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Original scientific paper

PATH ANALYSIS FOR SEED YIELD IN SESAME (*Sesamum indicum* L.) INOCULATED/NON-INOCULATED WITH MYCORRHIZAL FUNGI UNDER DROUGHT STRESS

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In order to determine the effective traits to improve seed yield in sesame (*Sesamum indicum* L.), an experimental using factorial split plot design was conducted with three replications in the experimental field of Agricultural Research Center, West-Azerbaijan (Saatloo Station) in the 2015 and 2016 cropping seasons. The main plots (factor A and B) consisted of three different levels of irrigations (normal irrigation: irrigation after 70 mm evaporation of crop or ETc, moderate drought stress: irrigation after 90 mm ETc and severe drought stress: irrigation after 110 mm ETc) and factor B included three levels: two species of mycorrhizal fungi *Glomus mosseae*, *Glomus intraradices* and non-inoculated (control). Sub plots (factor C) consisted of eight commercial cultivars of sesame. The results showed high heritability most studied traits under different levels of drought stress, except for productivity effort. Estimation of variance components showed that under optimum conditions, all studied traits had high heritability and were less affected by environment. Path analysis showed positive significant correlations between seed yield and all studied traits. Progress in yield components can therefore increase seed yield in sesame. In general the research showed that the number of seed per capsule is one of the most important indicators of sesame seed yield under optimum irrigation. Also the traits such as 1000-seed weight and number of capsules per plant can be used as an option index in breeding programs for enhancing seed yield and selection of genotypes under optimum irrigation conditions, due to the high positive direct effect on seed yield. Under

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moderate and severe drought stress, the effective traits on seed yield were different in different species of mycorrizal.

Keywords: correlation, genetic variance, heritability, path analysis, sesame.

INTRODUCTION

Sesame (*Sesamum indicum* L.), is recognized likely as the most olden plants consumed by humans (WEISS, 1983). The agronomic sesame belongs to order *Tubiflorae,* family *Pedaliaceae;* about 36 species have been explained in the genus Sesamum, but only *Sesamum indicum* has been cultivated (GETINET *et al.,* 1998). Global sesame seed cultivation area is about 10819558 hectares and its production reaches about 6235530 tons with an average yield of 576 kg per hectare. In Iran, the sesame cultivation area occupies about 48,000 hectares and its production is about 28,000 tons with an average yield of 583 kg per hectare (FAO, 2014).

Drought stress is a major threat of future global warming. In order to increase tolerance, adaptation and expansion are the most duration ways that show to be significant in the climate changing regions (YOUSEFZADEH NAJAFABADI and EHSANZADEH, 2017). Drought stress is an outstanding environment limitation that affects a broad scope of physiological reactions on a molecular and cellular level of an entire plant (YOUSEFZADEH NAJAFABADI and EHSANZADEH, 2017). Sesame is cultivated in places where temperatures and evaporation are high and there is a possibility of abrupt drought stress (WITCOMBE *et al.,* 2007). Sesame is relatively drought tolerant (BOUREIMA *et al.,* 2011). Tolerance to drought stress in sesame is substantial in low precipitation regions.

Traits such as yield components and physiological traits are suitable for choosing drought tolerant genotypes in breeding programs to decline the effect of drought stress on performance (SILVA *et al.,* 2008). Evaluation of the existing genetic- variability in any plant type is necessary for regulating useful improvement strategies because the access variation can be applied to enhance the performance of genotypes (PATIL *et al.,* 2012). Progress in sesame performance depends on the substance and amount of genetic mutability, heritability and genetic improvement in the base population. The suitable correlation among performance and its components can alter the output of a growing plan through application of the proper election indicators (SIVA PRASAD *et al.,* 2013; RAFIQ *et al.,* 2010). Researchers announced that phenotypic coefficients of variation and genotypic coefficients of variation were high for a number of primary- branches and seed yield per ha (BANDILA *et al.,* 2011). Similarly, GIDEY *et al.* (2012) stated that phenotypic coefficient of variation and genotypic coefficients of variation was high for the number of primary-branches, number of grains per capsule and seed yield per ha. According to results of GIDEY *et al.* (2012) heritability for number of capsules per plant and plant height was high. SIVA PRASAD *et al.* (2013) introduced that inheritance for capsules per plant was superior. Other researchers reported significantly positive correlation between number of capsules per plant and seed yield (AKBAR *et al.,* 2011). Researchers reported that traits such as number of capsules per plant and 1000-seed weight had a positive direct effect on seed yield. Plant- height showed negative direct effect on seed yield (AHADU, 2008). The former studies indicated that path analysis is more efficient than correlation coefficients determining the relationships among the features (BAHRAMINEJAD *et al.,* 2011; DARVISHZADEH *et al.,* 2011). Correlation coefficient and path analysis have been employed by many researchers (TALEBI *et al.,* 2007; BEHRADFAR *et al.,* 2009; BAYAT *et al.,* 2016; JOCKOVIĆ *et al*., 2015) to distinguish relevance among the quantitative characters.

Therefore, the study was carried out on commercial cultivars of sesame to determine the most effective traits for improved sesame seed yield, by path analysis, under different levels of drought stress, and with or without inoculation with mycorrhizal fungi.

MATERIALS AND METHODS

The study was done in two successive- years in 2015 and 2016 at the experimental field of Agricultural Research Center, West-Azerbaijan (Saatloo Station) located at 45° 10′ 53″ E and 37° 44′ 180″ N, 1338 meters above sea level.

