oregano** | Ethyl acetate | (2) |
| **Orange blossom** | n-hexane | (4) |
| **Organic pink savory** | Ethyl acetate | (21) |
| **Rosemary** | Methyl tert-butyl ether (MTBE) | (24) |

Based on prior studies, the common method of extraction of plant hydrosol is liquid-liquid extraction which is the simplest way to perform. However, the choice of solvent in liquid-liquid extraction will determine the composition of hydrosol obtained (11). Nonetheless, being the common method to separate hydrosol from EO mixture, liquid-liquid extraction can form an indistinct layer making substances difficult to differentiate. The extraction method plays an important role in determining the yield of hydrosol obtained, yet only Tsimogiannis et al. (21) reported the amount of hydrosol obtained. Therefore, the effectiveness of each method cannot be evaluated as fewer studies indicated the yield of hydrosol.

### 2.3. Chemical Composition Present in Plant Hydrosol

The existence of components that characterize hydrosol with their functional groups is responsible for their biological activity (9). Different hydrosols have different solubility of aromatic components, which is likely due to the chemical composition of the parent EO (25). According to Saha and Basak (1), hydrosols contain a variety of chemicals, including alcohol, ketone, phenol, ester, and methyl ether. Linalool, linalyl acetate, $\alpha$-terpineol, and limonene are primary active components of hydrosols, each with dissimilar bioactive capabilities (15).

As stated by D'Amato et al. (9), hydrosol's antibacterial activity is explained by the presence of its major and secondary components. Based on Gas Chromatography-Mass Spectrometry (GC-MS) analysis, each of the compounds identified by GC-MS had its relative abundance computed as a percentage of the peak area on the overall area of the identified peaks (17). Table 4 shows the chemical composition of various hydrosols based on GC-MS analysis.

D'Amato et al. (9) reported that the class of oxygenated monoterpenes like linalool and oxygenated sesquiterpenes, which are carvacrol and thymol, dominated the composition present in the hydrosol. Phenolic compounds such as carvacrol and thymol are known to be powerful antibacterial agents. On the contrary, Vuko et al. (26) indicated that the phenolic chemicals (i.e., thymol and carvacrol) are recognized to be the most effective natural antioxidants as antioxidant activity rises when their concentration in extracts rises (22). Figure 2 shows the common chemical structure of composition found in plant hydrosol.

As mentioned by Lante and Tinello (28), the compositions of hydrosols are known to be influenced by the profile of essential oils; selecting an extraction process is the first and most important step in producing high-quality extracts. The best results are also influenced by different plant types, varietals, agronomic techniques, and raw material climatic and storage conditions; thus, more research is needed to address these issues regarding the chemical composition presence. Previous researches have shown the chemical composition present in the hydrosol (17, 28, 29). The result was barely stated without explanation regarding the benefit of the compounds. Thus, some research have lacked information because the properties of the hydrosol should be explained based on the chemical composition present.

## 3. Results

### 3.1. Antioxidant Activity of Plant Hydrosol

Antioxidants are substances that can prevent or reduce the formation of free radicals (16). The accumulation of reactive oxygen species (ROS) has been identified as the cause of skin aging, resulting in dryness, loss of subcutaneous tissue, and wrinkle formation. Natural antioxidants are essential for skincare products and are widely used in the cosmetics industry (30). Several assay types can be used to evaluate the antioxidant activity of plant hydrosol. Based on Degirmenci and Erkurt (15), antioxidant activity is expressed as a percentage of scavenging (%) and 50% scavenging concentrations ($IC_{50}$ g/mL). Table 5 shows the antioxidant potential and biochemical composition of plant hydrosol.

According to Francezon and Stevanovic (14), antioxidant activity was assessed using two separate chemical pathways [i.e., 2,2-diphenyl-1-picrylhydrazyl hydrate (DPPH) and oxygen radical absorbance capacity (ORAC) assay] to gain a better understanding of the antioxidant potential based on hydrogen atom transfer. Not just that, natural phenolic compounds, such as phenolic acids and flavonoids, have been claimed to contribute to the biological activity of plant materials and play an essential role as

