MORPHOLOGICAL CHARACTERISTICS, PHYTOCHEMICAL COMPOSITION, AND FUNCTIONAL FOOD POTENTIAL OF FENNEL LEAVES (*FOENICULUM VULGARE* MILL.)

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ABSTRACT

Foeniculum vulgare Mill. (fennel) is an aromatic plant belonging to the family Apiaceae and has long been used as a medicinal plant, spice, and functional food. Although numerous studies have investigated the phytochemical composition and biological activities of F. vulgare, studies integrating the morphological characteristics of its leaves with phytochemical potential and food applications remain limited. This article aims to synthesize research findings on the morphology of F. vulgare leaves and their relationship with bioactive compounds and functional food potential. This review synthesized scientific publications retrieved from reputable databases, including Scopus, ScienceDirect, PubMed, SpringerLink, and Google Scholar, with an emphasis on recent literature. The review indicates that F. vulgare leaves are characterized by pinnately compound leaves with narrow, filiform segments, green to bluish-green coloration, and a distinctive aroma associated with essential oils. The leaves contain various bioactive compounds, including phenolic compounds, flavonoids, essential oils, and terpenoids, which are associated with antioxidant, antimicrobial, anti-inflammatory, and antihyperglycemic activities. Traditional uses, including pecel adas and jangan adas in Boyolali, demonstrate cultural acceptance and potential for local food development. Overall, F. vulgare leaves show potential as functional food ingredients for herbal teas, leaf powders, beverages, seasonings, and innovative value-added food products and formulations.

KEYWORDS

Foeniculum vulgare; F. vulgare leaves; phytochemicals; leaf morphology; functional food

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INTRODUCTION

The fennel plant (*Foeniculum vulgare* Mill.) is a species belonging to the family *Apiaceae* that has long been utilized as a food plant, spice, and medicinal plant in various countries. Almost all parts of the plant, including the seeds, stems, leaves, and roots, have been reported to have potential uses and contain various bioactive compounds that may provide biological and economic value (Haruna & Yahaya, 2021). In Indonesia, *F. vulgare* leaves have been utilized as part of traditional food practices, including as a vegetable and a culinary ingredient. The use of *F. vulgare* as a food plant has been specifically documented among communities living on the slopes of Mount Merapi–Merbabu, Central Java, where various parts of the *F. vulgare* plant are consumed as vegetables (Umartani & Nahdi, 2021). In addition to providing a distinctive taste and aroma, *F. vulgare* leaves are also believed to offer various health benefits, making their use as a functional food ingredient increasingly attractive.

Interest in the development of plant-based functional foods continues to increase alongside growing public awareness of the importance of consuming foods that not only meet nutritional requirements but also provide physiological health benefits. Various studies have shown that *F. vulgare* contains a wide range of bioactive compounds, particularly phenolic compounds, flavonoids, terpenoids, and essential oil components found in its seeds and leaves (Elbaz et al., 2024; Zahi et al., 2025). Phytochemical analysis of *F. vulgare* leaf extracts has revealed the presence of various secondary metabolites, while chemical analysis of the leaf essential oil has shown a predominance of monoterpenes and phenylpropanoids, such as α-pinene and estragole. These compounds contribute to various biological activities of *F. vulgare*, including antioxidant, anti-inflammatory, and antidiabetic activities (Abubakar & Haque, 2020; Di Napoli et al., 2022; Rafieian et al., 2024). These potentials make *F. vulgare* leaves a promising raw material for further development in the food, pharmaceutical, and nutraceutical industries.

Leaves are the primary photosynthetic organs of plants and possess a complex structure comprising the epidermis, stomata, mesophyll, vascular tissues, and various specialized secretory structures. These structures support physiological processes and, in some plant species, are involved in the production, storage, and secretion of secondary metabolites (Ossola & Farmer, 2024; Roth-Nebelsick & Krause, 2023). Leaf morphological characteristics, such as leaf shape, size, color, texture, venation patterns, and the degree of leaf blade division, are important features for botanical identification and reflect plant adaptations to environmental conditions (Wang et al., 2022).