The research was carried out in a factorial split plot with 3 replications. The main plots (factor A and B) consisted of three different levels of irrigations (normal irrigation: irrigation after 70 mm evaporation of crop or ETc, moderate drought stress: irrigation after 90 mm ETc and severe drought stress: irrigation after 110 mm ETc) and factor B included three levels: two species of mycorrhizal fungi *Glomus mosseae*, *Glomus intraradices* and non-inoculated (control). Sub plots (factor C) consisted of eight commercial cultivars of sesame. There was a combination of unproductive sand, mycorrhizal hyphae, spores (20 spores g^{-1} inoculum), and colonized root segments in mycorrhizal fungi. Ten grams of the suitable mycorrizal fungi was located into the pit below each seed and next coated with soil. No inoculums were added to non-mycorrhizal plants. The seeds were sown on May 20 in 2015 and on May 13 in 2016, with plant spacing of 50 by 15 cm containing 133333 plants per ha^{-1}. Each plot had 4 sowing lines of 4 meters in length. Cultivation and irrigation were done using furrowing and leakage method, respectively. At the time of planting, three seeds were placed in each clump and then they were thinned at 2-4 leaf stage. After this stage, different levels of drought stress were applied. The distance between sub-plots was considered one non-planted line and the between the two main plots considered two meters. The area of each sub plot and main plot was 10 and 96 square meters, respectively. The total area of the experiment, taking into account the intervals between experimental units and irrigation canals, was about 3000 square meters.

The experiment place was located at 25 km from Urmia and the region is considered to be arid and semi-arid in terms of climatic conditions. According to the long-term meteorological data, the average annual rainfall is 390 mm, the average temperature is 11.3°C and the relative humidity is 75%.

In order to ensure low spore mycorrhizal arbuscular spores in the test area, 10 points of the field were randomly sampled to 0-30 cm depth. From each sample, 50 g of soil were selected by spraying and centrifugation in 55% sucrose solution for examination of spores. First, the soil was poured into a relatively large dish, added to the water 4 times and mixed with a spoon. After dipping the water, the water along with the soil, was deposited on the mesh No. 30 (595 microns), No.80 (177 microns) and No.400 (37 microns) and mesh No.30 (595 microns) was screened for soil and roots. The remaining water and spores in meshes No.80 (177 microns) and No.400 (37 microns) were placed separately in Beakers. The solutions were then placed in plastic containers and centrifuged in a 4000 centrifuge machine for 6 minutes. Then, the up solution was placed in mesh No.400 (37 microns). The residual solution was poured in Beaker and added to it with 55% sucrose. They were stirred and then placed inside the plastic container and centrifuged at 2000 rounds for 2 minutes, then poured on mesh No.400 (37 microns) and then completely inserted into the Beaker which a filter paper was placed under it and divided into eight parts. Then spores were counted under a light microscope. After assuring that the number of spores in the soil is very rare, the target area for testing was selected.

The physical and chemical characteristics of the soil in the experiment site are shown in Supplementary Table 1. According to this table, it is observed that the soil of the test site had loam-clay loam, pH 8 and Ec was about 1.5 ds m^{-1}, which was not a problem for sesame cultivation.

The planting of the first year was carried out on May 10, 2015 and the second year on May 3, 2016 by hand and in a method of wet planting. The first irrigation was done about 10 days after planting. Weeding was done manually in two stages, 20 and 40 days after planting. There was no specific disease and pest in the field. To remove the edge effect, the side rows and half a meter from the beginning and the end of each row were removed. Bulk density, field capacity and permanent wilting point were calculated 1.37, 25 and 12, respectively.

$$\mathrm{RAW} = \frac{\mathrm{FC-PWP}}{100} \times \rho \times \mathrm{D} \times \mathrm{MAD} \qquad \text{Equation 1}$$

Where RAW is the readily available water (mm), FC is field capacity (%), PWP is the permanent wilting point (%), ρ is the bulk density, D is the root zone depth (mm) and MAD is the coefficient of the readily available water. In loam-clay loam soil, the soil capacity of 25 and the wilting point is constant 12. The bulk density is 1.37. Root development depth in sesame was 600 mm. The coefficient of water easy to use is F or MAD or θ.

$$RAW = \frac{25-12}{100} \times 1.37 \times 600 \times 0.65 \qquad \text{Equation 2}$$

MAD = coefficient of the readily available water is the same water that can be used between field capacity and permanent wilting point. The coefficient was 0.65 for optimal irrigation and 0.8 for moderate drought stress and 0.95 for severe drought stress. Under optimum irrigation, moderate drought stress and severe drought stress conditions, RAW were 70, 85 and 100 mm, respectively, which was considered to be the equivalent of ET_C or evapotranspiration.

$$ETo = ETp \times Kp \qquad \text{Equation 3}$$

$$ETc = ETo \times Kc \qquad \text{Equation 4}$$

Where ETo is the potential evapotranspiration, ETp is the pan evapotranspiration, ETc is the crop evapotranspiration, Kp is the pan coefficient and Kc is the crop coefficient of sesame.

Irrigation water was evaluated using Type III flumes (Washington State College). The mouth width and head of III flumes were 304.8 and 30 mm, respectively (CHAMBERLAIN, 1952).

Data concerning to 11 traits including seed yield, harvest index, productivity effort, seed number per m^{-2}, number of seeds per capsule, 1000-seed weight, number of capsules per plant, number of sub-branches, biological yield, stem diameter and plant height were collected on 10 plants increase each plot. Then registered data were analyzed by using SAS ver. 9.1 and SPSS ver. 21 software. Estimation of variance components and heritability was done by the restricted maximum likelihood method. For this purpose, the program prepared in SAS 9.12 software was used (HOLLAND *et al.*, 2003).

Genetic variability, environmental, heritability and phenotypic variance were calculated according to equations 5 to 9:

$$V_g = \frac{MS_g - MS_{cultivar \times year}}{r \times y} \qquad \text{Equation 5}$$

$$V_E = MS_e$$ Equation 6

$$V_{cultivar \times year} = \frac{MS_{cultivar \times year} - MSe}{r}$$ Equation 7

$$H = \frac{V_g}{V_{ph}} \times 100$$ Equation 8

$$V_{ph} = V_g + V_E + V_{cultivar \times year}$$ Equation 9

In high equations, Vg is genetic variance, MSg mean squared genotype, MSe mean square error, r number of replicates, y year, Ve environmental variance, H heritability and Vph phenotypic variance.

