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Biplot analysis of the genetic variation in the essential oil profile of Iranian landraces of *Anethum graveolens*

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This study evaluated four landraces of local dill (*Anethum graveolens*) from Ardabil, Moghan, Mashhad, and Kerman, with the objective of assessing genetic and phytochemical variabilities. Plants were cultivated under field conditions on loamy soil and harvested at full flowering, the stage associated with maximum production of essential oil. Essential oils were extracted from leaves and flowers using low-temperature oven drying (40°C) and assessed via gas chromatography-mass spectrometry for measuring major constituents, including carvone, limonene, α-phellandrene, myristicin, dill ether, and dillapiole. Genotype × trait biplot analysis explained 82% of the total variation, and positive associations were observed between myristicin and dill ether, as well as between α-terpinene and α-pinene, while negative correlations were found between these compounds and α-terpinolene, dibutyl phthalate, and other minor constituents. Trait discrimination and representativeness analyses identified β-pinene and sabinene as the most informative for differentiating genotypes, followed by 1-terpineol, 5-hydroxymethylfurfural, and 5-epi-neointermedeol. Although highly abundant, such traits as essential oil, carvone, and limonene exhibited low discriminative potential. Among genotypes, Moghan displayed the highest essential oil, D-carvone, and l-limonene content, consistent with a seed-type chemotype dominated by carvone and limonene. Ardabil was rich in myristicin, dill ether, and α-phellandrene, representing a herb-type chemotype. Mashhad emerged as the most favourable genotype overall, combining desirable essential oil yield with moderate stability, while Kerman exhibited a high and stable dillapiole content, making it suitable for applications requiring consistent essential oil quality.

Keywords: biplot analysis, dill, discriminative traits, genotype improvement

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INTRODUCTION

Medicinal plants represent a vital source of bioactive compounds used in food, health care, and industry. Dill (*Anethum graveolens* L.), an annual plant of the Apiaceae, is one of the most important species in this group, valued for its wide-ranging culinary and therapeutic properties (Farmanpour Kalalagh et al., 2025). Originating from central and southwestern Asia, dill is produced worldwide, like several regions of Iran such as the northeast, northwest, and central provinces. Both vegetative and reproductive parts are utilised: leaves and seeds as spices and flavour enhancers, flowers and seeds as rich sources of essential oil and phenolic acids (Thanuma et al., 2025), while stems and leaves generally contain lower levels of these metabolites. The essential oil of dill is chemically diverse and includes carvone, limonene, α-phellandrene, β-phellandrene, dillapiole, and germacrene D (Milenković et al., 2024). These constituents contribute to its antioxidant, antimicrobial, and antidiabetic activities, which make the species an attractive raw material for pharmaceuticals, nutraceuticals, and cosmetic industries. The essential oil profile composition is shaped by genetic factors, ecological conditions, and post-harvest handling, leading to marked variability in both content and quality (Castro-Alves et al., 2021). This diversity presents challenges for industrial standardisation, but also opportunities for targeted breeding to enhance desirable traits.

Genetic variation plays a decisive role in determining the yield and composition of essential oil in dill. Differences among populations and genotypes regulate the synthesis of specific phytochemicals and influence the adaptability of plants to contrasting environments. Such variation underpins the species' capacity to withstand changes in soil, climate, and water availability while also providing a basis for breeding programmes focused on improved yield, enhanced bioactivity, or resilience to stress (Mohanty et al., 2024). Environmental factors including climate, soil type, altitude, harvest stage, and drying methods, further interact with genetic background to shape phytochemical outcomes. Comparative studies highlight the magnitude of this variation: dill grown in Mediterranean regions tends to accumulate higher concentrations of carvone (El-Zaeddi et al., 2016), whereas plants from arid or semi-arid climates often produce more limonene and α-phellandrene (Amanpour et al., 2017). Such genotype × environment interactions emphasise the need to explore diversity across different ecological zones. Iran, with its wide range of climates and soil conditions, offers an especially valuable context for such investigations. Arid northeastern zones with alkaline soils may favour terpenoid biosynthesis, while temperate northwestern regions are more conducive to phenolic compound accumulation. Sabaghnia et al. (2024b), utilised genotype × trait interaction biplot model to analyse the relationships between genotypes and essential oil components on air-dried samples and highlighted the complexity of selecting genotypes with a high essential oil content. Also, they identified the Bushehr genotype as the most favourable for high essential oil production, exhibiting elevated levels of β-phellandrene and dillapiole, which are valuable bioactive compounds. Farmanpour Kalalagh et al. (2025) found significant interactions between genotypes and drying treatments, indicating that the optimal drying method varies depending on the genotype: shade-dried samples had high α-phellandrene in Kerman and Esfahan landraces, while oven-dried samples at 40°C had high myristicin in Ardabil genotype and high essential oil in Parsabad genotype, but high temperatures in oven-dried samples (60°C) decreased essential oil.

The optimal drying method for dill depends on the target essential oil yield, chemical profile, and genotype. Shade drying is generally recommended for preserving thermolabile compounds such as α-phellandrene and dillapiole, maintaining the quality and aroma of the essential oil. Low-temperature drying (around 40°C) provides a compromise between processing efficiency and essential oil preservation, sometimes enhancing yield in certain genotypes without severely degrading volatile compounds (Ayyobi et al., 2014). In contrast, high-temperature drying (70°C) is generally less favourable, as high temperatures can reduce overall oil yield and alter its chemical profile by degrading sensitive bioactive compounds (Thamkaew et al., 2021). Therefore, for medicinal, culinary, or high-quality essential oil production, shade-drying or low-temperature drying is preferred, with the choice depending on the specific genotype and production priorities (Farmanpour-Kalalagh et al., 2025). Understanding the interplay between genetic diversity and essential oil composition is critical for improving the economic and medicinal potential of dill. This study therefore investigates Iranian landraces of dill to characterise their variation in the essential oil content and profile under low-temperature drying (40°C), with the goal of identifying promising genotypes for breeding and cultivation.

