

COMPARATIVE ANALYSIS OF BIOACTIVE COMPOUNDS IN FENNEL AND CARAWAY SEEDS

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Abstract

Foeniculum vulgare Mill. (fennel) and *Carum carvi* L. (caraway) are aromatic plants widely used in the food, pharmaceutical, cosmetic, and feed industries due to their essential oils rich in biologically active compounds. This study characterized and compared the chemical composition, total phenolics, flavonoid content, and antioxidant capacity of essential oils and extracts from four fennel samples and one caraway sample. Essential oils were obtained by hydrodistillation and analyzed using gas chromatography–mass spectrometry (GC-MS). Fennel oils displayed a largely consistent qualitative profile, with trans-anethole as the predominant constituent (up to 60.5% in cv. Hestia), accompanied by minor compounds such as fenchone, α -pinene, β -pinene, limonene, and estragole, which varied quantitatively among cultivars. Caraway oil showed a distinct profile dominated by carvone and D-limonene, accounting for over 97% of the total volatile fraction. Caraway seeds exhibited the highest flavonoid content, while certain fennel cultivars accumulated more total phenolics, resulting in measurable differences in antioxidant capacity. These findings highlight the influence of species and cultivar on the accumulation of bioactive compounds and suggest that both fennel and caraway seeds have potential as natural feed additives to enhance antioxidant defenses, support metabolic efficiency, and improve dairy animal productivity.

Key words: *Foeniculum vulgare*, *Carum carvi*, bioactive compounds, volatile compounds, feed.

INTRODUCTION

Aromatic and medicinal plants have been used for centuries for their therapeutic properties and as spices to enhance the flavor and aroma of food (Rather et al., 2016). Among them, *Foeniculum vulgare* Mill. (fennel) and *Carum carvi* L. (caraway), members of the Apiaceae family, are extensively cultivated for their essential oils and bioactive compounds (Ahmad et al., 2018; Laribi et al., 2013).

Foeniculum vulgare Mill. is an annual, biennial, or perennial plant widely distributed in Central Europe and the Mediterranean region (Abdesslem et al., 2022). It has long been used as a natural remedy due to its antibacterial, antioxidant, antitumor, anti-inflammatory, galactogenic, and antiviral properties (Rahimi and Ardekani, 2013). These biological effects are attributed to its diverse phytochemical

composition, including flavonoids, hydrocarbons, fatty acids, amino acids, and volatile compounds. Within the volatile fraction of *Foeniculum vulgare* seeds, trans-anethole, estragole (methyl chavicol), fenchone, and α -phellandrene are reported as major constituents, with trans-anethole being the predominant compound, which contributes to the wide use of fennel extracts in the food and pharmaceutical industries (Mokhtari & Ghoreishi, 2019). *Carum carvi* L. is the best-known species of the genus *Carum*, which includes approximately 25–30 species. Caraway is cultivated in Europe, West Asia, Africa, and the United States as a spice and as a source of essential oil with recognized biological and technological value. Its essential oil exhibits diuretic, galactogenic, antibacterial, seed germination inhibitory, and insect-repellent activities (Bouzaid et al., 2024; Simic et al., 2008; Singh et al., 2006). Carvone

and limonene represent approximately 97% of the major components of caraway essential oil, while other compounds such as carveol, camphene, phellandrene, and anethole further contribute to its nutritional and therapeutic value (Sedláková et al., 2003). Essential oils from fennel and caraway are traditionally recognized for their galactogenic potential, mainly attributed to volatile constituents such as trans-anethole, fenchone, carvone, and limonene.

Beyond their volatile fractions, fennel and caraway seeds are important sources of phenolic acids and flavonoids. These secondary metabolites are well known for their antioxidant properties, primarily due to their ability to neutralize reactive oxygen species through hydrogen atom or electron donation. Total phenolic content (TPC) and total flavonoid content (TFC) are widely used indicators of antioxidant potential in plant extracts. Several studies have demonstrated a positive correlation between phenolic concentration and radical scavenging activity in Apiaceae species (Shan et al., 2005; Dai and Mumper, 2010). Therefore, evaluating both essential oil composition and phenolic profiles is essential for understanding the biological activity and functional value of these plants (Figueiredo et al., 2008).

In recent years, aromatic and medicinal plants have gained increasing attention as phytogetic feed additives in dairy nutrition, aiming to enhance productivity and product quality (Iommelli et al., 2025). Mahmoud et al. (2020) reported that supplementation of dairy rations with caraway and fennel seed powder at 0.7% of total dry matter improved animal performance and enhanced the milk fatty acid profile. Similarly, Attari et al. (2018) found that fennel supplementation increased milk yield without altering its composition. Moheghi et al. (2010) also demonstrated that increasing caraway seed powder in cattle diets improved milk fat content. Considering their phytochemical richness and documented biological effects, the aim of this study was to characterize the phytochemical composition, essential oil profile, and antioxidant activity of *Foeniculum vulgare* and *Carum carvi* seeds in order to evaluate their potential application as natural feed additives.

