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# Some Phenotypic Selection Criteria to Improve Seed Yield and Essential Oil Percentage of Sweet Fennel (*Foeniculum vulgare* Mill. var. *Dulce*)

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**Abstract:** The research was aimed to determine relationships between seed yield and some yield components of 20 sweet fennel (*Foeniculum vulgare* Mill. var *dulce*) lines. The highest positive correlation (r=0.915) was recorded between biological yield and single plant yield. Plant height, number of branches, number of umbels and umbellets had a positive effect on single plant yield. One thousand seed weight was negatively correlated with essential oil percentage. The highest positive and direct effect on seed yield was shown by number of umbellets, while maximum negative and direct contribution to it was made by biological yield. In addition, single plant yield, plant height and one thousand seed weight affected seed yield positively. Single plant yield had maximum direct effect (32.95%) on essential oil percentage followed by plant height (24.60%) and number of branches (15.11%). In conclusion, it could be suggested that single plant yield, number of umbellets and plant height are good phenotypic selection criteria to improve seed yield and essential oil percentage of sweet fennel.

**Key Words:** Sweet fennel, *Foeniculum vulgare* Mill. var. *dulce*, correlation, path analysis

# Tatlı Rezenenin (*Foeniculum vulgare* Mill. var. *Dulce*) Uçucu Yağ Oranı ve Tohum Veriminin Geliştirilmesine Yönelik Bazı Fenotipik Seleksiyon Kriterleri

**Öz:** Bu araştırmada, tatlı rezenin (*Foeniculum vulgare* Mill. var *dulce*) tohum verim ve bazı verim öğeleri arasındaki ilişkileri belirlemek amaçlanmıştır. Yirmi adet rezene hattı materyal olarak kullanılmıştır. En yüksek pozitif ilişki (r=0.915) biyolojik verim ile tek bitki verimi arasında belirlenmiştir. Bitki boyu, dal sayısı, şemsiye sayısı ve şemsiyecik sayısının tek bitki verimi üzerine etkisi pozitif olmuştur. Bin tohum ağırlığı, uçucu yağ oranı ile negatif yönde ilişkili bulunmuştur. Tohum verimine maksimum - negatif etkiyi biyolojik verim yaparken, en yüksek pozitif ve direk etkiyi şemsiyecik sayısı göstermiştir. Ayrıca, tek bitki verimi, bitki boyu ve bin tohum ağırlığı tohum verimini olumlu şekilde etkilemiştir. Uçucu yağ oranı üzerine tek bitki veriminin direk etkisi (%32.95) en yüksek olmuş, bunu bitki boyu (%24.60) ve dal sayısı (%15.11) takip etmiştir. Sonuç olarak, tek bitki verimi, şemsiyecik sayısı ve bitki boyu tatlı rezenenin uçucu yağ oranı ve tohum veriminin iyileştirmesine yönelik fenotipik seleksiyon kriterleri olarak önerilebilir.

**Anahtar Kelimeler:** Tatlı rezene, *Foeniculum vulgare* Mill. var. *dulce*, korelasyon, path analizi

## Introduction

There are many medicinal and aromatic plants grown all over the world. The genus *Foeniculum* (family Apiaceae) and many varieties of sweet fennel (*Foeniculum vulgare* Mill. var. *dulce*) are cultivated in central and Eastern Europe, France, Italy, Greece and Turkey (Anonymous 2003). Generally, sowing area and yield of fennel cultivated mainly in few provinces such as Bursa, Denizli, Gaziantep, Manisa and Antalya in Turkey is 350 ha and 550 kg $ha^{-1}$ , respectively. Also, although its sowing area shous change by years, 200-250 tons of fennel per year is produced (Yıldırım and Kan, 2006).

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The fennel fruits containing essential oil are official in pharmacopoeias of many countries. Fennel oil is rich in phenylpropanoids, mainly *trans*-anethole. Two types of oil are distinguished: bitter or wild fennel oil (30-75% anethole, 12-33% fenchone, α-pinene>limonene) and sweet fennel oil (80-90% anethole, 1-10% fenchone, limonene> α-pinene). Fennel fruits also contain various flavonoids and furanocoumarins (Wyk and Wink 2005).