MATERIALS AND METHODS

Trial protocol

Four local landraces of dill, representing diverse regions of Iran including Ardabil, Moghan (39°38′N, 47°54′E), Mashhad (36°19′N, 59°32′E) and Kerman (30°15′N, 57°03′E), were evaluated. The experiment was conducted at the agricultural research field in Ardabil, Iran, on loamy soil. Seeds of each genotype were collected, tested for vigour to ensure uniform germination, and sown in a randomised block scheme with three replicates. Irrigation was applied twice weekly to maintain optimal soil moisture. Average precipitation during the cultivation period was 20.6 mm, while daily mean temperature was recorded as 16.4°C. Plants were grown to the full flowering stage, the period known to produce the maximum essential oil yield, after which leaves and flowers were harvested. For oven drying of low-temperature drying (40°C), the samples were subjected at 40°C, with the results maintained for subsequent analysis after essential oil (EO) extraction using Memmert UF110/UN110 Oven, Germany.

Biochemical analysis

The extracted oils were assessed via gas spectrometry (GC-MS) (Agilent 5977A Series MSD) to quantify major constituents: A-TH (α-thujene), A-PI (α-pinene), 1R (1R-α-pinene), SA (sabinene), B-PI (β-pinene), B-MY (β-myrcene), A-PH (α-phellandrene), A-TER (α-terpinene), 1-LI (l-limonene), G-TE (γ-terpinene), A-TE (α-terpinolene), 1-TE (1-terpineol), DI-E (dill ether), HMF (5-hydroxymethylfurfural), D-CA (D-carvone), CA (carvacrol), B-SE (β-selinene), MY (myristicin), DI (dillapiole), NI (5-epi-neointermedeol), DP (dibutyl phthalate), and PA (palmitic acid). These components were characterised via retention time, retention index, and mass-spectral data obtained from the NIST05 and Wiley7 libraries. Retention indices were computed via a homologous series of n-alkanes analysed under identical chromatographic conditions. Their identification was confirmed by comparing the computed issues and mass spectra with the reference data of the NIST Chemistry WebBook.

Biplot analysis

Data distribution was tested for normality using the Shapiro-Wilk test. Following the confirmation of normality, statistical analyses were performed to examine genetic and phytochemical variability. Principal component (PC) analysis was conducted, and results were visualised through a genotype × trait biplot model to depict the associations between genotypes and essential oil traits. The model was based on the following equation:

$$\frac{a_{ij} - b_j}{c_j} = \sum_{n=1}^{2} \alpha_n \beta_{in} \gamma_{jn} + e_{ij},$$

where a_{ij} indicates the performance of entry i in tester j, b_j is the mean of all a_{ij} for tester j, c_j is the root square of variance trait j, α_n is the singular value for each PC, β_{in} and γ_{in} are magnitudes for entry i and tester j on principal component n, respectively, and e_{ij} is the error amount. For ensuring a correct representation of entries and testers, the dataset was scaled symmetrically and centred. Also, a singular value decomposition procedure was used to obtain scores, singular value partitioning (SVP = 2) applied to regular representation, while SVP = 1 was used to visualise the association of genotypes and traits. Thus, the fitted model provided a reliable assessing of variations and identifying of discriminative entries.

RESULTS AND DISCUSSION

The genotype × trait biplot described 45% and 37% of the variance, respectively, and captured 82% of the total variations (Fig. 1). Such a relatively high description indicates the robustness of the biplot model in explaining genotype × trait interrelationships. Vectors of testers were generated from the traits to the origin, permitting representation of association among traits via their orientations. The biplot model proved additive and nonadditive interaction types, demonstrating that rankings of genotypes ranged regarding each trait. Similar types of complex interactions in selecting of the best entries and testers is consistent with previous reports in *Spinacia oleracea* (Sabaghnia et al., 2016) and *Nigella sativa* (Mohebodini et al., 2024), who recommended the biplot model as an effective method for representing relationships among traits via the cosine of the vectors' angles. An acute angle showed positive correlations, a right angle indicated no correlations, and an obtuse angle indicated negative associations. Also, a long vector showed significance and more variation among traits (Fig. 1).