MATERIALS AND METHODS

Plant material

Seeds of *Foeniculum vulgare* Mill. and *Carum carvi* L. were provided by the Plant Genetic Resources Bank of Buzau, Romania. The experimental material included four fennel samples corresponding to different cultivars and one caraway sample (Table 1). The seeds were stored at room temperature in a desiccator prior to characterization.

Table 1. Samples and codification

Sample	Code
<i>Carum carvi</i> L.	C1
<i>F. vulgare</i> Mill. cv. Hestia	F1
<i>F. vulgare</i> Mill. cv. BRGV1 (Napoleon)	F2
<i>F. vulgare</i> Mill. cv. de Florenta	F3
<i>F. vulgare</i> Mill. cv. BRGV2	F4

Determination of dry matter content

Dry matter content was determined by oven-drying 1 g of seed material at 105°C until constant weight was achieved, according to Gül et al. (2023). The dried material was cooled in a desiccator to prevent moisture absorption and then weighed using an analytical balance.

Protein content analysis

Nitrogen content (%) was determined using a CHNS elemental analyzer based on the high-temperature combustion method (Dumas principle), as described by Serrano et al. (2013). Approximately 2 mg of sample was accurately weighed into tin capsules and introduced into the combustion furnace, where complete oxidation occurred at temperatures above 900°C in an oxygen-rich atmosphere. The resulting gases were transported by helium, reduced, and purified before separation by gas chromatography. Quantification was performed using cystine as the analytical standard.

Crude protein content was calculated from the measured nitrogen content using the conventional nitrogen-to-protein conversion factor of 6.25, based on the assumption that proteins contain approximately 16% nitrogen ($100/16 = 6.25$) (Mariotti et al., 2008; Posa et al., 2024). Protein content was therefore calculated according to the following equation:

Protein (%) = Nitrogen (%) $\times$ 6.25

Extraction of bioactive compounds

An amount of 1 g of seed sample was mixed with 10 mL of 70% aqueous methanol (v/v) and subjected to conventional extraction. The extraction procedure consisted of macerating and homogenizing the sample in the presence of quartz sand for 24 h in the dark at room temperature. After maceration, the samples were agitated to enhance extraction efficiency and then centrifuged for 5 min at 5000 rpm at 4°C. The supernatant was collected, and the extraction step was repeated twice under the same conditions. The obtained supernatants were pooled, resulting in a final extract volume of 30 mL (Stan et al., 2017).

Determination of total phenolic content

The total phenolic content of the seed extracts was determined using the Folin-Ciocalteu spectrophotometric method, following the protocol described by Ion et al. (2020). An aliquot of 0.5 mL of extract was mixed with 2.5 mL of Folin-Ciocalteu reagent (2 N), previously diluted tenfold with distilled water. A 70% methanol solution was used as the blank. After incubation for 2 minutes at room temperature, 2 mL of sodium carbonate solution (75 g/L) was added. The mixture was then placed in a water bath at 50°C for 15 minutes and subsequently cooled to room temperature in an ice-water bath. Absorbance was measured at 760 nm using a UV-Vis spectrophotometer. Total phenolic content was quantified using a gallic acid calibration curve ($y = 0.012x + 0.0277$, $R^2 = 0.9984$). The results are expressed as milligrams of gallic acid equivalents per gram of fresh sample (mg GAE/g).

Determination of total flavonoid content

Total flavonoid content was determined using the aluminum chloride colorimetric assay described by Samatha et al. (2012), with minor modifications. Briefly, 250 μ L of extract was transferred into a test tube, followed by the addition of 150 μ L of aluminum chloride solution (10% w/v). The mixture was incubated at room temperature for 5 minutes. Subsequently, 500 μ L of NaOH solution (5%) was added, and the reaction mixture was thoroughly vortexed. The final volume was

adjusted to 2.5 mL with distilled water. Absorbance was measured at 510 nm using a UV-Vis spectrophotometer. Quantification was performed using a calibration curve prepared with rutin, and the results were expressed as milligrams of rutin equivalents per gram of fresh sample (mg RE/g) (Ahmad et al., 2018).

Essential oils extraction and analysis

Ground seeds (approximately 200 g) were subjected to hydrodistillation for three hours using a Neo-Clevenger apparatus. The obtained essential oils were diluted in hexane and analyzed using an Agilent 6890 gas chromatograph coupled with a 5973 single-quadrupole mass spectrometer equipped with an HP-5MS capillary column (Ion et al., 2020). The compounds were identified based on their retention indices and by comparison of their mass spectra with those from the NIST database.

Determination of antioxidant capacity

Antioxidant activity was evaluated using the DPPH assay with the stable free radical 2,2-diphenyl-1-picrylhydrazyl, following the method described by Bujor et al. (2016). Absorbance was measured at 515 nm using a UV-Vis spectrophotometer. Antioxidant capacity was quantified using a Trolox calibration curve, and the results were expressed as milligrams of Trolox equivalents per gram of fresh sample (mg TE/g).