Research on the phytochemical composition and biological activities of *F. vulgare* has developed rapidly; however, most studies have focused on extracts, chemical constituents, or pharmacological activities of the seeds. In contrast, studies integrating the morphological characteristics of *F. vulgare* leaves with their phytochemical potential remain limited. Therefore, this review aims to provide a scientific synthesis of the morphological characteristics of *F. vulgare* leaves, their relationship with phytochemical composition, and their potential development as functional food ingredients. This article provides an overview of the relationship between leaf characteristics and their biological potential, while serving as a reference for further research in botany, food science, pharmaceuticals, and health.

RESEARCH METHOD

This article was prepared using a narrative review method by collecting, evaluating, and synthesizing various research findings related to the morphological characteristics, phytochemical composition, and potential of *F. vulgare* leaves as a functional food. The literature search was conducted through several reputable scientific databases, namely Scopus, ScienceDirect, PubMed, SpringerLink, Wiley Online Library, and Taylor & Francis Online, with Google Scholar used as a supporting source. The keywords used included combinations of English and Indonesian terms, such as *Foeniculum vulgare*, *F. vulgare*, fennel leaves, leaf morphology, phytochemical compounds, essential oil, functional food, medicinal plants, morfologi daun adas, fitokimia, and functional food.

The literature prioritized in this review comprised research articles and review articles published between 2015 and 2026, particularly publications from the past five years, to obtain up-to-date information. In addition, several classical references that provide fundamental knowledge in botany, plant anatomy, and phytochemistry were retained when they had high scientific relevance. The inclusion criteria comprised publications discussing the morphological or anatomical characteristics of F. vulgare leaves, the phytochemical composition of the leaves, the biological activities of bioactive compounds, and their utilization as food ingredients or medicinal plants. In contrast, articles that were not available in full-text form, had not undergone peer review, or were not relevant to the focus of the review were excluded from the synthesis.

The data obtained from the literature were then categorized into several main themes, namely: (1) botanical characteristics and leaf morphology, (2) phytochemical composition of *F. vulgare* leaves, (3) the relationship between morphological characteristics and the accumulation of bioactive compounds, and (4) the potential of *F. vulgare* leaves as functional food ingredients. Each theme was subsequently analyzed descriptively and comparatively by comparing findings from various studies to identify similarities, differences, research developments, and scientific gaps that require further investigation.

The synthesized findings were presented narratively by integrating the results of various studies to provide an overview of the morphological characteristics of *F. vulgare* leaves and their relationship with phytochemical composition and their potential development as functional food ingredients.

RESULTS AND DISCUSSION

Botany and Morphological Characteristics of *Foeniculum vulgare* Leaves

Botanical Classification

F. vulgare Mill. is an aromatic herb belonging to the family *Apiaceae (Umbelliferae)* (Jadid et al., 2023). This plant is widely recognized as both a spice and a medicinal plant and has been cultivated in various subtropical and tropical regions. The appearance of *F. vulgare* leaves is presented in Figure 1.



Figure 1. Appearance of *Foeniculum vulgare* leaves

F. vulgare is taxonomically classified under the Kingdom *Plantae*, phylum *Streptophyta*, class *Equisetopsida*, subclass *Magnoliidae*, order *Apiales*, family *Apiaceae*, genus *Foeniculum*, and species *Foeniculum vulgare* Mill. Within the family *Apiaceae*, *F. vulgare* belongs to the subfamily *Apioideae* and has phylogenetic relationships with several important plants, including celery (*Apium graveolens* L.), carrot (*Daucus carota* L.), coriander (*Coriandrum sativum* L.), dill (*Anethum graveolens* L.), cumin (*Cuminum cyminum* L.), and anise (*Pimpinella anisum* L.). Similar morphological characteristics within this family include compound umbel inflorescences, hollow stems, pinnately divided leaves, and the presence of secretory canals that produce essential oils (Jadid et al., 2023).