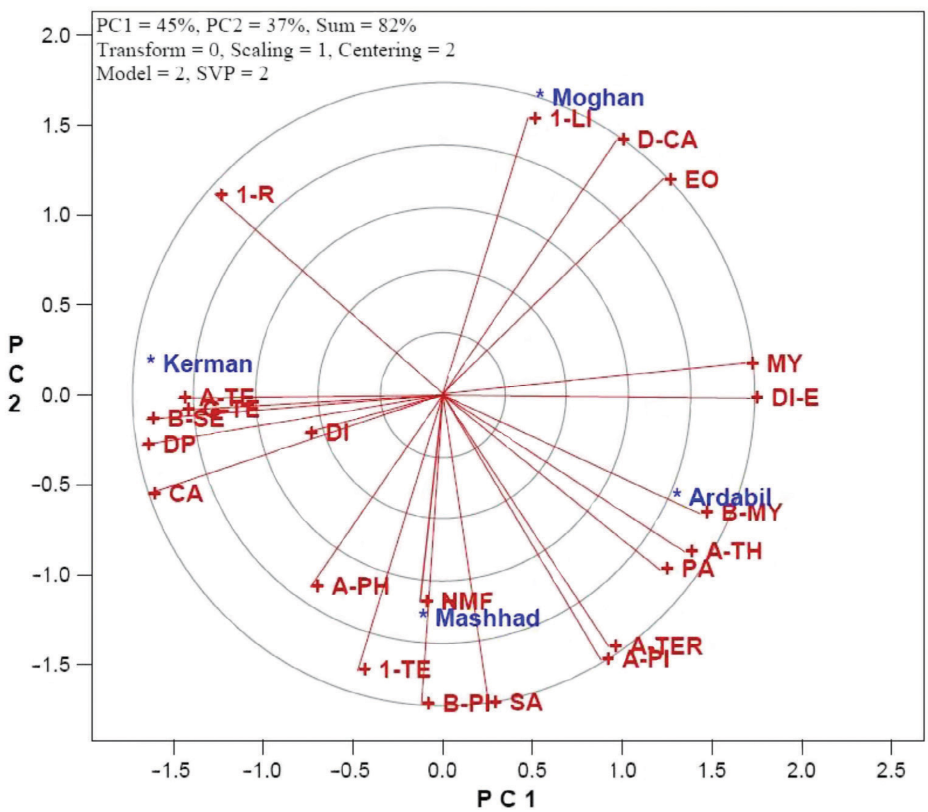

Fig. 1. Relations among traits (essential oil profile) among four dill landraces. Traits are: EO (essential oil), A-TH (α-thujene), A-PI (α-pinene), 1R (1R-α-pinene), SA (sabinene), B-PI (β-pinene), B-MY (β-myrcene), A-PH (α-phellandrene), A-TER (α-terpinene), 1-LI (l-limonene), G-TE (γ-terpinene), A-TE (α-terpinolene), 1-TE (1-terpineol), DI-E (dill ether), HMF (5-hydroxymethylfurfural), D-CA (D-carvone), CA (carvacrol), B-SE (β-selinene), MY (myristicin), DI (dillapiole), NI (5-epi-neointermedeol), DP (dibutyl phthalate), and PA (palmitic acid)

Myristicin (MY) and dill ether (DI-E) were positively correlated due to the acute angle between their vectors. Similarly, such positive correlations were seen for α-terpinene (A-TER) with α-pinene (A-PI); β-myrcene (B-MY) and α-thujene (A-TH) with palmitic acid (PA); and essential oil (EO) and D-carvone (D-CA) with l-limonene (1-LI), regarding acute angles. Also, 1-terpineol (1-TE), β-pinene (B-PI), sabinene (SA), α-phellandrene (A-PH), 5-hydroxymethylfurfural (HMF), and 5-epi-neointermedeol (NI), associated positively with each other (Fig. 1). Finally, α-terpinolene (A-TE), dibutyl phthalate (DP), β-selinene (B-SE), γ-terpinene (G-TE), carvacrol CA), and dillapiole (DI) correlated with each other positively due to acute angles. Jana and Shekhawat (2010) noted that α-phellandrene, dill ether, and myristicin are key odorants of the dill herb and often co-occur, so it supports current findings that these compounds commonly appear together in herb oils. Kadoglidou et al. (2023) found that α-phellandrene and dill ether were major constituents in leaf essential oil and showed a strong negative correlation between dill ether and myristicin, while a positive association was found in the current study, so the correlation can flip with genotype, organ (leaf vs. seed), harvest time, or environment.

Essential oil (EO), D-carvone (D-CA), and l-limonene (1-LI) indicated no correlation with β-myrcene (B-MY), α-thujene (A-TH), and PA (palmitic acid), due to right angles (Fig. 1). Myristicin (MY) and dill ether (DI-E), as well as 1R (1R-α-pinene), showed zero association with 1-terpineol (1-TE), β-pinene (B-PI), sabinene (SA), α-phellandrene (A-PH), 5-hydroxymethylfurfural (HMF), and 5-epi-neointermedeol (NI). Negative correlations were found for Myristicin (MY) and dill ether (DI-E) with α-terpinolene (A-TE), dibutyl phthalate (DP), β-selinene (B-SE), γ-terpinene (G-TE), carvacrol (CA), and dillapiole (DI), due to obtuse angles. Also, essential oil (EO), D-carvone (D-CA), with l-limonene (1-LI) indicated negative association with 1-terpineol (1-TE), β-pinene (B-PI), sabinene (SA), α-phellandrene (A-PH), 5-hydroxymethylfurfural (HMF), and 5-epi-neointermedeol (NI) due to obtuse angles. The observed lack of association between carvone and limonene with the α-phellandrene, dill ether, myrcene is consistent with the report of Ozliman et al. (2021) about interrelations of essential oil profile of seed vs. herb in some dill chemotypes. Dill essential oil is characterised by high α-phellandrene and dill ether, whereas seed oils show pronounced enrichment in limonene and carvone. It is important to consider that although biplot model enables an effective representation of multivariate associations, its outcome may not align completely with numerical correlations, which indicate direct relationships among traits, because this model uses less than 100% of variations (in this case 82% of variation was benefited).

Figure 2 shows how this procedure provides a way for the evaluating of genotypes according to the performances of all traits, making it possible to identify the most favourable candidate genotypes for plant breeding tasks and production. For simplifying comparison tasks, a square shape was generated via perpendicular lines to the related sides, thus four vertex genotypes were distinguished as Ardabil, Moghan, Mashhad, and Kerman. Among these, genotype Moghan exhibited the highest concentrations of essential oil (EO), D-carvone (D-CA), and l-limonene (1-LI), while genotype Ardabil showed dominance in Myristicin (MY), dill ether (DI-E), α-terpinene (A-TER), α-pinene (A-PI), β-myrcene (B-MY), α-thujene (A-TH), and palmitic acid (PA). Genotype Mashhad stood out for its elevated levels of 1-terpineol (1-TE), β-pinene (B-PIβ-pinene), sabinene SA (SA), α-phellandrene A-PH (A-PH), 5-hydroxymethylfurfural (HMF), and 5-epi-neointermedeol (NI), while ecotype Kerman displayed a high performance in α-terpinolene (A-TE), dibutyl phthalate (DP), β-selinene (B-SE), γ-terpinene (G-TE), carvacrol (CA), dillapiole (DI), and 1R-α-pinene (1R). The four identified genotypes correspond to chemotype patterns, whereas the Moghan genotype, characterised by high essential oil yield, elevated D-carvone, and l-limonene, aligns with the common seed-type chemotype dominated by carvone/limonene (Milenković et al., 2024).