RESULTS AND DISCUSSIONS

Plant material and seed characteristics

The analyzed fennel (*Foeniculum vulgare* Mill.) and caraway (*Carum carvi* L.) seeds exhibited morphological characteristics typical of umbelliferous fruits, including an elongated shape with longitudinal ridges. Fennel seeds were observed to be curved and cylindrical, with relatively large dimensions ranging from approximately 4 to 10 mm. Their color varied from green to yellowish-brown depending on the cultivar and maturity stage. The seed surface appeared smooth and was marked by five distinct longitudinal ridges. The fennel samples also presented a characteristic sweet and aromatic odor, which is commonly associated with the high trans-anethole content of fennel essential oil (Ahmed et al., 2019).

In comparison, caraway seeds were smaller, measuring approximately 3-6 mm in length. They displayed a dark brown to brownish-gray coloration and a pronounced spicy aroma, which is typically linked to the presence of carvone and limonene in their essential oil (Laribi et al., 2013). As in fennel, five longitudinal ridges were present on the seed surface; however, in caraway these ridges were more sharply defined. The dry matter content of the analyzed samples ranged from 81.50% to 90.33%. Caraway seeds exhibited the highest dry matter content ($90.33 \pm 2.36\%$), indicating a lower moisture level compared to the fennel samples (Figure 1). Among the fennel cultivars, *Foeniculum vulgare* Mill. cv. Hestia (F1) and the BRGV2 cultivar (F4) recorded similar dry matter values ($87.25 \pm 1.06\%$ and $87.00 \pm 0.71\%$, respectively). Consequently, the moisture content of fennel seeds ranged from 13.67% to 18.50%, which is higher than the values reported by Mehra et al. (2021), who observed moisture contents between 5.85% and 8.45%, depending on the variety or genotype.

The high dry matter content observed in *Carum carvi* L. (C1) seeds ($90.33 \pm 2.36\%$) is consistent with previously reported literature data. A comparative study on Apiaceae seeds reported a moisture content of 6.67% for caraway, corresponding to a dry matter level exceeding 90%, which is in agreement with the results obtained in the present study (El-Assri et al., 2023).

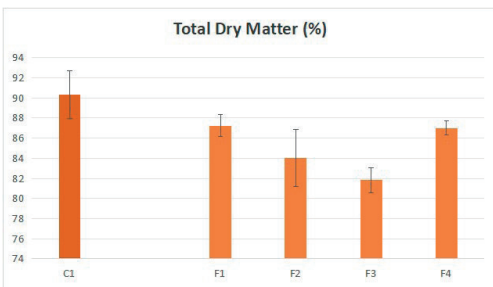


Figure 1. Variation of dry matter content in caraway and fennel seeds

Protein content

Crude protein content ranged from 10.95% to 19.68% (Figure 2), with the highest value recorded in *Foeniculum vulgare* Mill. cv. Hestia (F1), followed by *Carum carvi* L.(C1) ($17.29 \pm 0.90\%$).

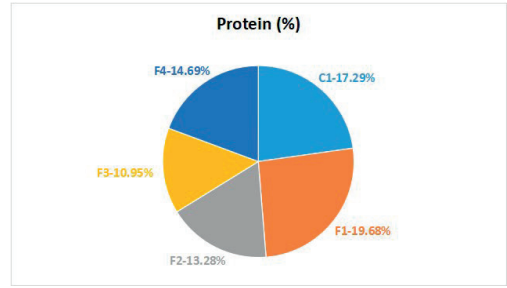


Figure 2. Crude protein content of raw seed

Previous investigations on the chemical composition of *Carum carvi* L. seeds have reported relatively high protein levels (15-20%), which supports the results obtained in the present study (Bouzaid et al., 2024; Filipović et al., 2014). The variability observed among the analyzed samples is consistent with literature data describing fennel seeds as rich in nutritional constituents whose levels may vary depending on cultivar and environmental conditions. For instance, a study evaluating the nutritional composition of seven fennel cultivars from Tunisia reported significant differences in protein content among cultivars, confirming that genetic background strongly influences seed chemical composition, including sugars and proteins (Abdesslem et al., 2022).

Bioactive Compounds

Variation in total phenolic content (TPC) among the analyzed samples is presented in Figure 3. The results revealed noticeable differences between species and cultivars. The highest TPC was recorded in *Foeniculum vulgare* Mill. cv. Florenta (F3) (8.01 ± 0.61 mg GAE/g), followed by the cv. BRGV1 (Napoleon) (F2) with 7.59 ± 0.41 mg GAE/g, indicating a greater accumulation of phenolic compounds in certain fennel cultivars. Intermediate TPC values were observed for *Foeniculum vulgare* Mill. cv. Hestia (F1) (6.70 ± 0.13 mg GAE/g) and the BRGV2 cultivar (F4) (6.47 ± 0.64 mg GAE/g), with relatively low variability recorded for the Hestia cultivar. A comparable TPC value was also recorded for *Carum carvi* L. (C1) (6.34 ± 0.64 mg GAE/g), suggesting a relatively lower accumulation of phenolic compounds under the studied conditions. Similar results were reported by Anwar et al. (2009), who demonstrated that *Foeniculum vulgare* seeds contain considerable amounts of phenolic compounds (627.21-

967.50 mg GAE/100 g), indicating that phenolic content in fennel seeds may vary depending on genetic and environmental factors. In contrast, Cherbal et al. (2023) reported a much higher total phenolic content for fennel seeds purchased from a grocery store (38.2 ± 2 mg GAE/g), which differs markedly from the values obtained in the present study. Such discrepancies may be attributed to differences in extraction methods, solvent type, seed origin, maturity stage, and storage conditions, all of which can significantly influence the phenolic composition of plant materials. In an earlier study, (Bouzaid et al., 2024 found a different level of phenolic compounds in *Carum carvi* L. seeds (13.66 ± 0.06 mg GAE/g), indicating that it fluctuates based on the variety and environmental factors.