The coefficient of variation of phenotypic, genetic and environmental variances was calculated according to equations 10, 11 and 12:

$$CV_{ph} = \frac{\sqrt{V_{ph}}}{\bar{x}}$$ Equation 10

$$CV_g = \frac{\sqrt{V_g}}{\bar{x}}$$ Equation 11

$$CV_E = \frac{\sqrt{V_E}}{\bar{x}}$$ Equation 12

In the above equations, CV_{ph} is the phenotypic coefficient of variation, V_{ph} is the phenotypic variance, CV_g is the genetic variation of coefficient and CV_E is the environmental variation of coefficient. Path analysis were evaluated based on EHSANZADEH *et al.* (2004), where seed yield was kept as the dependent variable and other contributing traits as independent variables.

To normalize some traits such as number of seed per square meter, number of seed per capsule, number of capsule per plant and number of branches, square root conversion (SQRT) transformation and for root colonization percentage, arcsine-square root transformation were used. Combined analysis of factorial split plot experiments based on randomized complete block design was performed using SAS software. The homogeneity of error variances was tested using Bartlett test. To reduce Type 1 error, Bonferroni correction was done by ANOVA and correlation coefficients. Comparison of the means was done by SNK test at 5% level in MSTATC software.

RESULTS AND DISCUSSION

Analysis of variance

The results of the variance analysis showed that the effect of genotype on all studied traits were significant under optimum, moderate and severe drought stress except for productivity effort (Supplementary Tables 2, 3 and 4). This indicates there was genetic variation among the genotypes for studied traits. Similarly, BANDILA *et al.* (2011) stated significant differences among 60 sesame accessions for plant-height, number of primary-branches per plant, capsules per plant, seeds per capsule, 1000-seed weight and seed yield per plant. Moreover, GIDEY *et al.* (2012) indicated extremely considerable differences among 81 sesame cultivars for plant-height, capsules per plant, number of primary-branches per plant, number of seeds per capsule, 1000-seed weight and seed yield per hectare.

Phenotypic and genotypic parameters and variance components

Optimum irrigation conditions

Variation coefficients, phenotypic, genotypic and environmental variance and heritability of all traits under different levels of drought stress over two successive years are shown in Supplementary Tables 5, 6 and 7. Heritability of the majority of studied traits under different levels of drought stress was high, except for productivity effort. Heritability has a fundamental function in determining the compatibility and tactics of selection choice in order to breed a specific trait. The traits under survey expressed wide heritability. Under optimum irrigation the average of heritability ranged from 0% for productivity effort to 99% for 1000-seed weight under inoculation with *Glomus mosseae* mycorrhizal fungi (supplementary Table 5). In non-inoculated (control) conditions, the highest heritability was observed for seed yield (93.87), number of seeds per capsule (86.48), seed number per m^2 (75.30) and biological yield (75.30) (supplementary Table 5). After inoculation with *Glomus mosseae* under optimum irrigation conditions, the maximum heritability was observed for 1000-seed weight (99.80), seed yield (88.95), number of seeds per capsule (79.66) and seed number per m^2 (75.92) (supplementary Table 5). The maximum heritability was seen in seed yield (93.44), 1000-seed weight (91.38), seed number per m^2 (80.60) and number of seeds per capsule (78.46) under optimum irrigation after inoculation with *Glomus intraradices* mycorrhizal fungus (supplementary Table 5).

Moderate drought stress conditions

Under moderate drought stress the maximum and minimum heritability was observed in productivity effort (0%) after inoculation with *Glomus mosseae* mycorrhizal fungus, and seed yield (98.62%) after inoculation with *Glomus intraradices* mycorrhizal fungi, respectively (supplementary Table 6). Under moderate drought stress in non-inoculated (control) conditions, the highest heritability was seen in number of seeds per capsule (93.89), seed yield (91.59), 1000-seed weight (90.87) and seed number per m^2 (82.87) (supplementary Table 6). After inoculation with *Glomus mosseae* under moderate drought stress, the maximum heritability was estimated for number of seeds per capsule (93.99), 1000-seed weight (89.93), seed number per m^2 (84.44) and plant height (80.12) (Supplementary Table 6). The highest heritability was observed for seed yield (98.62), number of seeds per capsule (92.74), 1000-seed weight (88.58), seed number per m^2 (84.58) and number of capsules per plant (78.08) under moderate drought stress conditions after inoculation with *Glomus intraradices* mycorrhizal fungus (Supplementary Table 6).

Severe drought stress conditions

Under the conditions of severe drought stress the highest and lowest heritability was observed in productivity effort (2.25%) after inoculation with *Glomus mosseae* mycorrhizal fungus and 99% for 1000-seed weight under non-inoculated conditions (control), respectively (Supplementary Table 7). Under severe drought stress and non-inoculated (control) conditions, the highest heritability was observed in 1000-seed weight (99.07), stem diameter (95.34), seed number per m^2 (85.60), and seed yield (84.30) (Supplementary Table 7). Under severe drought stress and inoculation with *Glomus mosseae* conditions, the maximum heritability was obtained by stem diameter (98.02), number of seed per capsule (92.04), 1000-seed weight (89.18) and seed number per m^2 (89.01) (Supplementary Table 7). Under severe drought stress and after inoculation with *Glomus intraradices*, the maximum heritability was observed in stem diameter

(96.93), seed number per m^2 (88.37), 1000-seed weight (87.76), biological yield (83.01), and number of seeds per capsule (81.05) (Supplementary Table 7). The results of the study revealed a broad scope of variability between the studied cultivars. Heritability is a criterion that identifies the breeding method and the inheritance power of each trait, and in fact represents the contribution of genetic variation to the total variation. The selection of each attribute depends on the extent of the influence of genetic and environmental factors on the occurrence of the trait. If the contribution of the genetic factors is greater than environmental factors, its role in phenotype development is higher. While otherwise the selection based on that trait will not be conclusive (FARSHADFAR, 1997). Contrary to our results, DESAWI *et al.* (2017) reported lower genotypic coefficients of variation values were than that of phenotypic coefficients of variation, exhibiting that the environment had a significant task in the explanation of these traits. Commonly, the environment mostly affects quantitative traits. According to DESAWI *et al.* (2017), heritability ranged from 0.03% for capsule length to 92.72% for number of capsules per plant. Other researchers reported high heritability for capsules per plant (SIVA PRASAD *et al.,* 2013).