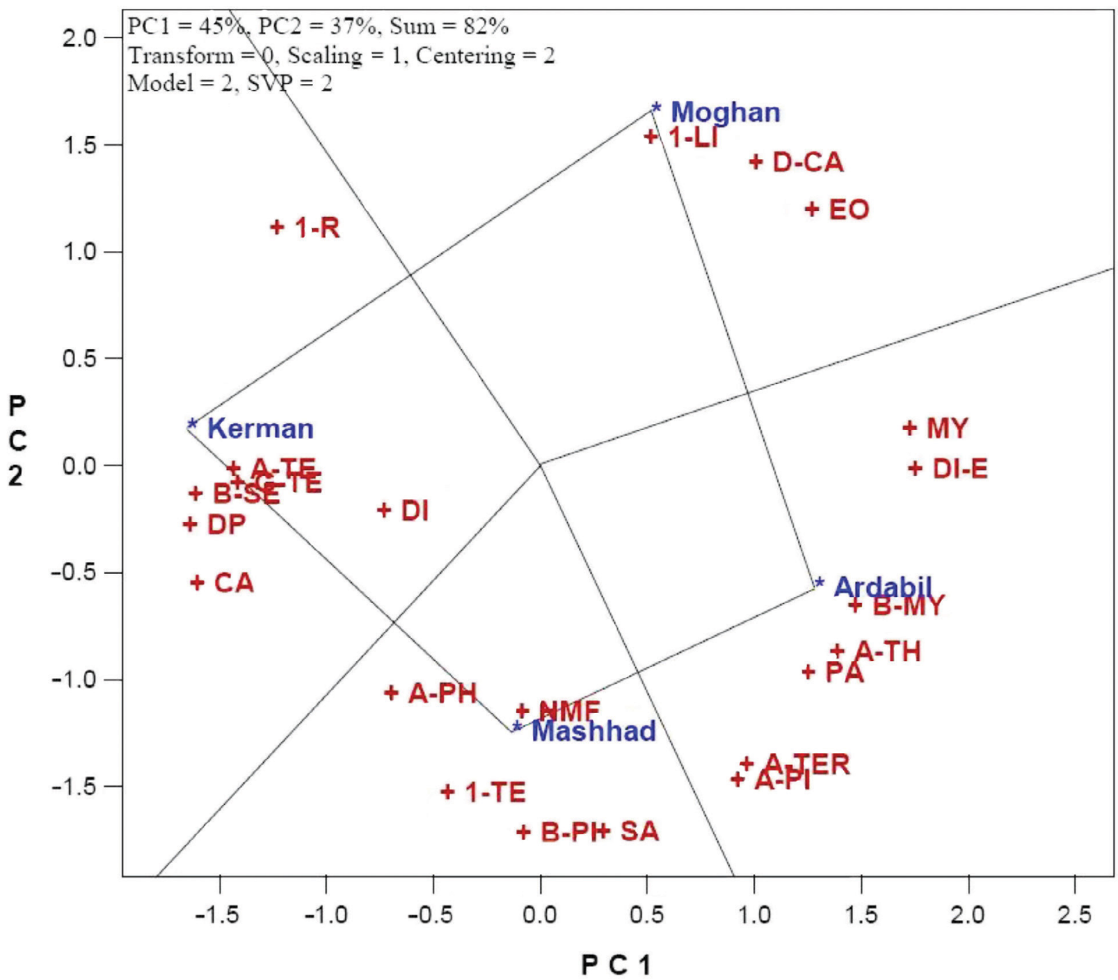

Fig. 2. Polygon-view of TT biplot for dill traits and landraces.
Traits are: EO (essential oil), A-TH (α-thujene), A-PI (α-pinene), 1R (1R-α-pinene), SA (sabinene), B-PI (β-pinene), B-MY (β-myrcene), A-PH (α-phellandrene), A-TER (α-terpinene), 1-LI (l-limonene), G-TE (γ-terpinene), A-TE (α-terpinolene), 1-TE (1-terpineol), DI-E (dill ether), HMF (5-hydroxymethylfurfural), D-CA (D-carvone), CA (carvacrol), B-SE (β-selinene), MY (myristicin), DI (dillapiole), NI (5-epi-neointermedeol), DP (dibutyl phthalate), and PA (palmitic acid)

In contrast, the Ardabil genotype resembles typical herb-type profiles of dill in myristicin, dill ether and α-phellandrene, while Mashhad and Kerman genotypes, which are richer in oxygenated monoterpenes and sesquiterpene/phenylpropanoid components, respectively, reflect ecotype-specific shifts also observed in previous investigations (El-Zaeddi et al., 2016; Hadi et al., 2024). Thus, both genetic background and environmental conditions strongly shape dill chemotypes and can explain the distinct trait associations. Such diversity among local landraces verifies the report of Sabaghnia et al. (2024b), who, using a genotype × trait interaction biplot tool, also reported high genetic variation among native *Satureja hortensis* genotypes.

The discrimination ability of a trait is identified by the amount of variance, and higher magnitudes showing a stronger capacity for distinguishing genotypes, which is shown in Fig. 3, where traits located closer to the ideal position indicate higher capacity of discrimination, and those positioned further away are less effective. Thus, β-pinene (B-PI) and sabinene (SA) emerged as the most discriminative traits. Traits such as 1-TE (1-terpineol), HMF