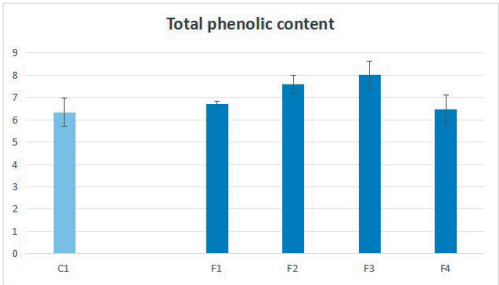


Figure 3. Comparative TPC of fennel cultivars and caraway

Total flavonoid content (TFC) varied among the analyzed samples, with species exerting a stronger influence than cultivar (Figure 4). *Carum carvi* L. (C1) exhibited the highest flavonoid content (7.04 ± 0.56 mg RE/g), indicating a greater accumulation of flavonoid compounds compared with the fennel samples under the studied conditions. In the fennel samples, TFC ranged from 3.99 ± 0.31 to 5.42 ± 0.35 mg RE/g, with the highest value recorded for *Foeniculum vulgare* Mill. cv. Florenta (F3).

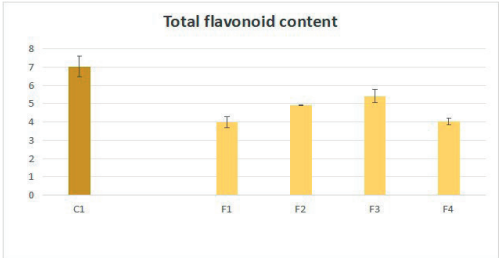


Figure 4. Comparative TFC of fennel and caraway cultivars

These results are consistent with previous reports highlighting caraway seeds as a rich source of flavonoids. For instance, Ulewicz-Magulska et al. (2023) reported a flavonoid content of 5.97 mg RE/g in caraway seeds, while Bamdad et al. (2006) emphasized the substantial phenolic content contributing to their antioxidant potential. In fennel, Ghanem et al. (2012) observed that cultivated varieties contain higher flavonoid levels (1.6%) than wild types (1.2%), confirming that flavonoid accumulation is influenced by genotype and environmental factors. Notably, the values obtained in the present study are substantially higher than those reported by Crescenzi et al. (2023) for hydroalcoholic extracts of various fennel plant parts, which ranged from 0.083 to 1.497 mg RE/g extract, with the highest levels found in leaves.

Antioxidant capacity

The observed antioxidant capacity generally mirrored the pattern of total flavonoid content. Caraway extracts exhibited the highest capacity (97.13 ± 3.14 mg TE/g), indicating strong radical scavenging potential.

As shown in Figure 5, among the fennel samples, *Foeniculum vulgare* Mill. cv. Florenta (F3) and the BRGV1 (Napoleon) cultivar (F2) displayed the highest antioxidant capacity, followed closely by the BRGV2 (F4) cultivar.

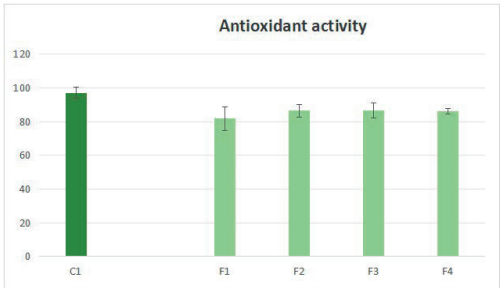


Figure 5. Antioxidant capacity of seed extracts

This correlation between phenolic compounds and antioxidant capacity is consistent with previous reports on fennel and caraway. In methanolic extracts of fennel, total phenolic and flavonoid contents have been shown to significantly contribute to DPPH radical scavenging, indicating that higher phenolic concentrations are generally associated with enhanced antioxidant capacity.

Shan et al. (2005) reported high DPPH radical scavenging activity in caraway, which correlated with elevated phenolic content, highlighting the contribution of these compounds to antioxidant potential.

In this study, antioxidant capacity closely followed the trend of total flavonoid content, suggesting that non-volatile phenolic constituents contribute substantially to radical scavenging capacity, as previously reported (Bamdad et al., 2006). Additionally, variations in phenolic and flavonoid contents, as well as differences in essential oil composition, may explain the observed differences in antioxidant capacity among the samples.