Habitat and Distribution

F. vulgare is generally considered to have originated in the Mediterranean region and subsequently spread and became naturalized across various parts of the world, including Europe, Asia, Africa, the Americas, and Oceania. Currently, *F. vulgare* is widely cultivated and/or introduced in various countries, including India, China, Egypt, Turkey, Iran, Italy, Spain, and several regions of Southeast Asia, including Indonesia (Jadid et al., 2023). In Indonesia, *F. vulgare* is commonly found in upland areas at elevations of approximately 600–1,800 m above sea level. The plant grows optimally at temperatures ranging from 15 to 25 °C, under adequate sunlight, and in loose, fertile soils with good drainage. Environmental factors, including light intensity, temperature, humidity, altitude, and soil fertility, can influence vegetative growth, leaf development, and the accumulation of secondary metabolites in *F. vulgare*.

Plant Morphology

F. vulgare is a perennial aromatic herb that can grow up to approximately 2 m in height, although some cultivated types may be grown as annual or biennial plants. The stem is erect, cylindrical, longitudinally grooved, glabrous, and green to bluish-green (*glaucous*), with branching occurring primarily in the upper part of the plant. The root system is well developed and taprooted. The leaves are alternately arranged and finely divided into thread-like segments. The inflorescence is a compound umbel consisting of numerous small yellow flowers. The fruit is a schizocarp, oblong to ellipsoid in shape, which splits at maturity into two mericarps, each bearing longitudinal ridges and oil ducts (*vittae*) containing essential oil (Jadid et al., 2023).

Leaf Morphology

F. vulgare leaves represent a distinctive botanical characteristic and are an important feature for distinguishing the species from other plants. The leaves are alternately arranged along the stem, with leaf sheaths that partially enclose the stem. The leaf blade is repeatedly divided, forming pinnately compound leaves with very narrow, thread-like (*filiform*) segments (Magon et al., 2025). The morphology of *F. vulgare* leaves is presented in Figure 2.



(a) (b)

Figure 2. (a) *F. vulgare* leaf morphology, (b) appearance of the *F. vulgare* leaf stalk.

The size of *F. vulgare* leaves varies depending on plant age, cultivar, and environmental conditions. The leaf blade generally ranges from 15 to 40 cm in length and has a relatively long leaf sheath, while the leaf segments are very narrow in diameter, giving the leaves a delicate and lightweight appearance. The leaf color ranges from light green to bluish-green due to the waxy cuticle covering the leaf surface. This layer helps reduce water loss and enhances the plant's tolerance to environmental stress (Magon et al., 2025).

F. vulgare leaves have a smooth, glossy, and glabrous surface and produce a characteristic strong aroma associated with their essential oil content. The composition of *F. vulgare* essential oil varies depending on the plant part, genotype, geographical origin, and environmental conditions, but generally includes volatile compounds such as anethole, fenchone, estragole, limonene, and other terpenoid compounds. In *F. vulgare* leaf essential oil, anethole, estragole, limonene, fenchone, and other terpenoid compounds have been reported as important constituents contributing to its characteristic aroma (Di Napoli et al., 2022; Milenković et al., 2022).

Phytochemical Composition of *F. vulgare* Leaves

F. vulgare leaves are a source of various secondary metabolites that contribute to their characteristic aroma, biological activities, and potential as functional food ingredients (Liu et al., 2024). The leaves contain phenolic compounds, flavonoids, terpenoids, and essential oil components, whereas the fruits/seeds generally have a higher essential oil content and are predominantly characterized by compounds such as trans-anethole and fenchone (Di Napoli et al., 2022; Šunić et al., 2023).

Phytochemicals in *F. vulgare* leaves play important roles in plant metabolism and defense mechanisms against environmental stress. In addition, the phytochemical

compounds present in *F. vulgare* leaves exhibit various biological activities with potential health benefits. Previous studies have reported that *F. vulgare* exhibits diverse biological activities, including antioxidant, antimicrobial, anti-inflammatory, antihyperglycemic, and hypolipidemic activities, as well as potential antitumor and chemomodulatory effects (Di Napoli et al., 2022; Noreen et al., 2023). In *F. vulgare* leaves, antioxidant and antimicrobial activities have been demonstrated in studies of leaf extracts and essential oils, while leaf extracts have also shown *in vitro* antihyperglycemic activity (Rafieian et al., 2024; Sayah et al., 2020).