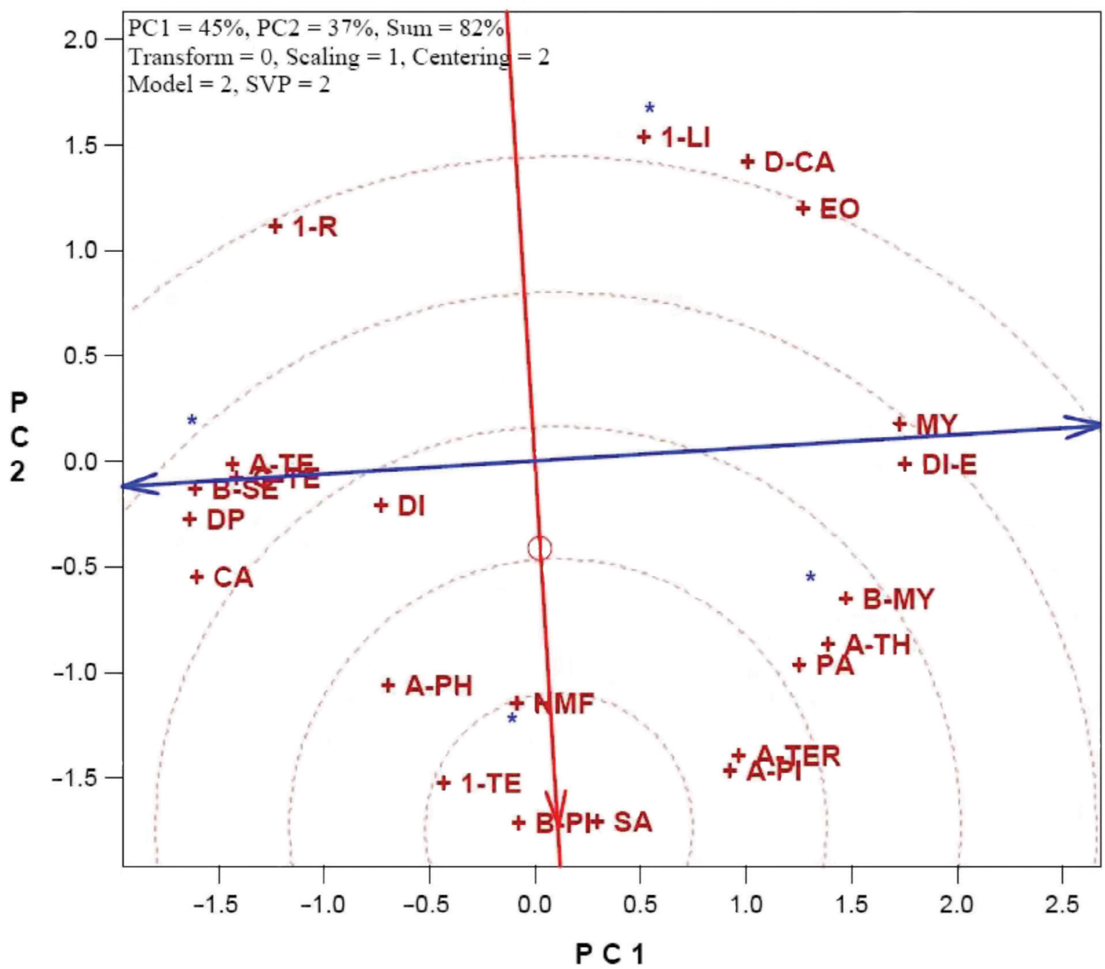

Fig. 3. Ideal trait tool of TT biplot for dill traits.
Traits are: EO (essential oil), A-TH (α-thujene), A-PI (α-pinene), 1R (1R-α-pinene), SA (sabinene), B-PI (β-pinene), B-MY (β-myrcene), A-PH (α-phellandrene), A-TER (α-terpinene), 1-LI (l-limonene), G-TE (γ-terpinene), A-TE (α-terpinolene), 1-TE (1-terpineol), DI-E (dill ether), HMF (5-hydroxymethylfurfural), D-CA (D-carvone), CA (carvacrol), B-SE (β-selinene), MY (myristicin), DI (dillapiole), NI (5-epi-neointermedeol), DP (dibutyl phthalate), and PA (palmitic acid)

(5-hydroxymethylfurfural), and NI (5-epi-neointermedeol), also demonstrated high discriminative ability, verifying their potential for differentiating dill genotypes. By contrast, 1R-α-pinene 1R D-carvone (D-CA) and l-limonene (1-LI) showed low discriminative ability and are therefore less promising for next investigations as detection tool. In addition to discriminative power, the representativeness of a trait is evaluated by the angle between its vector and the axis of the average trait. A smaller angle shows a stronger typical role for the trait; thus, B-PI and SA followed by 1-TE, HMF, and NI, indicated the highest representativeness potential, while Myristicin (MY) and dill ether (DI-E), as well as α-terpinolene (A-TE), dibutyl phthalate (DP), β-selinene (B-SE), γ-terpinene (G-TE), carvacrol (CA), and dillapiole DI (DI) indicated a large angle, showing a weaker typical potential. The identified ideal genotypes should have high representativeness ability, permitting differentiation among genotypes according to the most informative traits. The fitted biplot model gives a valuable framework by highlighting traits with both discriminative and representativeness issues, thereby guiding trait prioritisation in breeding projects. The utility of this model in the dill has been reported by Sabgahnia et al. (2024a) and Farmanpour Kalalagh et al. (2025).

Figure 4 indicates the position of the ideal genotype, and genotypes located closest to this position are regarded most favourable. Thus, dill genotypes were ranked as Mashhad > Ardabil > Kerman > Moghan, with Mashhad identified as the most desirable and Moghan as the least. Identification of such ideal genotype is essential for genetic improvement of dill. However, essential oil profile and quality traits often show low association or negative relation in most crops. The integration of multivariate models with graphical tools supplies an effective base to identification of the most favourable genotypes in dill. In current investigation, Mashhad emerged as the most reliable genotype to assess essential oil profile, showing its favourable combination of traits. Said-Al Ahl and Omer (2016) found considerable variation among dill accessions for essential oil composition, highlighting that certain genotypes combine higher carvone and limonene with acceptable yield performance, while others perform well only in specific traits. Similarly, Ayyobi and Peyvast (2014) reported that genotype origin significantly influenced both essential oil yield and composition, and they recommended multivariate approaches for identifying stable genotypes across environments.