Essential oil composition

GC-MS analysis of fennel essential oils identified 24 constituents, revealing a consistent qualitative profile across all four cultivars, with only minor quantitative differences. Trans-anethole was the major constituent, ranging from 51.41% in the BRGV2 (F4) cultivar to 60.48% in cv. Hestia (F1) (Figure 6), confirming that the analyzed samples belong to the anethole chemotype, the most common for fennel essential oil (Rather et al., 2016). Fenchone was the second major component, varying between 20.73% and 22.42% (Figure 7), reflecting a typical sweet fennel profile. Other significant constituents included α -pinene (5.54-8.00%), D-limonene (4.05-6.80%), and estragole (4.90-5.65%), which contribute to the aromatic profile. Minor volatiles, such as γ -terpinene (1.08-1.67%), β -pinene (0.45-0.54%), camphene (0.86-1.06%), camphor (0.59-0.76%), and linalool derivatives, showed noticeable quantitative variation among cultivars.

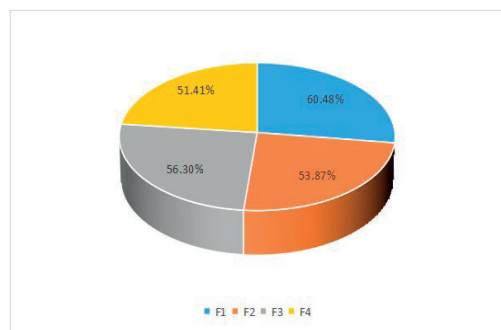


Figure 6. Trans-anethole composition in the fennel essential oil samples

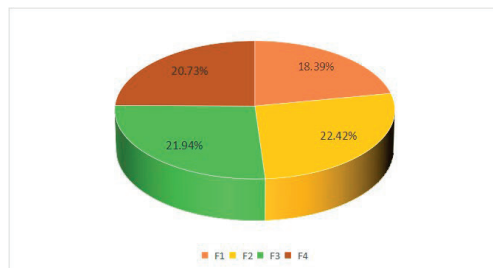


Figure 7. Fenchone in composition in the fennel essential oil samples

Although the qualitative composition was similar across fennel cultivars, the quantitative differences highlight the influence of genetic background and environmental factors. Previous studies have reported variability in fennel essential oil composition depending on geographical origin and genotype. For instance, Egyptian fennel oil was rich in estragole (51.04%), limonene (11.45%), L-fenchone (8.19%), and trans-anethole (3.62%) (Ahmed et al., 2019), whereas Turkish fennel oils contained higher trans-anethole (81.12%) but lower estragole (4.19-5.53%), limonene (2.96-4.60%), and fenchone (1.17-2.65%) (Telci et al., 2009). Similar major compounds were reported in fennel oils from Yugoslavia and Montenegro (Mimica-Dukić et al., 2003; Šunić et al., 2023), while bitter fennel from Turkey exhibited a different profile with estragole (40.49%), fenchone (16.9%), and limonene (17.66%) (Özcan and Chalchat, 2006).

In caraway, essential oil was dominated by carvone (54.25%) and D-limonene (43.37%), together accounting for 97.62% of the total volatile fraction. Minor constituents, including β -pinene, (Z)- β -ocimene, limonene oxide, trans-carveol, perillal, and caryophyllene, were present at <1%, contributing marginally to the overall profile. These results align with previous reports of carvone and limonene as the main components of caraway essential oil (Meshkatsadat et al., 2012; Simić et al., 2008). The composition differs from other *Carum* species, such as *C. nigrum*, where dillapiol and germacrene derivatives dominate (Singh et al., 2006).

A clear interspecific difference was observed: fennel oils are dominated by trans-anethole (phenylpropanoid chemotype), whereas caraway oils exhibit the carvone-limonene

chemotype. These differences are reflected in antioxidant capacity, with caraway showing higher radical scavenging potential, likely linked to its volatile profile. Major volatile constituents such as trans-anethole, fenchone, carvone, and limonene, along with minor compounds like α -pinene, β -pinene, and estragole, contribute to antioxidant effects either individually or synergistically with non-volatile phenolics (Rather et al., 2016; Figueiredo et al., 2008).

The identified bioactive compounds - phenolics, flavonoids, and key volatiles - have practical implications for dairy feed applications. Their antioxidant properties may reduce oxidative stress in animals, which is known to impair metabolism, immune function, and milk production (Celi, 2011). Volatile compounds such as trans-anethole and carvone may enhance appetite, feed intake, and digestive efficiency, supporting nutrient utilization and milk yield (Benchaar et al., 2008). Additionally, essential oil constituents can modulate rumen microbiota, suppressing harmful microbes while promoting beneficial populations, further improving energy availability and nutrient absorption (Patra & Yu, 2012).

CONCLUSIONS

The study demonstrated notable differences between *Foeniculum vulgare* and *Carum carvi* seeds in terms of phytochemical composition, nutritional profile, and antioxidant capacity, highlighting the combined influence of species and cultivar on bioactive compound accumulation. Caraway seeds showed the highest flavonoid content and dry matter, while fennel cultivars exhibited greater variation in total phenolics. Essential oil analysis revealed distinct chemotypes: fennel oils were rich in trans-anethole, whereas caraway oils were dominated by carvone and limonene, compounds known to support digestive health and appetite in livestock.