Fennel has been used in folk medicine for a long time. It relieves digestive problems, increases milk flow, relives spasms and reduces inflammation. Moreover, the essential oil of this herb is used in cosmetic, pharmaceutical, and perfumer industry and as a food additive (Albert-Puleo 1980, Charles et al. 1993, Kandil et al. 2002).

Many medicinal and aromatic plants are not cultivated and their demands are met by gathering of wild populations. Production of a stable quality and quantity of these plants is important to growing world market, which make it necessary to breed high growing world market quality varietiels.

Relationship among yield components and their direct and indirect effects one another provide basis for a successful breeding program (Choudhry et al.1986, Ali et al. 2003). Optimizing yield is one of the most important aims of agronomists. Seed yield is positively associated with several characters such as plant height, branches number, umbel number and seed weight in fennel (Singh and Mittal 2003).Several components have positive or negative effects on seed yield a complex character. Correlation and path analysis have been used in breeding studies in different aromatic plants (Bhandari and Gupta 1991, Sade et al. 1996, Gürbüz 2001).

The objective of this study was to determine the relationships among some yield components and determine best selection criteria for seed yield and essential oil content for improvement of sweet fennel.

## Material and Methods

The trial was carried out at experimental area of the Department of Field Crops, Faculty of Agriculture, Ankara University during 2004 and 2005 growing seasons selecting 20 lines from single plants taking care of morphological characters such as seed size and number of umbels from open pollinated population of sweet fennels in experimental area of General Directorate of Agricultural research in Haymana/Ankara during 2004. Seeds of all lines were sown in a randomized complete block design with three replications during 2005. Three rows of 3 m length, 40 cm apart were planted for each line in each replication.

The experiment received all the agronomic and cultural treatments (weed control irrigation etc.) throughout the season. At the maturity the data for 9 different characters, including plant height (PH), number of branches per plant (BN), number of umbels per plant (UN), number of umbellets per umbel (ULN), biological yield (BY) per plant, single plant yield (SPY), seed yield (SY), one thousand seed weight (TSW) and essential oil ratio (EOR) were recorded. The first six characters were obtained from 10 randomly selected plants for each plot. For SY, TSW and EOR were used all plants in each plot.

Data collected were subjected to correlation and path analysis by using Tarist computer statistical program (Acıkgöz et al. 2004). Correlation analysis was performed to determine the relationships among the characters investigated according to Steel and Torrie (1980) and Acıkgoz et al. (2004). Path Coefficients were computed (Dewey and Lu 1959, Singh et al. 1988, Orhan and Kasıkcı 2002) to separate the direct and indirect effects of correlation coefficient. Also, in path analysis studies, single plant yield and essential oil percentage were kept as dependent variables and all other characters as independent variables.

## Results and Discussion

Among investigated lines plant height, number of branches per plant, number of umbellets per umbel, biological yield, single plant yield, seed yield, 1000 seed weight and essential oil percentage ranged 40.08-80.36 cm, 4.00-11.90, 10.33-18.80, 10.89-32.80 g/plant, 3.57-15.72 g, 483.3-1566.7 kg $ha^{-1}$, 6.58-9.80 g and 1.30-5.38%. A great variation was observed in between minimum and maximum values of all characters.

**Correlation analysis:** The results of correlation coefficients among the characters studied are shown in Table 1. Number of branches was positively and significantly associated with number of umbels. This is in agreement with Gürbüz (2001) who observed significant positive relationship (r=0.542) between number of branches and number of umbels at 0.01 level in coriander.

Plant height and number of umbels were positively and significantly correlated with number of umbellets. In addition, significant positive correlations were found between biological yield and plant height, number of branches, number of umbels and number of umbellets. Similarly, a positive relation among the

number of umbels per plant, the plant weight, and the umbel weight percentage was recorded by Piccaglia and Marotti (2000).