As genotypic and phenotypic variances are influenced by many traits, the scales are not standard, so phenotypic and genotypic coefficient of variation was calculated (Supplementary Tables 5, 6, 7). Using genetic, environmental and phenotypic variances, the coefficient of variation was calculated in nine different environments (Supplementary Tables 5, 6, 7). Among the traits under optimum irrigation conditions in inoculation and non-inoculated with mycorrhizal fungi, seed yield, biological yield and stem diameter, under moderate and severe drought stress conditions, seed yield, biological yield, stem diameter and plant height had very high diversity coefficients, which indicates that these traits have a relatively high genetic variance (Supplementary Tables 5, 6 ,7). The variation in seed yield and biological yield in all three different irrigation conditions was high. Similar reports have been published on genetic diversity for seed yield and its components in rapeseed (AMIRI OGHAN *et al.,* 2002). Small differences between the genetic and phenotypic variation coefficients for all traits in all three different irrigation conditions indicate a higher role of genotypic effect and less environmental impact on these traits. For traits such as seed number per m^2, 1000-seed weight, number of capsules per plant, number of sub-branches, biological yield, stem diameter and plant height, heritability under severe drought stress conditions was higher than under optimum irrigation condition, indicating that the phenotypic variance of these traits is much higher than their genetic variance under optimal conditions. In this study, under optimum irrigation and moderate drought stress, heritability of seed yield, 1000-seed weight, number of capsules per plant and seed number per capsule was higher. Therefore, suitable genotypes with high values of the above mentioned traits can be selected and used in breeding programs. Under severe drought stress, heritability of stem diameter was higher than other traits, so stem diameter can be used as suitable index for producing high seed yield in this condition.

Under optimum irrigation and inoculation with *Glomus mosseae* mycorrizal fungus conditions, among seed yield components, due to the fact that the heritability of 1000-seed weight was higher than seeds per capsule, selection through 1000-seed weight would be more effective for increasing seed yield under high moisture conditions. Under moderate drought stress, heritability of the number of seeds per capsule was higher than 1000-seed weight. Heritability has changed due to the different reaction of the cultivars to different environmental conditions. Usually, the traits related to adaptive phenomena show low variation to environmental conditions. Under drought stress, heritability in some traits, such as plant height was reduced compared to optimum conditions, which is consistent with the results of other researchers who reported reduced heritability due to varied environmental conditions (MONIRIFAR *et al.*, 2004). Also based on this research, inoculation with mycorrhizal fungi increased heritability of plant height under drought stress conditions. The estimated heritability in this study is consistent with those of other researchers (CHALISH and HOUSHMAND, 2011; SUBHASCHANDRA *et al.*, 2009). We found that phenotypic variances were larger than genetic variances in all traits (Supplementary Tables 5, 6, 7). Thus, selecting the best genotypes can be applied based on phenotypic mean values.

SAXENA and BISEN (2017) reported high heritability for seeds per capsule, yield per plant, harvest index, number of primary-branches per plant, number of secondary-branches per plant, plant-height, 1000-seed weight and number of capsules per plant.

However, if the traits have good heritability in all three different irrigation conditions, the selection will have high efficiency. Increase in seed yield components the seed number per capsule, the number of capsules per plant and 1000-seed weight and phenotypic selection can improve seed yield.

Estimation of variance components showed that, all the traits studied in this research had high heritability (except productivity effort) and were less affected by the environment under optimum conditions, but by increasing drought stress, the effect of environment enhanced which was confirmed by increased environmental variability. AHMED *et al.* (2012) and SINGH *et al.* (2003, 2004) also measured phenotypic and genotypic criterions such as correlation coefficient, variances, variance coefficient and stated that those criteria should be considered for genetic progress. Heritability of most traits under stress conditions was higher than the corresponding traits in non-stress conditions, which indicates that phenotypic variance of these traits has fallen in proportion to much higher genetic variation under stress conditions. The environmental variance is not important. In other words, in case of these traits the major part of phenotypic variance is related to genotypic variance. Generally, genetic, phenotypic and heritability variances of traits under nine different experimental conditions do not follow a steady trend.

Simple correlation of traits over two years

Optimum irrigation conditions

Under optimum irrigation conditions in three treatment of non-inoculated and inoculation with two mycorrhizal fungi, there was significant positive correlation among seed yield with all studied traits except for productivity effort. Seed yield had the highest significant positive correlation with biological yield under these conditions. Correlation among seed yield with the number of seeds per capsule, capsule number per plant, 1000-seed weight and plant-height was important and significant (Supplementary Table 8). Similar to our findings about positive correlation between seed yield and its components in sesame were reported by NARAYANAN and MURUGAN (2013), TRIPATHI *et al.* (2013), VANISHREE and GOUDAPPAGUDAR BANAKAR (2013), HIKA *et al.* (2015), MAHMOUD *et al.* (2015), and SAXENA and BISEN (2017).

Moderate drought stress conditions

The correlations among seed yield and other traits under moderate drought stress conditions in three treatment of non-inoculated and inoculation with two mycorrhizal fungi shown in Supplementary Table 9. The maximum significant positive correlation was observed between seed yield and biological yield. In condition of non-inoculated under moderate drought stress, the correlation between seed yield with biological yield, seeds per capsule, capsules per plant and 1000-seed weight were 0.87**, 0.78**, 0.63** and 0.78**, respectively (Supplementary Table 9). A significant positive correlation among seed yield and its components was observed under inoculation with two mycorrhizal fungi. Our findings show that the selection of these traits is suitable for increasing performance.

Severe drought stress conditions

Supplementary Table 10 indicates the maximum significant positive correlation between capsules per plant and seed number per m^2. Since seeds per square meter are dependent on seeds per capsule, observing this correlation coefficient is expected. Under severe drought stress in three treatments non-inoculated and inoculation with two mycorrhizal fungi; seed yield had significant positive correlation with all studied traits except for productivity effort under control. Traits such as productivity effort had significant negative correlation with the majority of studied traits under different levels of drought stress. Our findings were consistent with the results of SIVA PRASAD *et al.* (2013), and RAMIREDDY and SUNDARAM (2002).