These findings indicate that both fennel and caraway seeds can serve as natural feed additives to improve antioxidant status, enhance nutrient utilization, and potentially increase milk production in dairy animals. Cultivar selection is crucial for maximizing beneficial traits, such as phenolic and flavonoid content, antioxidant

capacity, and essential oil composition, to optimize animal health and productivity.

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REFERENCES

- Abdesslem, S. B., Elbaz, M., Boulares, M., Ben Moussa, O., Timoumi, M., & Hassouna, M. (2022). Value adding search among a selection of Tunisian fennel (*Foeniculum vulgare* Mill.) cultivars: Nutritional composition, chlorophyll and β -carotene contents of fennel seeds. *Journal of Oasis Agriculture and Sustainable Development*, 4, 110–116. <https://doi.org/10.56027/JOASD.spiss152022>
- Ahmad, B. S., Talou, T., Saad, Z., Hijazi, A., Cerny, M., Kanaan, H., Chokr, A., & Merah, O. (2018). Fennel oil and by-products seed characterization and their potential applications. *Industrial Crops and Products*, 111, 92–98. <https://doi.org/10.1016/j.indcrop.2017.10.008>
- Ahmed, A.F., Shi, M., Liu, C., Kang, W. (2019). Comparative analysis of antioxidant activities of essential oils and extracts of fennel (*Foeniculum vulgare* Mill.) seeds from Egypt and China. *Food Science and Human Wellness*, 8, 67–72. <https://doi.org/10.1016/j.fshw.2019.03.004>
- Anwar, F., Ali, M., Hussain, A.I., Shahid, M. (2009). Antioxidant and antimicrobial activities of essential oil and extracts of Fennel (*Foeniculum Vulgare* Mill.) seeds from Pakistan. *Flavour and fragrance journal*, 24, pp. 170–176, <https://doi.org/10.1002/ffj.1929>
- Attari, V., Basiri, Sh., & Taheri, V. (2018). Effects of feeding fennel, black seed and black caraway plant on milk yield, growth hormone and prolactin in lactating Holstein cows. *Journal of Animal Science Research*, 28(3), 169–179.
- Bamdad, F., Kadivar, M., & Keramat, J. (2006). Evaluation of phenolic content and antioxidant activity of Iranian caraway in comparison with clove and BHT using model systems and vegetable oil. *International Journal of Food Science and Technology*, 41(Suppl. 1), 20–27. <https://doi.org/10.1111/j.1365-2621.2006.01238.x>
- Benchaar, C., Calsamiglia, S., Chaves, A.V., Fraser, G.R., Colombatto, D., McAllister, T.A. and Beauchemin, K.A. (2008) A Review of Plant-Derived Essential Oils in Ruminant Nutrition and Production. *Animal Feed Science and Technology*, 145, 209–228. <http://dx.doi.org/10.1016/j.anifeedsci.2007.04.014>
- Bouzaid, H., Espirito Santo, L., Ferreira, D. M., Machado, S., Costa, A. S. G., Dias, M. I., Calhella, R. C., Barros, L., Chater, O., Rodi, Y. K., Errachidi, F., Chahdi, F. O., Oliveira, M. B. P. P., & Alves, R. C. (2024). Detailed Phytochemical Composition, Cytotoxicity/Hepatotoxicity, and Antioxidant/Anti-Inflammatory Profile of Moroccan Spices: A Study on Coriander,