Plant height, number of branches, number of umbels, number of umbellets and biological yield had a positive effect on single plant yield, and had significant correlation. Sanker and Khader (1991) also reported a significantly positive relationship between seed yield and branch number in coriander. As seen in Table 1, seed yield was positively and significantly associated with plant height and number of umbellets.

Singh and Mittal (2003) reported that seed yield/plant was positively and significantly associated with plant height, number of primary branches/plant, number of secondary branches/plant, number of umbels/plant and 100-seed weight. The results of this study showed low correlations between one thousand seed weight, single plant yield (r=0.125) and seed yield (r=0.109). While highly significant and positive correlation of one thousand seed weight was recorded with plant height. One thousand seed weight was negatively associated with number of umbels and essential oil percentage. Piccaglia and Marotti (2000) explained that the number of umbels per plant and the plant weight were significantly and positively related to the essential oil content (r=0.651 and r=0.569, respectively). Contrary to these findings, correlations between essential oil percentage, number of umbels (r=0.011) and biological yield (r=0.009) were weak in this study. The highest positive relationship (r=0.915) was recorded between biological yield and single plant yield. The results are in line with the findings of Singh and Mittal (2003).

Table 1. Correlation coefficients among the some yield characters in sweet fennel

| Character | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| **1.**PH | ---- | -0.096 | 0.041 | 0.373** | 0.347** | 0.294* | 0.276* | 0.313** | -0.078 |
| **2.**BN | | ---- | 0.679** | 0.180 | 0.685** | 0.701** | -0.084 | -0.079 | 0.009 |
| **3.**UN | | | ---- | 0.307** | 0.652** | 0.641** | -0.025 | -0.235* | 0.011 |
| **4.**ULN | | | | ---- | 0.395** | 0.383** | 0.285* | 0.208 | -0.197 |
| **5.**BY | | | | | ---- | 0.915** | -0.017 | 0.074 | -0.083 |
| **6.**SPY | | | | | | ---- | 0.064 | 0.125 | -0.057 |
| **7.** SY | | | | | | | ---- | 0.109 | -0.046 |
| **8.** T SW | | | | | | | | ---- | -0.372** |
| **9.** EOR | | | | | | | | | ---- |

* P <0.05 significant, ** P<0.01 significant

Table 2. Path-coefficient values estimated for seed yield and plant height, number of branches, biological yield and single plant yield in sweet fennel (n=20)

| Direct effect | Indirect effect | Path coefficient | Effect ratio (%) | Direct effect | Indirect effect | Path coefficient | Effect ratio (%) |
|---|---|---|---|---|---|---|---|
| **PH** | | 0.1555 | 21.22 | **BY** | | -0.6259 | 44.79 |
| | BN | -0.0031 | 0.42 | | PH | 0.0540 | 3.86 |
| | UN | -0.0051 | 0.70 | | BN | 0.0219 | 1.57 |
| | ULN | 0.1151 | 15.70 | | UN | -0.081 | 5.80 |
| | BY | -0.2174 | 29.65 | | ULN | 0.1220 | 8.73 |
| | SPY | 0.1381 | 18.83 | | SPY | 0.4294 | 30.73 |
| | TSW | 0.0121 | 1.65 | | TSW | 0.0029 | 0.20 |
| | EOR | 0.0006 | 0.09 | | EOR | 0.0007 | 0.05 |
| **BN** | | 0.0320 | 3.23 | **SPY** | | 0.4693 | 34.27 |
| | PH | -0.0149 | 1.50 | | PH | 0.0458 | 3.41 |
| | UN | -0.0844 | 8.51 | | BN | 0.0224 | 1.64 |
| | ULN | 0.0556 | 5.60 | | UN | -0.0797 | 5.82 |
| | BY | -0.4286 | 43.22 | | ULN | 0.1182 | 8.64 |
| | SPY | 0.3289 | 33.16 | | BY | -0.5728 | 41.83 |
| | TSW | -0.0031 | 0.31 | | TSW | 0.0049 | 0.35 |
| | EOR | -0.0001 | 0.01 | | EOR | 0.0005 | 0.03 |