In our study, there were positive and significant correlations between seed yield and all the studied traits. An improvement in yield components can therefore have a positive effect on seed yield increase in sesame cultivars.

SUMATHI and MURALIDHARAN (2010) reported significantly positive correlation between seed yield per plant and with plant-height, branches per plant, capsules per plant, days to 50% flowering, days to maturity and 1000-seed weight. SAXENA and BISEN (2016) stated that correlation analysis indicated strong positive dependence of seed yield per plant with number of secondary-branches per plant and capsules per plant.

Generally, according to correlation coefficients, we can deduce that biological yield, seeds per capsule, capsules per plant, 1000-seed weight, plant-height, stem diameter, and harvest index are the most important traits for seed yield improvement. Our works were consistent with other researchers (AHADU, 2008; DESAWI *et al.,* 2017) that the declared capsules per plant and 1000-seed weight had positive direct effect on seed yield.

Stepwise regression analysis and path analysis for seed yield

Since seed yield components are interdepended and expand at various growth phases, correlations may not provide an obvious image of the significance of each part in distinguishing seed yield (NASTASIC *et al.,* 2010). Several researches thus showed that path coefficients analysis supplies data on the inter-relevance between yield components and yield, rather than correlation coefficients (BAHRAMINEJAD *et al.,* 2011; BASALMA, 2008; DARVISHZADEH *et al.,* 2011). In order to remove the effect of ineffective traits in regression model, seed yield was used as a dependent variable from stepwise regression. Independent variables with high impact were identified and path analysis was performed on them.

Optimum irrigation conditions

In non-inoculated (control) treatment under optimum irrigation over the course of two years, path analysis indicated a maximum direct effect on seed yield by seed number per capsule (13.738) and productivity effort (13.348). The maximum negative direct effect was seen in harvest index (-14.022) and stem diameter (-13.97) (Table 1). Increase in the number of seeds per capsule and productivity effort can therefore be expected to increase seed yield under the given conditions. The most indirect effect on seed yield was observed in stem diameter by number of seeds per capsule. The number of seeds per capsule can therefore be considered an indicator of the positive effect of stem diameter on seed yield.

Table 1. Path analysis for seed yield in non-inoculated (control) under optimum irrigation in two years

Trait	Harvest index	Productivity effort	Seed number per m^2	Number of seeds per capsule	Number of capsules per plant	Biological yield	Stem diameter	Sum of effects
Harvest index (HI)	<u>-14.022</u>	7.341	0.079	2.198	-0.003	5.344	-0.28	0.66
Productivity effort (EP)	-7.712	<u>13.348</u>	2.382	-5.084	1.006	-4.231	0.838	0.55
Seed number per m^2 (SNM)	-0.281	8.009	<u>3.97</u>	-5.221	-0.448	8.239	-13.691	0.579
Number of seeds per capsule (NSC)	-2.244	-4.939	-1.509	<u>13.738</u>	-2.163	6.346	-8.662	0.569
Number of capsules per plant (NCP)	-0.012	-3.605	0.476	7.968	<u>-3.728</u>	7.57	-8.103	0.569
Biological yield (BY)	-6.731	-5.073	2.938	7.83	-2.536	<u>11.133</u>	-6.706	0.86
Stem diameter (SD)	-0.281	-0.801	3.891	8.517	-2.163	5.344	<u>-13.97</u>	0.54
Residual	-7.129	Regression Equation: Seed yield =-105.35 + HI×2.270+EF×0.749+SNM×0.002-NCP×2.143+BY×0.133						R^2=0.91

The numbers that have been drawn underneath them are direct effects and the other numbers are indirect effects.

Under inoculation with *Glomus mosseae* mycorrhizal fungus in optimum irrigation, the most positive direct effect on seed yield was observed in harvest index (11.328) and 1000-seed weight (9.603) (Table 2). Seed yield improvement under optimum irrigation (when *Glomus mosseae* mycorrhizal fungus is added) can be obtained by increasing the value of traits.

Path analysis revealed that harvest index (0.801), seeds per capsule (0.777) and capsules per plant (0.492) had the most direct effect on seed yield (under optimum irrigation and inoculation with *Glomus intraradices* mycorrhizal fungus) (Table 3). Harvest index (0.52) had an important positive indirect effect on productivity effort.

Table 2. Path analysis for seed yield in inoculation with Glomus mosseae mycorrhizal fungus under optimum irrigation in two years

Traits	Harvest index	Productivity effort	1000-seed weight	Number of sub-branches	Biological yield	Sum of effects
Harvest index	11.328	-9.641	2.208	-0.053	-3.125	0.72
Productivity effort	8.043	-13.578	6.146	0.247	-0.139	0.72
1000-seed weight (TSW)	2.605	-8.69	9.603	-0.371	-2.569	0.579
Number of sub-branches (NSB)	0.339	1.9	2.016	-1.766	-2.153	0.34
Biological yield	5.097	-0.272	3.553	-0.548	-6.943	0.899
Residual	1.956	Regression Equation: Seed yield =-227.987 + HI×1.760+EF×1.001+TSW×65.525-NSB×1.044+BY×0.237				R^2=0.90

The numbers that have been drawn underneath them are direct effects and the other numbers are indirect effects.

Table 3. Path analysis for seed yield in inoculation with Glomus intraradices mycorrhizal fungus under optimum irrigation in two years

Traits	Harvest index	Productivity effort	Number of seeds per capsule	Number of capsules per plant	Biological yield	Sum of effects
Harvest index	0.801	-0.127	-0.039	0.024	-0.021	0.639
Productivity effort	0.52	-0.195	0.443	-0.173	0.012	0.61
Number of seeds per capsule	-0.41	0.111	0.777	0.044	-0.012	0.66
Number of capsules per plant	0.04	0.068	0.07	0.492	-0.032	0.639
Biological yield	0.352	0.052	0.186	0.325	-0.048	0.87
Residual	-0.183	Regression Equation: Seed yield = -222.136 + HI×2.708+EF×0.978+NSC×1.686+NCP×0.373+BY×0.126				R^2=0.86

The numbers that have been drawn underneath them are direct effects and the other numbers are indirect effects.