- Caraway, and Mystical Cumin. *Molecules*, 29(15), 3485. <https://doi.org/10.3390/molecules29153485>
- Bujor, O. C., Le Bourvellec, C., Volf, I., Popa, V. I., & Dufour, C. (2016). Seasonal variations of the phenolic constituents in bilberry (*Vaccinium myrtillus* L.) leaves, stems and fruits and their antioxidant activity. *Food Chemistry*, 213, 58–68. <https://doi.org/10.1016/j.foodchem.2016.03.064>
- Celi, P. (2011). Oxidative Stress in Ruminants. In: Mandelker, L., Vajdovich, P. (eds) Studies on Veterinary Medicine. Oxidative Stress in Applied Basic Research and Clinical Practice. *Humana Press*, Totowa, NJ. https://doi.org/10.1007/978-1-61779-071-3_13.
- Cherbal, A., Bouabdallah, M., Benhalla, M., Hireche, S., & Desdous, R. (2023). Phytochemical Screening, Phenolic Content, and Anti-Inflammatory Effect of *Foeniculum vulgare* Seed Extract. *Preventive nutrition and food science*, 28(2), 141–148. <https://doi.org/10.3746/pnf.2023.28.2.141>
- Crescenzi, M. A., D'Urso, G., Piacente, S., & Montoro, P. (2023). A Comparative UHPLC-Q-Trap-MS/MS-Based Metabolomics Analysis to Distinguish *Foeniculum vulgare* Cultivars' Antioxidant Extracts. *Molecules*, 28(2), 900. <https://doi.org/10.3390/molecules28020900>
- Dai, J., & Mumper, R. J. (2010). Plant Phenolics: Extraction, Analysis and Their Antioxidant and Anticancer Properties. *Molecules*, 15(10), 7313–7352. <https://doi.org/10.3390/molecules15107313>
- El-Assri, B.-M., Hajib, A., Choukri, H., Gharby, S., Lahkimi, A., Eloutassi, N., & Bonia, A. (2023). Nutritional quality, lipid, and mineral profiling of seven Moroccan Apiaceae family seeds. *South African Journal of Botany*, 160, 23–35. <https://doi.org/10.1016/j.sajb.2023.06.042>
- Figueiredo, A. C., Barroso, J. G., Pedro, L. G., & Scheffer, J. J. C. (2008). Factors affecting secondary metabolite production in plants: Volatile components and essential oils. *Flavour and Fragrance Journal*, 23(4), 213–226. <https://doi.org/10.1002/ffj.1875>
- Filipović, V., Ugrešević, V., Popović, V. M., Marković, T. Lj., Radanović, D., Glamočlija, Đ., & Protić, R. (2014). Protein and oil content of different age seeds of some herb species. *II International Congress Food Technology, Quality and Safety, Novi Sad, Serbia*, 315–319. DOI: 10.13140/2.1.1697.8240
- Ghanem, M.T., Radwan, H.M., Mahdy, el-S.M., Elkholy, Y.M., Hassanein, H.D., Shahat, A.A. (2012). Phenolic compounds from *Foeniculum vulgare* (subsp. Piperitum) (*Apiaceae*) herb and evaluation of hepatoprotective antioxidant activity. *Pharmacognosy Research*, 4(2): 104-8. DOI: 10.4103/0974-8490.94735
- Gül, E. N., Altuntaş, E., & Oktay, Z. E. (2023). Determination of important biotechnical characteristics of some safflower (*Carthamus tinctorius* L.) cultivars. *Journal of New Results in Science*, 12(1), 47-54. <https://doi.org/10.54187/jnrs.1241678>
- Iommelli, P., Spina, A. A., Vastolo, A., Infascelli, L., Lotito, D., Musco, N., & Tudisco, R. (2025). Functional and Economic Role of Some Mediterranean Medicinal Plants in Dairy Ruminants' Feeding: A Review of the Effects of Garlic, Oregano, and Rosemary. *Animals*, 15(5), 657. <https://doi.org/10.3390/ani15050657>
- Ion, V. A., Nicolau, F., Petre, A., Bujor, O. C., & Badulescu, L. (2020). Variation of bioactive compounds in organic *Ocimum basilicum* L. during freeze-drying processing. *Scientific Papers. Series B, Horticulture.*, 64(1), 397-404, ISSN 2285-5653.
- Laribi, B., Kouki, K., Bettaieb, T., Mougou, A., & Marzouk, B. (2013). Essential oils and fatty acids composition of Tunisian, German and Egyptian caraway (*Carum carvi* L.) seed ecotypes: A comparative study. *Industrial Crops and Products*, 41, 312–318. <https://doi.org/10.1016/j.indcrop.2012.04.060>
- Mahmoud, A. E. M., Rahmy, H. A. F., & Ghoneem, W. M. A. (2020). Role of caraway, fennel and melissa addition on productive performance of lactating Frisian cows. *Pakistan journal of biological sciences*, 23(11), 1380-1389. <https://doi.org/10.3923/pjbs.2020.1380.1389>
- Mariotti, F., Tomé, D., & Mirand, P. P. (2008). Converting nitrogen into protein Beyond 6.25 and Jones' factors. *Critical Reviews in Food Science and Nutrition*, 48(2), 177–184. <https://doi.org/10.1080/10408390701279749>
- Mehra, N., Tamta, G., Nand, V., & Biswas, S. (2021). Compositional analysis of *Foeniculum vulgare* seeds genotypes collected from Tarai region of Uttarakhand. *The Pharma Innovation Journal*, 10(1), 268–271. <https://doi.org/10.22271/tpi.2021.v10.i1d.5524>
- Meshkatsadat, M. H., Salahvarzi, S. A. B.A. H., Aminiradpoor, R., Abdollahi, A. (2012). Identification of essential oil constituents of caraway (*Carum carvi*) using ultrasonic assist with headspace solid phase microextraction (UA-HS-SPME). *Digest Journal of Nanomaterials and Biostructures*, 7(2): 637-640 https://chalcogen.ro/637_Meshkatsadat.pdf
- Mimica-Dukic, N., Kujundzic, S., Sokovic, M., Couladis, M. (2003). Essential oil composition and antifungal activity of *Foeniculum vulgare* Mill. obtained by different distillation conditions. *Phytotherapy Research*, 17:368–371. <https://doi.org/10.1002/ptr.1159>.
- Moheghi, M., Tahmasbi, A., Naserian, A., Omid, A. (2010). Assessment of nutritional value of caraway-seed pulp for feeding Holstein dairy cattle. *Journal of Animal and Veterinary Advances*, 9, 306–310. DOI: 10.3923/javaa.2010.306.310
- Mokhtari, L., & Ghoreishi, S. M. (2019). Supercritical carbon dioxide extraction of trans-anethole from *Foeniculum vulgare* (fennel) seeds: Optimization of operating conditions through response surface methodology and genetic algorithm. *Journal of CO₂ Utilization*, 30, 1–10. <https://doi.org/10.1016/j.jcou.2018.12.018>
- Özcan, M.M., & Chalchat, J. (2006). Effect of collection time on chemical composition of the essential oil of *Foeniculum vulgare* subsp. piperitum growing wild in Turkey. *European Food Research and Technology*, 224, 279-281. DOI: 10.1007/s00217-006-0309-x
- Patra, A. K., & Yu, Z. (2012). Effects of Essential Oils on