Figure 5 illustrates the performance of dill genotypes in terms of essential oil, with the horizontal axis representing essential oil. Essential oil was the highest in genotype Moghan and the lowest in Kerman. Ardabil was

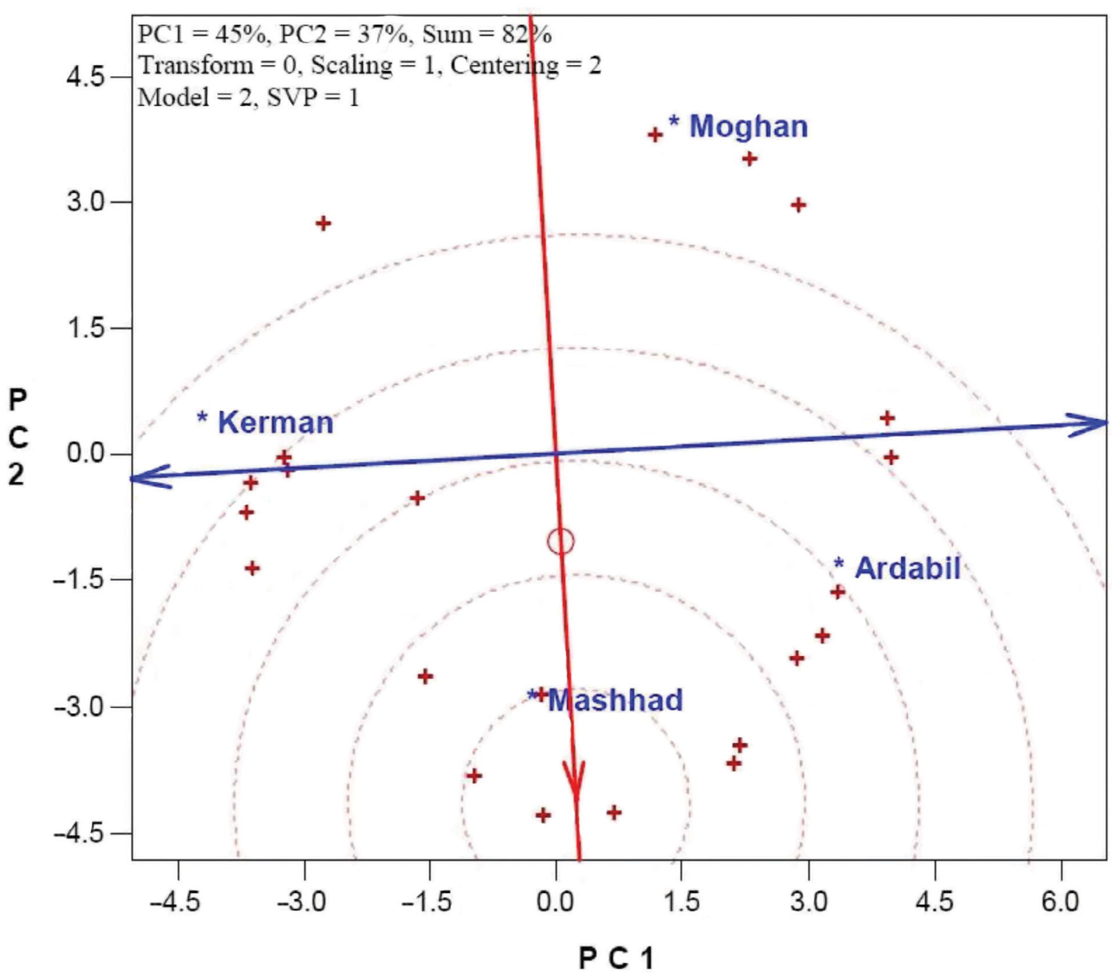

Fig. 4. Ideal genotype tool of TT biplot for dill landraces

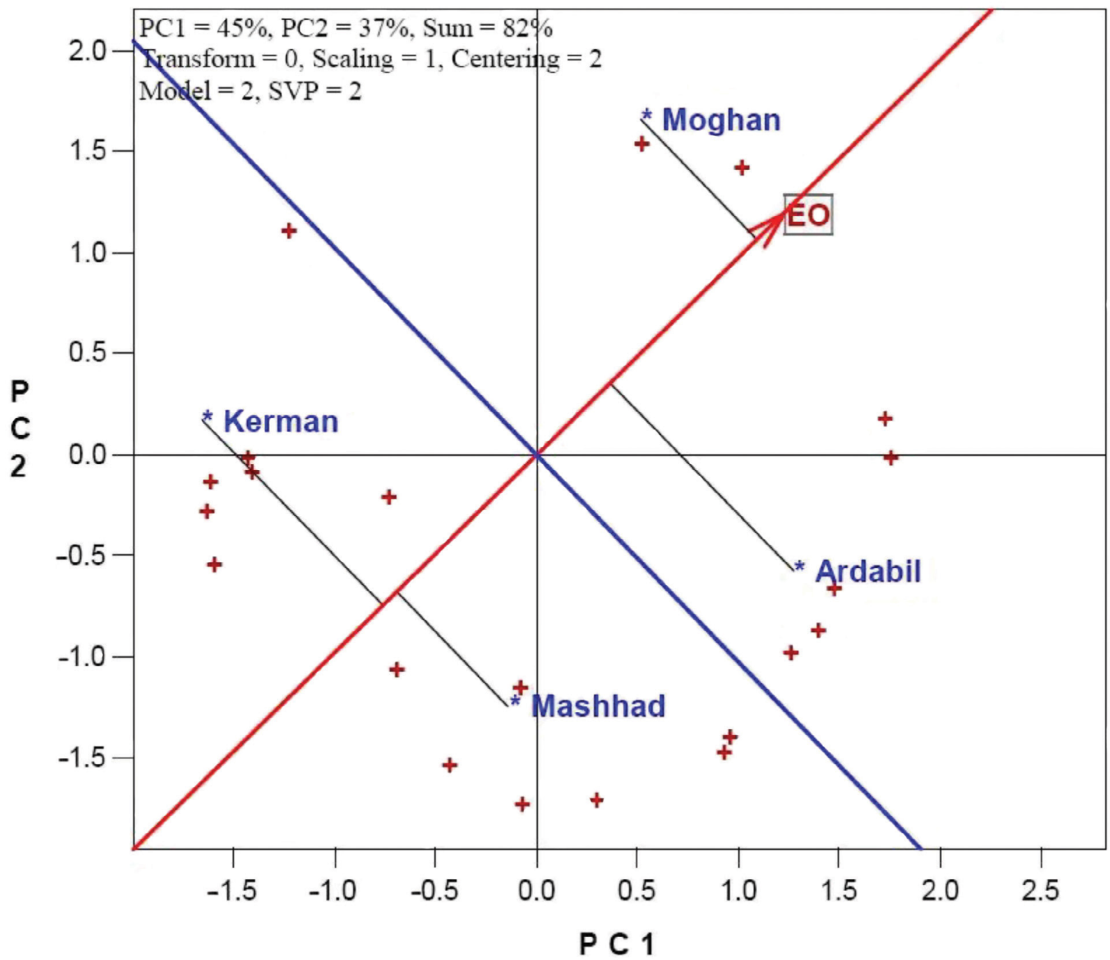

Fig. 5. Examination of essential oil across dill landraces

categorised above the mean axis, confirming its above-average performance, while Mashhad was positioned as below-mean. The distance of genotypes from the horizontal axis indicates variance, so shorter distances show higher stability, making such genotypes more desirable. In this context, almost all of the genotypes had moderate variability, confirming them as moderate candidates for breeding for essential oil. The observed moderate variability in the current study suggests that the studied genotypes could provide a balanced combination of performance and stability, which is critical for breeding programmes targeting both high essential oil content and reliable genotype performance across environments. Such variability among genotypes is consistent with previous reports highlighting the need to select cultivars that combine high EO with stability for breeding programmes targeting both quality and reliable performance across environments (Bhattacharya et al., 2024; Ezzougari et al., 2025). EO composition is dominated by compounds such as carvone, limonene, α-phellandrene, and dillapiole, which contribute not only to the characteristic dill aroma but also to biological activities, including antioxidant, antimicrobial, and insecticidal properties (Fatima et al., 2025).

Dillapiole (DI) is a significant compound found in dill essential oil, contributing to its distinctive aroma and potential therapeutic properties, but studies on dillapiole in dill are limited, thus the performance of DI, across dill genotypes is examined in Fig. 6. Kerman shows the highest and Ardabil the lowest DI content; Mashhad is above the mean axis, confirming