Moderate drought stress conditions

Table 4 showed that under moderate drought stress and non-inoculation, harvest index (4.445), number of seed per capsule (2.543) and number of sub-branches (2.729) had the most positive direct effect on seed yield. The maximum negative direct effect was observed from biological yield (-4.754) and productivity effort (-4.503). The effect of biological yield on seed yield via other traits had been positive.

Table 4. Path analysis for seed yield in non-inoculated (control) under moderate drought stress in two years

Traits	Harvest index	Productivity effort	Number of seeds per capsule	Number of sub-branches	Biological yield	Sum of effects
Harvest index	4.445	-2.567	1.042	-0.055	-2.187	0.68
Productivity effort	2.533	-4.503	1.678	-0.546	1.616	0.779
Number of seeds per capsule	1.822	-2.972	2.543	-0.219	-0.666	0.509
Number of sub-branches	-0.089	0.9	-0.204	2.729	-2.948	0.389
Biological yield	2.044	1.53	0.356	1.692	-4.754	0.87
Residual	1.806	Regression Equation: Seed yield = -115.879 + EF×0.848+NSC×2.057-NSB×4.299+BY×0.184				R^2=0.90

The numbers that have been drawn underneath them are direct effects and the other numbers are indirect effects.

Under inoculation with *Glomus mosseae* mycorrhizal fungus and moderate drought stress, harvest index (7.722) and plant height (7.085) had the most positive direct effect on seed yield (Table 5). Based on this result, it can be concluded that it is better to increase the value of harvest index and plant height for seed yield improvement under moderate drought stress (when *Glomus mosseae* mycorrhizal fungus is added). Biological yield (-9.606) and productivity effort (-5.522) had the maximum negative direct effect. The effect of other traits on biological yield on seed yield was positive.

Table 5. Path analysis for seed yield in inoculation with Glomus mosseae mycorrhizal fungus under moderate drought stress in two years

Traits	Harvest index	Productivity effort	Number of seeds per capsule	Biological yield	Plant height	Sum of effects
Harvest index	7.722	-3.314	-0.417	-4.803	1.629	0.819
Productivity effort	4.633	-5.522	-0.922	1.921	0.708	0.75
Number of seeds per capsule	2.239	-3.811	-1.437	1.44	2.196	0.629
Biological yield	3.861	1.104	0.215	-9.606	5.313	0.889
Plant height	1.776	-0.553	-0.446	-7.204	7.085	0.66
Residual	1.893	Regression Equation: Seed yield = -171.035 + HI×2.010+EF×0.869+NSC×1.695+BY×0.155				R^2=0.91

The numbers that have been drawn underneath them are direct effects and the other numbers are indirect effects.

Results showed that productivity effort (3.779) and biological yield (3.006) had the high positive direct effects on seed yield under moderate drought stress and inoculation with *Glomus intraradices* mycorrhizal fungus (Table 6). These characteristics were stated as the most substantial and the most effective on seed yield. Increase in the values of these traits can therefore also improve seed yield. It was also deduced that the harvest index (-3.366) had the highest negative direct effect on seed yield (Table 6). Traits such as productivity effort and biological yield had a high positive correlation with seed yield (0.730 and 0.90 respectively). Selection of sesame cultivars with high productivity effort and biological yield may instantly increase seed yield.

Table 6. Path analysis for seed yield in inoculation with Glomus intraradices mycorrhizal fungus under moderate drought stress in two years

Traits	Harvest index	Productivity effort	Number of seeds per capsule	Biological yield	Sum of effects
Harvest index	<u>-3.366</u>	2.456	-0.255	1.443	0.28
Productivity effort	-2.188	<u>3.779</u>	-0.502	-0.361	0.73
Number of seeds per capsule	-1.145	2.532	<u>-0.749</u>	0.15	0.79
Biological yield	-1.616	-0.454	-0.038	<u>3.006</u>	0.90
Residual	-2.932	Regression Equation: Seed yield = -151.789 + HI×1.232+EF×0.970+NSC×1.635+BY×0.171			R^2=0.93

The numbers that have been drawn underneath them are direct effects and the other numbers are indirect effects.

Severe drought stress conditions

Under severe drought stress with non-inoculated mycorrhizal fungus, and inoculation with *Glomus mosseae* and *Glomus intraradices* mycorrhizal fungi, traits such as the harvest index and biological yield inserted in regression model and together about 96%, 89% and 92% of seed yield changes, respectively. The highest positive direct effect was observed between harvest index (0.211) and biological yield (0.839) with seed yield (Tables 7, 8, 9). The direct effect of the number of capsules per plant on seed yield was negative and partial. The indirect effect of this trait via harvest index (0.034) and biological yield (0.548) on seed yield was positive (Table 8). SAXENA and BISEN (2016) reported high positive direct effect of secondary-branches and capsules per plant on seed yield. Number of secondary-branches and capsules per plant may therefore be a suitable choosing scale for seed yield per plant.

Table 7. Path analysis for seed yield in non-inoculated (control) under severe drought stress in two years

Traits	Harvest index	Biological yield	Sum of effects
Harvest index	<u>0.211</u>	0.478	0.689
Biological yield	0.12	<u>0.839</u>	0.959
Residual	0.219	Regression Equation: Seed yield = -19.007 + HI×1.067 +BY×0.201	R^2=0.96

The numbers that have been drawn underneath them are direct effects and the other numbers are indirect effects.