- Methane Production and Fermentation by, and Abundance and Diversity of, Rumen Microbial Populations. *Applied and Environmental Microbiology*, 78(12):4271-80, <https://doi.org/10.1128/AEM.00309-12>
- Posan, P., Nistor, L., Ion, V. A., Dobrin, A., Suler, A., Ianitchi, D., Defta, N., & Marin, M. (2024). Evaluation of some chemical compounds in *Foeniculum vulgare* seeds. *Scientific Papers. Series D. Animal Science*, 67(1), 275–281, ISSN 2285-5750.
- Rahimi, R., & Ardekani, M. R. (2013). Medicinal properties of *Foeniculum vulgare* Mill. in traditional Iranian medicine and modern phytotherapy. *Chinese Journal of Integrative Medicine*, 19(1), 73–79. <https://doi.org/10.1007/s11655-013-1327-0>
- Rather, M. A., Dar, B. A., Sofi, S. N., Bhat, B. A., & Qurishi, M. A. (2016). *Foeniculum vulgare*: A comprehensive review of its traditional use, phytochemistry, pharmacology, and safety. *Arabian Journal of Chemistry*, 9, S1574-S1583. <https://doi.org/10.1016/j.arabjc.2012.04.011>
- Samatha, T., Shyamsundarachary, R., Srinivas, P., Rama, Swamy, N. (2012). Quantification of total phenolic and total flavonoid contents in extracts of *Oroxylum indicum* L. kurz., *Asian Journal of Pharmaceutical and Clinical Research*. 5(Suppl 4): 177–179.
- Sedláková, J., Kocourková, B., Lojková, L., & Kubáň, V. (2003). The essential oil content in caraway species (*Carum carvi* L.). *Horticultural Science*, 30(2), 73-79. DOI: 10.17221/3818
- Serrano, S., Rincón, F., & García-Olmo, J. (2013). Cereal protein analysis via Dumas method: Standardization of a micro-method using the EuroVector elemental analyser. *Journal of Cereal Science*, 58, 31–36. <https://doi.org/10.1016/j.jcs.2013.04.006>
- Shan, B., Cai, Y. Z., Sun, M., & Corke, H. (2005). Antioxidant capacity of 26 spice extracts and characterization of their phenolic constituents. *Journal of Agricultural and Food Chemistry*, 53(20), 7749–7759. <https://doi.org/10.1021/jf051513y>
- Simic, A., Rančić, A., Sokovic, M. D., Ristic, M., Grujic-Jovanovic, S., Vukojevic, J., & Marin, P. D. (2008). Essential Oil Composition of *Cymbopogon winterianus*. And *Carum carvi*. and Their Antimicrobial Activities. *Pharmaceutical Biology*, 46(6), 437–441. <https://doi.org/10.1080/13880200802055917>
- Singh, G., Marimuthu, P., de Heluani, C. S., & Catalan, C. A. (2006). Antioxidant and biocidal activities of *Carum nigrum* (seed) essential oil, oleoresin, and their selected components. *Journal of agricultural and food chemistry*, 54(1), 174–181. <https://doi.org/10.1021/jf0518610>
- Stan, A., Bujor, O. C., Badulescu, L. (2017). Extraction of phenolic compounds from organic dried apples: comparison between conventional, microwave- and ultrasound-assisted extraction methods, *Journal of Horticulture, Forestry and Biotechnology (JHFB)*, Volumul 21(3), ISSN 2066-1797.
- Šunić, L., Ilić, Z. S., Stanojević, L., Milenković, L., Stanojević, J., Kovač, R., Milenković, A., & Cvetković, D. (2023). Comparison of the Essential Oil Content, Constituents and Antioxidant Activity from Different Plant Parts during Development Stages of Wild Fennel (*Foeniculum vulgare* Mill.). *Horticulturae*, 9(3), 364. <https://doi.org/10.3390/horticulturae9030364>
- Telci, I., Demirtas, I., & Sahin, A. (2009). Variation in plant properties and essential oil composition of sweet fennel (*Foeniculum vulgare* Mill.) fruits during stages of maturity. *Industrial Crops and Products*, 30(1), 126–130. <https://doi.org/10.1016/j.indcrop.2009.02.010>
- Ulewicz-Magulska, B., & Wesolowski, M. (2023). Antioxidant Activity of Medicinal Herbs and Spices from Plants of the Lamiaceae, Apiaceae and Asteraceae Families: Chemometric Interpretation of the Data. *Antioxidants*, 12(12), 2039. <https://doi.org/10.3390/antiox12122039>