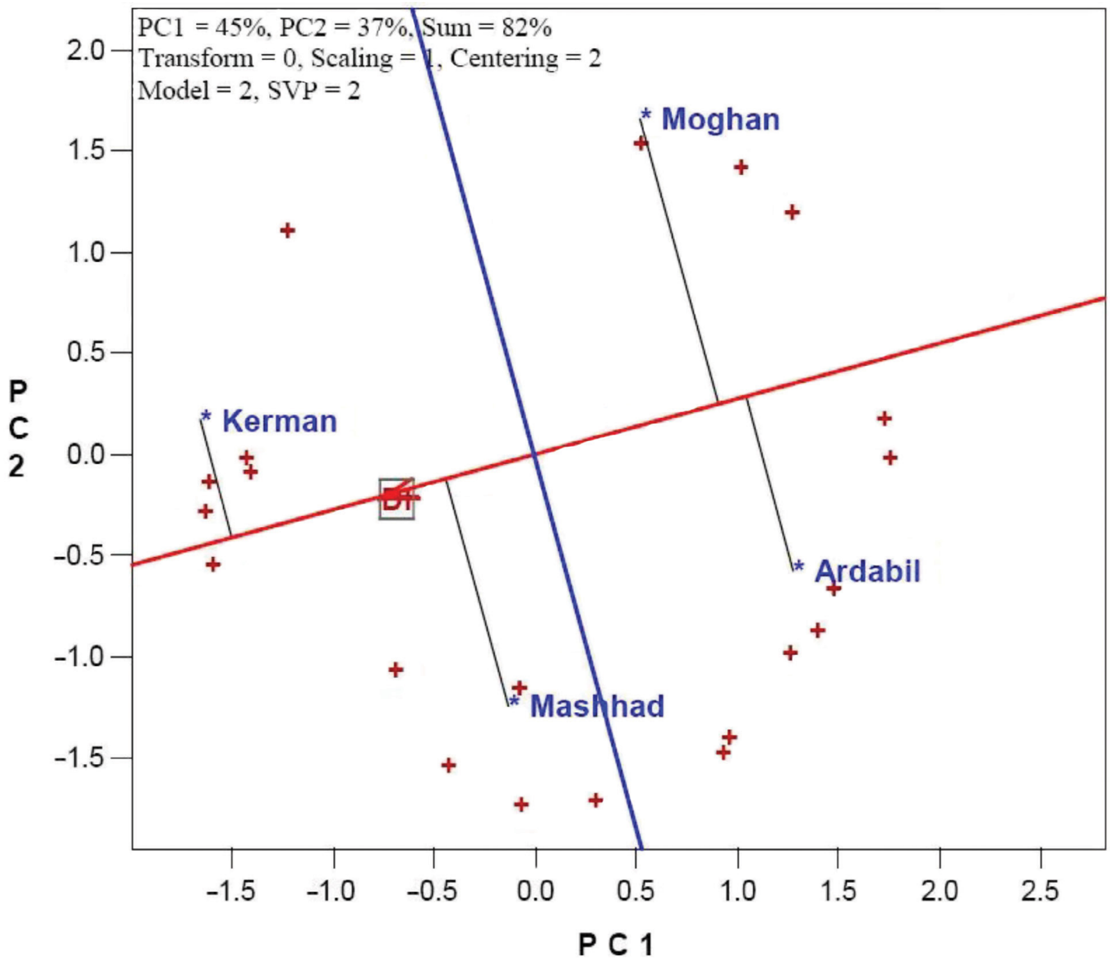

Fig. 6. Examination of dillapiole (DI) across dill landraces

above-average performance, while Moghan is below the mean. The distance from the horizontal axis reflects stability; shorter distances indicate higher stability, making genotypes more desirable. Regarding the shorter distance of Kerman from the horizontal axis, it exhibited lower variability, while Moghan with the highest distance from the horizontal axis indicated higher variance. The presence of dillapiole in dill essential oil contributes to its characteristic aroma and potential therapeutic properties, and along with other compounds like α-phellandrene and carvone, defines the aromatic profile of dill (Jana, Shekhawat, 2010). The observed variability in DI content among genotypes emphasises the importance of selecting appropriate cultivars for specific applications. Genotype Kerman, with a high and stable DI content, may be preferred for applications requiring consistent quality. This study highlighted the complementary roles of genotype selection and multivariate analytical tools in optimising the essential oil content and quality. The observed diversity among landraces offers valuable genetic resources for breeding programmes aimed at producing dill cultivars with targeted chemotypes, a high essential oil content, and a stable performance across environments. Moreover, the combination of biplot modeling, discriminative trait analysis, and identification of ideal genotypes provides a robust framework for guiding future selection and cultivation strategies in dill and other aromatic crops.

The studied four landraces formed clear chemotype-like groups: Moghan – carvone/limonene; Ardabil – α-phellandrene/dill ether/

myristicin; Mashhad and Kerman – oxygenated monoterpenes vs. sesquiterpene/phenylpropanoid leaning. A positive association between myristicin and dill ether was found, while Kadoglidou et al. (2023) reported a strong negative relationship. Together with harvest-stage and environment effects that shift dill ether/α-phellandrene dominance in tops, this suggests that the myristicin ↔ dill-ether correlation is plastic and can flip across genotype, organ, and timing. Current leaf-and-flower sampling at full bloom under low-temperature drying may favour the co-occurrence we observed. Conversely, biplot model showed limited/negative association of carvone/limonene with α-phellandrene/dill ether, consistent with the well-known segregation of seed-type vs. herb-type chemistries and with reports that seed oils are largely carvone/limonene while shoots concentrate α-phellandrene/dill ether (Charles et al., 1995). The fitted GT biplot is broadly concordant with the literature on strong genotype × trait/processing effects, and the utility of biplots for trait/entry selection. The one apparent discrepancy, myristicin vs. dill-ether correlation, has credible explanations in organ, harvest stage, and genotype structure reported elsewhere, so it strengthens rather than weakens our interpretation.