Table 8. Path analysis for seed yield in inoculation with Glomus mosseae mycorrhizal fungus under severe drought stress in two years

Traits	Harvest index	Number of capsules per plant	Biological yield	Sum of effects
Harvest index	0.244	-0.013	0.428	0.66
Number of capsules per plant	0.034	-0.093	0.548	0.49
Biological yield	0.122	-0.06	0.857	0.92
Residual	0.309	Regression Equation: Seed yield = -38.941 + HI×1.901+NCP×0.170 +BY×0.274		R^2=0.89

The numbers that have been drawn underneath them are direct effects and the other numbers are indirect effects.

Table 9. Path analysis for seed yield in inoculation with Glomus intraradices mycorrhizal fungus under severe drought stress in two years

Traits	Harvest index	Biological yield	Sum of effects
Harvest index	0.281	0.438	0.72
Biological yield	0.16	0.769	0.93
Residual	0.285	Regression Equation: Seed yield = -39.533 + HI×2.020+BY×0.211	R^2=0.92

The numbers that have been drawn underneath them are direct effects and the other numbers are indirect effects.

CONCLUSIONS

Based on our study, the studied traits in sesame cultivars had variability and many of the observed alternations showed genotypic diversity. Improvements in seed yield components would directly or indirectly increase seed yield in sesame cultivars. In general the conclusion introduces that the number of seeds per capsule is one of the most important components of sesame seed yield under optimum irrigation. According to correlation coefficients, we can conclude that traits such as biological yield, seeds per capsule, capsules per plant, 1000-seed weight, plant-height and harvest index are the most important traits for seed yield improvement. Due to having positive direct effect on seed yield, traits such as 1000-seed weight can be used as a selection index for increasing seed yield in breeding programs and selection of genotypes under optimum irrigation conditions. Under moderate drought stress and different species of mycorrhiza, the effects of the traits on seed yield were different. Under severe drought stress, there was the highest positive direct effect between harvest index and biological yield with seed yield.

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REFERENCES

AHADU, M. (2008): Genetic variability and association of characters in sesame (*Sesamum indicum* L.) genotypes. An MSc thesis presented to school of graduate studies of Haramaya University: 20-45p.

AHMED, H. M., G. SARWAR, M. A. HAQ (2012): Genetic variability and interdependence of morphological traits in castor bean (*Ricinus communis* L.) mutants. Songklanakarin J. Sci. Technol, *34 (3)*: 279-286.

AKBAR, F., M.A. RABBANI, Z.K. SHINWARI, S.J. KHAN (2011): Genetic Divergence in Sesame (*Sesamum indicum* L.) Landraces based on qualitative and quantitative traits. Pak. J. Bot., *43*(6): 2737-2744.

AMIRI OGHAN, H., M.R., AHMADI, M., MOGHADDAM, M., VALIZADEH, M.R., SHAKIBA (2002): Heritability of seed yield and yield components in rapeseed (*Brassica napus*) under drought stress and normal conditions. Seed and Plant, *18(2)*: 179-199.

BAHRAMINEJAD, A., G., MOHAMMADI-NEJAD, M., ABDUL KHADIR (2011): Genetic diversity evaluation of cumin (*Cumin cyminum* L.) based on phenotypic characteristics. Aust. J. Crop Sci., *5(3)*: 304–310.

BANDILA, S., A., GHANTA, S., NATARAJAN, S., SUBRAMONIAM (2011): Determination of Genetic Variation in Indian Sesame (*Sesamum indicum* L.) Genotypes for agro-morphological traits. Institute of Biotechnology (IBT), Acharya N.G. Ranga Agricultural University (ANGRAU), Hyderabad-500030, India. J. Res. Agric. Sci., *7(2):* 88-99.

BASALMA, D. (2008): The correlation and path analysis of yield and yield components of different winter rapeseed *(Brassica napus oleifera* L.) cultivars. Res. J. Agric. Biol. Sci., *4(2):* 120–125.

BAYAT, M., M., RAHIMI, M., RAMEZANI (2016): Determining the most effective traits to improve saffron (*Crocus sativus* L.) yield. Physiol. Mol. Biol. Plants, *22 (1):* 153–161.

BEHRADFAR, A., A.H., GORTTAPEH, M.R., ZARDASHTY, F., TALAT (2009): Evaluation correlated traits for seed and oil yield in sunflower (*Helianthus annuus* L.) through path analysis in under condition relay cropping. Res. J. Biol. Sci., *4:* 82–85.

BOUREIMA, S., M., EYLETTERS, M., DIOUF, T.A., DIOP, P., VAN DAMME (2011): Sensitivity of seed germination and seedling radicle growth to drought stress in sesame *Sesamum indicum* L. Res. J. Environ. Sci., *5(6):* 557-564.

CHALISH, L. and S., HOUSHMAND (2011): Estimate of heritability and relationship of some durum wheat characters using recombinant inbred lines. Eur. J. Crop Prod., *4(2):* 223-238.

CHAMBERLAIN, A.R. (1952): Measuring water in small channels with WSC flume. Washington Agricultural Experiment Stations, Institute of Agricultural Sciences, State College of Washington

DARVISHZADEH, R., H. H., MALEKI, A., SARRAFI (2011): Path analysis of the relationships between yield and some related traits in diallel population of sunflower (*Helianthus annuus* L.) under well-watered and water-stressed conditions. Aust. J. Crop Sci., *5 (6):* 674-680.

DESAWI, H.T., A.K., SENTAYEHU, E.G., DANIEL (2017): Assessment of genetic variability, genetic advance, correlation and path analysis for morphological traits in sesame genotypes. Int. J. Novel Res. Life Sci., *4 (2):* 34-44.

EHSANZADEH, P., A.A., YADOLLAHI, A. M., MAIBODI (2004) Productivity, growth and quality attributes of 10 Iranian saffron accessions under climatic conditions of Chahar-Mahal Bakhtiari. Central Iran Acta Hortic., *650*: 183–188.

FAOSTAT of the United Nations (2014): "Production Crops: sesame seeds".

FARSHADFAR, E. (1997): Plant breeding methodology. Razi University Publishing. Kermanshah, Iran. P. 381.

GETINET, A., T., GEREMEW, Z., KASSAHUN, W., BULCHA (1998): Lowland Oil Crops: a three - decade research experiences in Ethiopia. Research Report No. 31. Institute of Agriculture, Addis Abeba. Ethiopia.