**Path coefficient analysis:** The path coefficients for direct and indirect effects of the characters studied on seed yield and essential oil percentage are given in Table 2, 3 and 4, and 5. The highest positive and direct effect on seed yield was shown by number of umbellets, while the maximum negative and direct contribution to it was made by biological yield (Table 2, Table 3). In addition, single plant yield, plant height and one thousand seed weight affected seed yield positively. This is well reflected in effect ratio on seed yield which was contributed 36.00% by number of umbellets, 34.27% by single plant yield, 21.22% by plant height and 10.31% by one thousand seed weight. Similarly, correlation analysis also indicated that the association between seed yield, number of umbellets and plant height showed positive and significant consistent trend. But, the correlations between seed yield, single plant yield and one thousand seed weight were low or non-significant statistically (r=0.064 and r=0.109, respectively) (Table 1). While the direct effect of number of branches on seed yield was positive, the correlation between these characters was negative and non-significant statistically (r= -0.084) (Table 1). Bhandari and Gupta (1991) recorded the maximum direct effects umbellet/plant, single plant weight, umbels/plant and seeds/umbel, respectively on single plant yield in coriander. But, this study showed biological yield or single plant weight had the highest negative effect (44.79%) on seed yield. Sanker and Khader (1991) reported that the highest direct effect was exerted by umbels/plant on single plant yield. In addition, Singh and Mittal (2003) reported that 100-seed weight had maximum direct contribution towards yield followed by number of umbels/plant and seeds/umbel. These findings are in agreement with this study.

The path coefficient analysis further indicated that positive direct effects of number of umbellets, single plant yield and plant height were masked by negative indirect effect of biological yield and number of umbels. Also, the negative indirect effect of number of branches was observed on positive direct effect of plant height. Based on correlation analysis, likewise, relationships between seed yield, biological yield (r= -0.017) and number of umbels (r= -0.025) were negative but non-significant statistically (Table 1). The data further indicated that total positive effect of number of umbellets (0.0961%) on seed yield was result of positive and indirect effect of single plant yield (20.95%), plant height (6.76%), one thousand seed weight (0.94 %), number of branches (0.67%) and essential oil percentage (0.19%). As results of correlation analysis, number of umbellets was positively correlated with single plant yield (r=0.383), plant height (r=0.373), one thousand seed weight (r=0.208) and number of branches (r=0.108), the first two correlations were significant statistically at 0.01 level and the others were non-significant (Table 1). Also, number of umbellets was negative, (r= - 0.197) non-significant statistically correlated with essential oil percentage. The total positive effect of single plant yield seemed to be due to positive indirect effect of number of umbellets (0.1182), plant height (0.0458), and number of branches (0.0224). These results agree with correlation analysis (Table 1). The indirect effect on single plant yield of one thousand seed weight and essential oil percentage were positive but quite low (0.0049 and 0.0005, respectively).

Table 3. Path-coefficient values estimated for seed yield and number of umbels, number of umbellets, one thousand seed weight and essential oil percentage in sweet fennel (n=20)