CONCLUSIONS

Genotype Mashhad was identified as the most favourable for a balanced combination of essential oil yield and composition, while Moghan excelled in the essential oil content but showed higher variability. Kerman demonstrated a high and stable dillapiole content, making it suitable for applications requiring consistent quality. The observed variation in chemotypes reflects the combined influence of genetic background and environmental adaptation, emphasising the importance of integrating multivariate tools in selection programmes.

Conflict of interest

The authors declare no conflict of interest

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KAI KURIŲ IRANO VIETINIŲ KRAPŲ *ANETHUM GRAVEOLENS* VEISLIŲ ETERINIŲ ALIEJŲ PROFILIO GENETINĖS VARIACIJOS DVIMATĖ ANALIZĖ

Santrauka

Šiame tyrime buvo analizuojamos keturios vietinės krapų (*Anethum graveolens*) veislės iš Ardabilo, Mogano, Mašhado ir Kermano siekiant įvertinti genetinį ir fitocheminį kintamumą. Augalai buvo auginami lauko sąlygomis priemolio dirvožemyje, o derlius nuimamas žydėjimo metu. Eteriniai aliejai buvo išgauti iš lapų ir žiedų, džiovinant žemoje temperatūroje (40 °C), ir įvertinti dujų chromatografijos-masių spektrometrijos metodu, išmatuoti jų pagrindiniai komponentai, tarp jų karvonas, limonenas, α-fellandrenas, miristicinas, krapų eteris ir dilapiolis. Genotipo × požymių dvimatė (biplot) analizė paaiškino 82 % viso kintamumo, nustatyti teigiami ryšiai tarp miristicino ir krapų eterio, α-terpineno ir α-pineno, taip pat neigiamos koreliacijos tarp šių junginių ir α-terpinoleno, dibutilftalato ir kitų mažiau paplitusių sudedamųjų dalių. Požymių diferenciacijos ir reprezentatyvumo analizės rodo, kad β-pinenas ir sabinenas yra informatyviausi nustatant genotipų diferenciaciją, po jų eina 1-terpineolis, 5-hidroksimetilfurfurolas ir 5-epi-neointermedeolis. Tokie požymiai kaip eterinis aliejus, karvonas ir limonenas, nors ir labai gausūs, pasižymėjo mažu diferenciacijos potencialu. Genotipe iš Mogano nustatyti didžiausi eterinio aliejaus, D-karvono ir l-limoneno kiekiai, atitinkantys sėklų tipo chemotipą, kuriame vyrauja karvonas ir limonenas. Ardabilo veislėje gausu miristicino, krapų eterio ir α-fellandreno, atstovaujančių žolelių tipo chemotipui. Mašhado veislė išsiskyrė kaip palankiausias genotipas, derinantis pageidaujamą eterinio aliejaus derlių su vidutiniu stabilumu, o Kermano pasižymėjo dideliu ir stabiliu dilapiolio kiekiu, todėl ji tinka tuo atveju, kai reikalinga pastovi eterinio aliejaus kokybė.

Reikšminiai žodžiai: dvimatė analizė, krapai, skiriamieji požymiai, genotipo gerinimas