**Table 4.** The Chemical Composition of Various Hydrosols Based on GC-MS Analysis

| Plant Source of Hydrosol and Major components | Percentage (%) | References |
|---|---|---|
| **Bitter orange (*Citrus aurantium* L.)** | | (15) |
| Linalool | 16.58 | |
| Linalyl acetate | 5 | |
| Neryl acetate | 6.48 | |
| d-limonene | 4.79 | |
| Trans- Caryophyllene | 1.85 | |
| $\alpha$-terpineol | 4.54 | |
| Nerolidol | 5.87 | |
| Farnesol 3 | 1.99 | |
| Dotriacontane | 4.3 | |
| Tetrapentacontane. | 2.56 | |
| Hexacontan | 2.1 | |
| **Bay Leaf (*Laurus nobilis* L.)** | | (9) |
| Eugenol | 4.02 | |
| $\alpha$-curcumene | 3.76 | |
| ß-selinenol | 3.75 | |
| **Black cumin (*Nigella sativa* L.)** | | |
| Cuminaldehyde | 16.59 | |
| Carvacrol | 11.26 | |
| $\rho$-cymene | 8.92 | |
| **Rosemary (*Rosmanirus officinalis* L.)** | | |
| $\alpha$- terpineol | 3.68 | |
| 4-chlorobenzenesulfonamide | 3.02 | |
| N-methyl eucalyptol | 2.88 | |
| **Sage (*Salvia officinalis* L.)** | | |
| Linalool | 13.41 | |
| $\delta$-cadinene | 10.18 | |
| Carvacrol | 8.96 | |
| **Thyme (*Thymus vulgaris* L.)** | | |
| Carvacrol | 48.3 | |
| Thymol | 17.55 | |
| **Lavender (*Lavandula angustifolia*)** | | |
| Linalool | 26.5 | |
| Borneol | 9 | |
| Cis-linalool oxide | 6.6 | |
| Trans-linalool oxide | 5.2 | |

**Table 5.** The Antioxidant Potential and Biochemical Composition of Plant Hydrosol

| Type of Plant Hydrosol | Classification | Origin | Type of Antioxidant Assay | Antioxidant Activity | References |
|---|---|---|---|---|---|
| **Bitter orange** | Flower | Cyprus | DPPH radical scavenging | 384.33 g/mL | (15) |
| | | | $H_2O_2$ scavenging activity | 354.00 g/mL | |
| **Arecanut and coconut** | Flower, floral axis, and root | China | Reducing power assay | 5 $\mu$g/mL | (3) |
| | | | ABTS radical scavenging | 13.05 to 24.28% | |
| **Black spruce** | Bark | Canada | ORAC | 4991 $\pm$ 296 mol Trolox equivalent (TE)/g dry extract | (14) |
| **Shrub** | Aerial part, stem, and leaf | Mediterranean basin | DPPH radical scavenging | 0.62 $\pm$ 0.09 mg/mL | (27) |

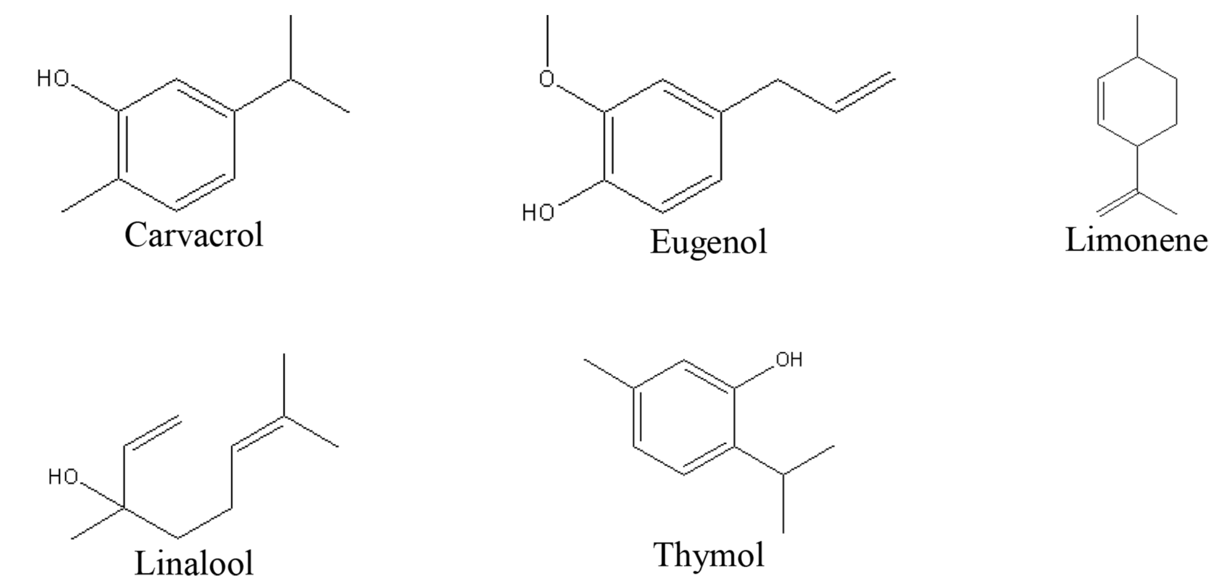


**Figure 2.** Chemical structure of composition found in plant hydrosol (27).

antioxidant properties (15), where they can be used to assess hydrosol's antioxidant potential (31). Due to the capacity of hydrogen donation atoms to free radicals, phenolic and flavonoid molecules are significant antioxidant components that deactivate free radicals. They also have the perfect structural properties for scavenging free radicals (32).