Essential Oils

Essential oils are one of the characteristic groups of bioactive compounds found in *F. vulgare*. Their composition consists of various volatile compounds, particularly monoterpenes and phenylpropanoids, with chemical profiles that may vary depending on the plant part, cultivar, geographical origin, and environmental conditions. In *F. vulgare* leaf essential oil, α-pinene and estragole have been reported as major constituents, accompanied by various other monoterpenes and volatile compounds (Abdelbaky et al., 2023). In contrast, *F. vulgare* fruit/seed essential oil is commonly characterized by high levels of trans-anethole, fenchone, and limonene. These volatile compounds contribute to the characteristic aroma of *F. vulgare* and exhibit various biological activities, including antioxidant, antimicrobial, and antibiofilm activities (Ben Abdesslem et al., 2021; Benkhoud et al., 2022).

Phenolic Compounds

Phenolic compounds are an important group of secondary metabolites that contribute to the antioxidant activity of *F. vulgare* leaves. These compounds can act as hydrogen or electron donors, thereby helping to neutralize free radicals and inhibit oxidative reactions. Various phenolic compounds have been reported in *F. vulgare*, including caffeic acid, chlorogenic acid, ferulic acid, gallic acid, and *p*-coumaric acid. Total phenolic content (TPC) is commonly used as one of the parameters for evaluating the antioxidant potential of plant extracts. Studies on *F. vulgare* have demonstrated an association between phenolic content and radical-scavenging activity, although the strength of this relationship may be influenced by phenolic composition, extraction methods, and the antioxidant assay employed (Sayah et al., 2020).

Flavonoids

Flavonoids are a major group of secondary metabolites commonly found in photosynthetic plant tissues, including *F. vulgare* leaves. Flavonoid profiling of *F. vulgare* has identified several compounds, including quercetin, kaempferol, rutin, isorhamnetin, and their glycoside derivatives. Studies specifically examining *F. vulgare* leaves have reported quercetin 3-*O*-glucoside, isorhamnetin 3-*O*-glucuronide, kaempferol 3-*O*-rutinoside, and kaempferol 3-*O*-glucoside among the detected flavonoid compounds (Crescenzi et al., 2023; Youssef et al., 2023; Zahi et al., 2025).

Potential of *F. vulgare* Leaves as Functional Food

F. vulgare leaves are plant-based food materials with considerable potential for development as functional food ingredients because they contain various secondary metabolites, such as phenolic compounds, flavonoids, essential oils, terpenoids, vitamins, and natural antioxidants. These compounds have been associated with antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and cardioprotective activities in previous studies.

Use as a Vegetable

F. vulgare leaves and young shoots have been used as food ingredients in various culinary traditions, either consumed fresh or incorporated into cooked dishes. In some Mediterranean culinary traditions, the vegetative parts of *F. vulgare* are used as vegetables and flavoring ingredients, while the leaves and young stems are also utilized in various food preparations. In addition to providing a distinctive aroma and flavor, the vegetative parts of *F. vulgare* contain various nutrients and bioactive compounds that support their potential as food ingredients (Noreen et al., 2023). The leaves of *F. vulgare* contain nutritional components as well as phenolic compounds and flavonoids that may contribute to antioxidant activity. Analysis of the vegetative parts of *F. vulgare* has shown that the leaves contain water, ash, protein, fat, and carbohydrates, while other studies have reported the presence of various phenolic compounds in *F. vulgare* leaf extracts (Sayah et al., 2020).

Herbal Tea

vulgare leaves have a distinctive aroma derived from their essential oil content, making them highly suitable for development as an herbal tea. This product can be prepared using either fresh or dried *F. vulgare* leaves. During the brewing process, some phenolic compounds and flavonoids may dissolve in water, potentially producing a beverage with considerable antioxidant activity. In addition to providing a distinctive flavor, *F. vulgare* leaf herbal tea has been reported to have potential as a relaxing beverage, to support digestive health, and to contribute to immune system function. The use of *F. vulgare* leaves as an herbal tea ingredient also offers opportunities for developing value-added products because the processing method is relatively simple.