| Direct effect | Indirect effect | Path coefficient | Effect ratio (%) | Direct effect | Indirect effect | Path coefficient | Effect ratio (%) |
|---|---|---|---|---|---|---|---|
| **UN** | | -0.1243 | 11.74 | **TSW** | | 0.0387 | 10.31 |
| | PH | 0.0064 | 0.60 | | PH | 0.0486 | 12.94 |
| | BN | 0.0217 | 2.05 | | BN | -0.0025 | 0.67 |
| | UN | 0.0949 | 8.96 | | UN | 0.0292 | 7.76 |
| | ULN | -0.4083 | 38.57 | | ULN | 0.0642 | 17.09 |
| | BY | 0.3009 | 28.43 | | BY | -0.0463 | 12.32 |
| | SPY | -0.0091 | 0.86 | | SPY | 0.0588 | 15.65 |
| | TSW | -0.0001 | 0.01 | | EOR | 0.0030 | 0.80 |
| **ULN** | | 0.3088 | 36.00 | **EOR** | | -0.0081 | 4.03 |
| | PH | 0.0580 | 6.76 | | PH | -0.0122 | 6.05 |
| | BN | 0.0058 | 0.67 | | BN | 0.0003 | 0.14 |
| | UN | -0.0382 | 4.45 | | UN | -0.0013 | 0.66 |
| | BY | -0.2472 | 28.82 | | ULN | -0.0609 | 30.22 |
| | SPY | 0.1797 | 20.95 | | BY | 0.0521 | 25.85 |
| | TSW | 0.0081 | 0.94 | | SPY | -0.0268 | 13.27 |
| | EOR | 0.0016 | 0.19 | | TSW | -0.0144 | 7.15 |

Negative direct effects on seed yield were exhibited by biological yield, number of umbels and essential oil percentage with values of 44.79%, 11.74 and 4.03%, respectively. The corresponding correlation coefficients of three characters on seed yield were negative (Table 1).

The data presented in Table 4 revealed that the direct effect (32.95%) of single plant yield on essential oil percentage was highest followed by plant height (24.60%) and number of branches (15.11%). In contrast to these results, except number of branches, the other two characters were negatively correlated with essential oil percentage, and the correlations regarding the four characters were found non-significant statistically (Table 1). Positive direct effect of single plant yield on essential oil percentage was masked by the negative indirect effects of other characters, except plant height and number of branches. The maximum negative indirect effect on essential oil percentage was made single plant yield via number of branches and its effect ratio was 31.78%.

The positive and direct effect of plant height on essential oil percentage was masked by the all characters, except single plant yield. One thousand seed weight had the highest negative contribution (26.66%, -0.1440). Likewise, the highest negative correlation (r=-0.372) was also recorded between one thousand seed weight and essential oil percentage (Table 1). According to this result, the plants with small seeds should be selected in improving sweet fennel varieties for high essential oil percentage. That there is a correlation between seed size and essential oil, and small seeds contain more essential oil compared to large seeds (Zeybek,1985 and Gürbüz, 2001). The positive and direct effect of number of branches was the result of positive and indirect effect of single plant yield (29.79%), one thousand seed weight (5.65%) and seed yield (0.11%). For this character, the highest negative and indirect effect was observed on biological yield (30.69%), followed by number of umbels (8.14%), number of umbellets (3.80%) and plant height (1.99%). The other character exhibiting the direct and positive effect on essential oil percentage was seed yield.

This was due to indirect positive effect of plant height (19.38%), single plant yield (9.27%), biological yield (2.53%) and number of umbels (1.02%). On the other hand, this effect was masked by indirect negative effect of one thousand seed weight (26.66%), number of umbellets (20.44%) and number of branches (4.30%) (Table 4, Table 5).

One thousand seed weight had the highest negative direct effect on essential oil percentage (68.74%). The other negative direct effect on essential oil percentage were exhibited by biological yield, number of umbellets, number of umbels and seed yield with values of 35.16%, 24.89%, 10.81% and 4.58%, respectively. On the other hand, number of umbellets made the highest negative indirect effect via biological yield and its effect ratio was 20.84%.

Table 4. Path-coefficient values estimated for essential oil percentage and plant height, Number of branches, biological yield and single plant yield in sweet fennel (n=20)