The chemical composition of hydrosol, in particular, a high level of phenolic and flavonoids, was found to be associated with antioxidant activity measured using the DPPH method (22). The difference in the result obtained could be related to the distinct mechanisms involved or the presence of encapsulated bioactive compounds (3). According to Wollinger et al. (16), the DPPH assays were always chosen since they are a quick and simple way to look at total antioxidant scavenging activity. In addition, the experimental approach may be readily adapted to the analytic experiments. The analysis of antioxidant activity may need further research and require more than one method in order to determine the suitable method for producing the best result to avoid misunderstanding in the result of the study. According to Johari and Khong (33), determining the phenolic content in samples is known as total phenolic content (TPC) activity. The redox characteristics of phenolic chemicals found in plants allow them to act as antioxidants. The Folin-Ciocalteu colorimetric test was used to obtain the TPC values (15). Phenolic compounds have direct antioxidant properties due to the presence of hydroxy groups acting as hydrogen donors; thus, they might contribute to antioxidant activity. Shen et al. (3) reported that total phenolic levels of hydrosols from several sections of arecanut and coconut ranged from 0.17 to 3.88 $\mu$g/mL of gallic acid equivalent. Other than that, flavonoids are secondary antioxidant metabolites where the strength is determined by the amount and position of free hydroxy (OH) groups (32). The total flavonoid content (TFC) values were calculated using the aluminum chloride colorimetric method and represented in milligrams of quercetin equivalents per gram of extract (mg QE/g). Research by Degirmenci and Erkurt (15) reported that the hydrosol of *Citrus aurantium* flowers, the TFC, was found to be lower than essential oil.

### *3.2. Antimicrobial Activity of Plant Hydrosol*

Antimicrobial activity is a term referring to all active agents that inhibit the growth of bacteria, prevent the formation of microbial colonies, and kill microorganisms. The quality and shelf life of cosmetics and pharmaceuticals are determined partly by microbial control during production and storage. Effective control measures throughout the cosmetic and therapeutic system can benefit from the knowledge of natural-derived products for preventing potential sources and pathways of bacterial contamination (3). According to Tornuk et al. (29), the hydrosols' antimicrobial properties could be due to their monoterpenic phenolic compounds. Table 6 below shows the antimicrobial activity of certain plant hydrosol.

Based on Table 6, hydrosol can be applied for cultural heritage protection as it can delay sporulation, involving a few methods, either in situ or in vitro, where the results are different. As Kunicka-Styczynska et al. stated (34), hydrosol showed no antibacterial activity due to hydrosols being too dilute to form antimicrobial activity. The antimicrobial activity of plant hydrosols is still not analyzed much as compared to essential oil; hence further research is required to fully determine the effectiveness of antimicrobial properties of hydrosol as hydrosol has the potential to be produced for a product in the cosmetic industry.

### *3.3. Application of Plant Hydrosol in the Cosmetic Industry*

Medicinal and aromatic plant (MAP) active ingredients are commonly used in medicines, food flavoring, preservation, cosmetics, and pharmaceuticals. In the form of secondary metabolites, MAPs include biologically active chemical compounds. In most cases, secondary metabolites are created by plants and found as a variety of chemical compounds such as alkaloids, flavonoids, saponins, steroids, and terpenoids. These secondary metabolites are intended to be the primary ingredients giving the plant its therapeutic effects (20). As mentioned by Barra (35), lavender hydrosols may help maintain the microbiological stability of the formulations when used as a water phase replacement in cosmetics. The author also indicated the usefulness of lavender hydrosols as a natural and environmentally friendly component in cosmetics with potential preservative activity in formulations. Using lavender hydrosols in the cosmetic industry as a replacement for the water phase in cosmetics could result in not only cost savings for chemical stabilizers and preservatives but also a significant reduction in sewage disposal. Lavender hydrosols may contribute to maintaining microbiological stability and appear to be promising cosmetic components, which can be proved by the formation of moisturizing body gels obtained from fresh or dried *Lavandula angustifolia* herbs or flowers (35). In addition, Lante and Tinello (28) also stated that aromatherapeutic and cosmetic uses for hydrosols are prevalent.