Functional Beverages

In addition to being used as an herbal tea, *F. vulgare* leaves can be utilized as a raw material for various functional beverages, such as instant beverages, herbal beverages, fermented beverages, and ready-to-drink products. The development of *F. vulgare* leaf-based beverages requires careful consideration of the stability of bioactive compounds, particularly essential oils and flavonoids, which are sensitive to temperature, light, and oxidation. Processing technologies, such as low-temperature drying, encapsulation, and microencapsulation, may help improve the stability of bioactive compounds during production and storage.

F. vulgare Leaf Powder

Processing *F. vulgare* leaves into powder is a promising alternative for extending shelf life while facilitating distribution and incorporation into various food products. *F. vulgare* leaf powder can be produced through washing, drying, grinding, and sieving processes to obtain a uniform particle size. As a food ingredient, *F. vulgare* leaf powder can be used in the formulation of instant soups, powdered beverages, functional seasonings, bakery products, and cereal-based foods. However, the drying method is an important factor because it can affect the phenolic content, antioxidant activity, color, aroma, and sensory quality of the final product. Therefore, selecting an appropriate drying technology is essential for maintaining the quality of *F. vulgare* leaf powder as a functional food ingredient.

Vulgare Leaf Ethnogastronomy As A Basis For Functional Food Development

In Indonesia, the use of *F. vulgare* leaves as a food ingredient remains largely localized and is closely associated with the culinary traditions of communities living in highland areas. One example of this practice can still be found in Boyolali Regency, Central

Java, particularly in areas on the slopes of Mount Merapi and Mount Merbabu. Local communities have traditionally used *F. vulgare* leaves as a main ingredient in various traditional dishes, including *pecel adas* and *jangan adas*. In these dishes, *F. vulgare* leaves are prepared together with various local vegetables and traditional spices, producing distinctive flavors that form part of the local culinary identity. This practice demonstrates that *F. vulgare* leaves are not only regarded as a medicinal plant but have also become part of the local food system passed down from generation to generation. The appearance of *pecel adas* and *jangan adas* is presented in Figure 3.



(a) (b)

Figure 3. (a) Appearance of pecel adas, (b) appearance of jangan adas

From a food science perspective, these ethnogastronomic practices provide an important basis for the development of functional foods. The use of *F. vulgare* leaves in traditional foods indicates a long history of consumption and relatively high cultural acceptance. In addition, several recent studies have demonstrated that *F. vulgare* leaves contain bioactive compounds, including flavonoids, phenolic compounds, essential oils, and terpenoids, which exhibit antioxidant, antimicrobial, anti-inflammatory, and antidiabetic activities. Thus, some traditional perceptions regarding the health benefits of F. vulgare leaves may be supported by scientific evidence on their phytochemical composition and biological activities.

The integration of traditional knowledge and scientific research provides opportunities for developing various *F. vulgare* leaf-based functional food products. Beyond their traditional culinary uses, *F. vulgare* leaves have potential for development as value-added food ingredients, including herbal preparations, dried leaf products, and functional food formulations. *F. vulgare* has also been investigated as an ingredient in functional beverages and herbal tea formulations, demonstrating opportunities for further food product development (Rafieian et al., 2024). This approach may contribute to preserving local culinary heritage while increasing economic value through product innovation based on local biological resources.

The development of ethnogastronomy-based functional foods also supports the concepts of food diversification and sustainable food security. The utilization of local plants that are adapted to local environmental conditions may reduce dependence on imported raw materials while strengthening regional food systems. In addition, the involvement of local communities in the cultivation, processing, and marketing of *F.*

vulgare leaf-based products may increase farmers' income and encourage the development of micro, small, and medium-sized enterprises (MSMEs) in the food sector.