| Direct effect | Indirect effect | Path coefficient | Effect ratio (%) | Direct effect | Indirect effect | Path coefficient | Effect ratio (%) |
|---|---|---|---|---|---|---|---|
| **PH** | | 0.1329 | 24.60 | **BY** | | -0.2877 | 35.16 |
| | BN | -0.0093 | 1.72 | | PH | 0.0462 | 5.64 |
| | UN | -0.0032 | 0.58 | | BN | 0.0664 | 8.12 |
| | ULN | -0.0506 | 9.36 | | UN | -0.0502 | 6.13 |
| | BY | -0.0999 | 18.49 | | ULN | -0.0536 | 6.55 |
| | SPY | 0.0803 | 14.86 | | SPY | 0.2498 | 30.52 |
| | SY | -0.0024 | 0.44 | | SY | 0.0001 | 0.02 |
| | TSW | -0.1440 | 26.66 | | TSW | -0.0341 | 4.16 |
| **BN** | | 0.0970 | 15.11 | **SPY** | | 0.2729 | 32.95 |
| | PH | -0.0127 | 1.99 | | PH | 0.0391 | 4.72 |
| | UN | -0.0523 | 8.14 | | BN | 0.0680 | 8.21 |
| | ULN | -0.0244 | 3.80 | | UN | -0.0493 | 5.96 |
| | BY | -0.1970 | 30.69 | | ULN | -0.0520 | 6.27 |
| | SPY | 0.1913 | 29.79 | | BY | -0.2633 | 31.78 |
| | SY | 0.0007 | 0.11 | | SY | -0.0006 | 0.07 |
| | TSW | 0.0363 | 5.65 | | TSW | -0.0577 | 6.97 |

Table 5. Path-coefficient values estimated for essential oil percentage and number of umbels, Number of umbellets, seed yield and one thousand seed weight in sweet fennel (n=20)

| Direct effect | Indirect effect | Path coefficient | Effect ratio (%) | Direct effect | Indirect effect | Path coefficient | Effect ratio (%) |
|---|---|---|---|---|---|---|---|
| **UN** | | -0.0770 | 10.81 | **SY** | | -0.0087 | 4.58 |
| | PH | 0.0055 | 0.77 | | PH | 0.0367 | 19.38 |
| | BN | 0.0659 | 9.26 | | BN | -0.0081 | 4.30 |
| | ULN | -0.0417 | 5.86 | | UN | 0.0019 | 1.02 |
| | BY | -0.1877 | 26.36 | | ULN | -0.0387 | 20.44 |
| | SPY | 0.1750 | 24.58 | | BY | 0.0048 | 2.53 |
| | SY | 0.0002 | 0.03 | | SPY | 0.0176 | 9.27 |
| | TSW | 0.1081 | 15.18 | | TSW | -0.0504 | 26.60 |
| **ULN** | | -0.1357 | 24.89 | **TSW** | | -0.4609 | 68.74 |
| | PH | 0.0495 | 9.09 | | PH | 0.0415 | 6.20 |
| | BN | 0.0175 | 3.20 | | BN | -0.0076 | 1.14 |
| | UN | -0.0236 | 4.33 | | UN | 0.0180 | 2.69 |
| | BY | -0.1136 | 20.84 | | ULN | -0.0282 | 4.21 |
| | SPY | 0.1045 | 19.17 | | BY | -0.0213 | 3.17 |
| | SY | -0.0025 | 0.45 | | SPY | 0.0342 | 5.10 |
| | TSW | -0.0958 | 17.57 | | SY | -0.0009 | 0.14 |

## Conclusion

By comparing the correlation coefficient values of eight independent variables against the seed yield and essential oil percentage, significant differences became evident. Plant height and number of umbellets had significant statistically association with seed yield. On the other hand, the only significant statistically correlation was found between one thousand seed weight and essential oil percentage, but this correlation had negative direction. Also, the other relationships were very low. By partitioning the mutual relationship among the independent variables into direct and indirect effects on seed yield and essential oil percentage, it came into account that number of umbellets, single plant yield and plant height for seed yield; single plant yield, plant height and number of branches for essential oil percentage had the highest direct effect. In addition, plant height and single plant yield were the only character that exhibited highly direct effect on both seed yield and essential oil percentage. Therefore, it could be suggested that single plant yield, number of umbellets and plant height among investigated characters are good phenotypic selection criteria to improve seed yield and essential oil percentage of sweet fennel

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