Antimicrobial is one of the important properties during the production and storage of cosmetics in order to maintain the quality and extend shelf life (3). Meanwhile, antioxidant properties in cosmetics can combat skin aging and naturally prevent skin illness (6). Plant hydrosol from coconut, bamboo, rose, and orange constitutes antimicrobial and antioxidant activities where it has potential application as cosmetic ingredients. The usage of plants that contain antioxidant and antimicrobial properties has proven to be effective in cosmeceutical a very long time ago (36). For example, aloe vera and papaya have been used in skincare for antioxidant properties, while lemon grass and rose with antimicrobial activities were utilized as fragrances (37).

Recently, the flower hydrosol has been used to improve skin health in perfumes and cosmetics, as well as in aromatherapy to relieve tension and induce relaxation (38). According to D'Amato et al. (9), hydrosols are also well tolerated by the skin due to the low amount of terpenes and sesquiterpene hydrocarbons, which do not induce irritation. Hydrosol has already entered the cosmetic market, where aromatic waters are widely used in cosmetics, such as face and body tonics, lotions, aftershaves, and therapeutic and rejuvenating facials. Since hydrosols normally have an acidic to neutral pH, they can be used as toners in regular skincare procedures to restore natural skin pH. However, there is no specific research study related to the process of production of cosmetic products and the effectiveness of hydrosol as the ingredient in the cosmetic product.

## 4. Conclusions and Recommendation

Hydrosol was initially only known as the by-product of EO; however, the research about hydrosol began to increase due to some researchers starting to compare the chemical composition between hydrosol with EO. The finding was then expanded towards the extraction method of hydrosol, as hydrosol can only be produced from EO by the liquid-liquid extraction method. Previous studies have shown that the major chemical composition of some plant hydrosols is linalool, carvacrol, and $\alpha$-terpineol. It potentially exhibits antimicrobial or antioxidant properties; hence based on the data on chemical composition, there are studies about the antimicrobial and antioxidant properties of hydrosol. Hydrosol can be used as an additive to boost a product's antioxidant activity without further purification, or it can be re-extracted to obtain pure antioxidants. The use of hydrosol also complies with the biorefinery and green extraction concepts as it is no longer treated as waste. Plant hydrosol can also be used in cosmeceutical as a raw or alternative ingredient since it exhibits antioxidant and antimicrobial properties. A hydrosol study is limited to a particular plant despite its potential. Plant hydrosol also needed further research to establish its usage in cosmeceutical industries. Many studies have reported the potential application of hydrosol in the cosmetic industry, but none had specifically studied the cosmetic formulation involving hydrosol as an ingredient. Due to the possibility of interactions between the hydrosol ingredients and the cosmetic components, the actual utility of any given hydrosol should be investigated in specific cosmetic formulations.

## Footnotes

**Authors' Contribution:** Shafie MH, study concept and design; Kamal ML, analysis and interpretation of data; Abd Razak NA, drafting of the manuscript; Hasan S, drafting of the manuscript; Uyop NH, drafting the manuscript; Abd

**Table 6.** Antimicrobial Activity of Plant Hydrosol

| Plant Source of Hydrosol | Tested Microorganisms | Experiment Matrix | Antimicrobial Activity | References |
|---|---|---|---|---|
| **Arecanut (*Areca catechu* L.)** | *E. coli* O157: H7, *E. coli*, *Candida albicans*, *Staphylococcus aureus* | In vitro | 6.8 - 14.2 diameter of zones inhibition in mm (5 mm disc) | (3) |
| **Coconut (*Cocos nucifera* L.)** | | | | |
| **Bay leaf (*Laurus nobilis* L.)** | *Salmonella Typhimurium*, *E. coli* O157: H7 | Fresh cut apples and carrots | 4.32 - 6.07 log cfu/g between 20 - 60 minutes of treatment | (29) |
| **Black cumin (*Nigella sativa* L.)** | | | | |
| **Rosemary (*Rosmarinus officinalis* L.)** | | | | |
| **Sage (*Salvia officinalis* L.)** | | | | |
| **Thyme (*Thymus vulgaris* L.)** | | | | |
| **Lemon (*Monarda citriodora*)** | *Enterococcus faecalis*, *E. coli*, *Streptococcus pyogenes*, *Klebsiella penumoniae*, *Staphyloccocus aureus*, *Pseudomonas aeruginosa*, *Candida albicans*, *Candida glabrata*, *Candida parapsilosis*, *Candida tropicalis*, *Meyerozyma caribbica*, *Saccharomyces cerevisiae*, *Aspergillus sydowii*, *Cladosporium cladosporioides*, *Penicillum chrysogenum* | In vitro | 1.9 - 21.5 % v/v $IC_{50}$, concentration determining 50% inhibition | (18) |

Rashid NF, analysis and interpretation of data; Zafarina Z, critical revision of the manuscript for important intellectual content.

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