Nevertheless, the utilization of *F. vulgare* leaves as functional food ingredients still faces several challenges. Raw material quality standardization, variations in phytochemical composition caused by environmental factors, the stability of bioactive compounds during processing, and the limited availability of human clinical trials remain important aspects requiring further investigation. Therefore, multidisciplinary research integrating botany, phytochemistry, food technology, nutrition, and social sciences is needed to develop functional food products that are safe, high-quality, and supported by strong scientific evidence.

Overall, the ethnogastronomy of *F. vulgare* leaves demonstrates that traditional knowledge can provide an important foundation for the development of modern functional foods. Synergy between local knowledge and scientific research can not only support the preservation of Indonesian culinary heritage but also create opportunities for food product innovation with health, economic, and sustainability benefits. Thus, *F. vulgare* leaves have the potential to become a local commodity contributing to the development of functional foods based on Indonesia's biodiversity.

Research Gap and Future Perspectives

Although studies on the morphology, phytochemical composition, and biological activities of *F. vulgare* have increased, research specifically integrating *F. vulgare* leaf morphology with phytochemical composition remains limited. Further studies are needed to clarify how morphological characteristics and environmental conditions influence the quality and accumulation of bioactive compounds in *F. vulgare* leaves.

Another important research gap is the limited availability of quality standards specifically for *F. vulgare* leaves as functional food ingredients. Parameters such as leaf morphology, moisture content, color, essential oil content, total phenolic content, flavonoid content, and antioxidant capacity could be considered as potential quality indicators. Establishing standardized quality parameters would support raw material consistency, product safety, and the development of *F. vulgare* leaf-based products.

Although *in vitro* and *in vivo* studies have demonstrated various biological activities of *F. vulgare*, evidence from human studies remains limited. Further research, particularly well-designed clinical studies, is needed to evaluate the efficacy, safety, appropriate dosage, and potential interactions of *F. vulgare* leaf-based products. Such evidence is important to strengthen the scientific basis for their development as functional food and nutraceutical ingredients.

From a food development perspective, *F. vulgare* leaves have considerable potential to be developed into value-added products, including herbal teas, leaf powders, functional beverages, seasonings, and fortified foods. Future research should focus on maintaining bioactive compound stability during processing and storage while ensuring acceptable sensory characteristics. In addition, ethnogastronomic knowledge regarding traditional foods such as *pecel adas* and *jangan adas* provides an important foundation for developing innovative products that preserve local culinary identity while increasing the economic value of *F. vulgare* as a local food resource.

Overall, future research should integrate morphological characterization, phytochemical analysis, food processing, biological evaluation, and ethnogastronomic knowledge to support the development of *F. vulgare* leaves as standardized, safe, and innovative functional food ingredients.

CONCLUSION

F. vulgare has distinctive morphological characteristics, including pinnately compound leaves with fine, filiform segments, a smooth surface, and a characteristic aroma associated with its essential oil content. *F. vulgare* leaves contain various bioactive compounds, including essential oils, phenolic compounds, flavonoids, and terpenoids, which have been associated with several biological activities. From an ethnogastronomic perspective, *F. vulgare* leaves have been traditionally utilized as a food ingredient, including in traditional dishes such as *pecel adas* and *jangan adas* among communities in Boyolali and the Merapi–Merbabu region. This traditional utilization demonstrates the important nutritional, cultural, and economic value of fennel leaves. Their phytochemical composition and distinctive sensory characteristics also provide opportunities for developing fennel leaves as functional food ingredients in various forms, including herbal teas, leaf powders, functional beverages, seasonings, and other food products. However, the development of fennel leaves as functional food ingredients still faces several challenges, particularly the lack of standardized raw material quality, variations in phytochemical composition caused by environmental and processing factors, bioactive compound stability, and limited clinical evidence in humans. Future research should therefore integrate morphological characterization, phytochemical analysis, food processing, biological evaluation, and clinical studies. The integration of traditional knowledge with scientific approaches has the potential to transform *F. vulgare* leaves from a local food resource into standardized, innovative, and economically valuable functional food ingredients while supporting the preservation of Indonesia's ethnogastronomic heritage.

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