GIDEY, Y.T., S.A., KEBEDE, G.T., GASHAWBEZA (2012): Extent and pattern of the genetic diversity for morpho-agronomic traits in Ethiopian sesame landraces (*Sesamum indicum* L.). Asian J. Agric. Res., *6(3):*118-128.

HIKA, G., N., GELETA, Z., JALETA (2015): Genetic variability, heritability and genetic advance for the phenotypic traits in sesame (*Sesamum indicum* L.) populations from Ethiopia. Sci. Technol. Arts Res. J., *4(1):* 20-26.

HOLLAND, J.B., W.E., NYQUIST, C.T., CERVANTES-MARTINEZ (2003): Estimating and interpreting heritability for plant breeding: an update. Plant Breeding Reviews, *22:* 9–111.

MAHMOUD, M. W. SH., A.A., ABO-ELEZZ, T. H.A., HASSAN (2015): Genetic variability, heritability and correlation coefficients of yield and its components in sesame. Egypt J. Plant Breed., *19 (4):* 1101-1116.

MONOROFAR, H., M., VALIZADEH, M., MOGHADDAM, F., RAHIMZADEH KHOUEI (2004): Inheritance of yield and morphological traits in Iranian alfalfa germplasm. Pajouhesh and Sazandegi, *62:* 96-102.

NARAYANAN, R., S., MURUGAN (2013): Studies on variability and heritability in sesame (*Sesamum indicum* L.). Int. J. Current Agric. Res., *2 (11):* 052-055.

NASTASIC, A., D., JOCKOVIC, M., IVANOVIC, M., STOJAKOVIC, J., BOCANSKI, I., DALOVIC, Z., SRECKOV (2010): Genetic relationship between yield and yield components of maize. Genetika, *42 (3):* 529-534.

PATIL, P.R., V.H., SURVE, H.D., MEHTA (2012): Line x Tester analysis in rice (*Oryza sativa* L.). Madras Agric. J., *99:* 210-213.

RAFIQ, C. M., M., RAFIQ, A., HUSSAIN, M., ALTAF (2010): Studies on heritability, correlation and path analysis in maize (*Zea mays* L.). J. Agri. Res., *48(1):* 35-38.

RAMIREDDY, K.A. and T., SUNDARAM (2002): Interrelationship among yield and yield components in sesame (*Sesamum indicum* L.). J. Res. Acharya. N. G. Ranga Agricultural University, *30:* 42-44.

SAXENA, K. and R., BISEN (2016): Genetic variability, correlation and path analysis studies for yield and yield component traits in sesame (*Sesamum indicum* L.). Int. J. Agr. Sci., *8(61):* 3487-3489.

SAXENA, K. and R., BISEN (2017): Genetic variability, heritability and genetic advance for the phenotypic traits in sesame (*Sesamum indicum* L.). Int. J. Pure App. Biosci., *5(2):* 1126-1131.

SILVA, M.D.A., G.D., SILVA, J., ENCISO, V., SHARMA, J., JIFON (2008): Yield components as indicators of drought tolerance of sugarcane. Sci. Agric., *65:* 620-627.

SINGH, S.P., H. K., YADAV, S., SHUKLA, A., CHATTERJEE (2003): Studies on different selection parameters in opium poppy (*Papaver somniferum* L.). J. Med. Arom. Plant Sci., *25:* 8–12.

SINGH, S.P., S., SHUKLA, H. K., YADAV (2004): Genetic studies and their implication to breed desired plant type in opium poppy, *Papaver somniferum* L. Genetika, *36(1):* 69–81.

SIVA PRASAD, Y.V.N., M.S.R., KRISHNA, Y., VENKATESWARLU (2013): Correlation, path analysis and genetic variability for economical characteristics in F2 and F3 generations of the cross AVT 3 × TC 25 in Sesamum (*Sesamum indicum* L.). J. Environ. Appl. Biores., *1 (2):* 14-18.

SUBHASHCHANDRA, B., H.C., LOHITHASWA, S.A., DESAI, R.R., HANCHINAL, I. K., KALAPPANAVAR, K. K., MATH, P. M., SALIMATH (2009): Assessment of genetic variability and relationship between genetic diversity and transgressive segregation in tetraploid wheat. Karanataka J. Agric. Res., *22(1):* 36-38.

SUMATHI, P. and V., MURALIDHARAN (2011): Analysis of genetic variability, association and path analysis in the hybrids of sesame (*Sesamum indicum* L.). Tropical Agric. Res. Ext., *13(3):* 63-67.

TALEBI, R., F., FAYAZ, N.A.B., JELODAR (2007): Correlation and path coefficient analysis of yield and yield components of chickpea (*Cicer arietinum* L.) under dry land condition in the west of Iran. Asian J. Plant Sci., *6(7):* 1151–1154.

TRIPATHI, A., R., BISEN, R.P., AHIRWAL, S., PAROHA, R., SAHU, A.R.G., RANGANATHA (2013): Study on genetic divergence in sesame (*Sesamum indicum* L.) germplasm based on morphological and quality traits. Bioscan., *8 (4):* 1387-1391.

VANISHREE, R. L., R., GOUDAPPAGOUDAR, C.N., BANAKAR (2013): Analysis of genetic variability for yield and its components in sesame (*Sesamum indicum* L.). Int. J. Plant Sci., *8 (1):* 91-93.

WEISS, E.A. (1983): Oilseed Crops. Tropical Series, pp. 603, Longman Inc. Leonard Hill Books, New York

WITCOMBE, J.R., P.A., HOLLINGTON, C.J., HOWARTH, S., READER, K.A., STEELE (2007): Breeding for abiotic stresses for sustainable agriculture. Philos. Trans. R. Soc. Lond. B. Biol. Sci., *363(1492)*: 703–716.

YOUSEFZADEH NAJAFABADI, M. and P., EHSANZADEH (2017): Photosynthetic and ant oxidative up regulation in drought-stressed sesame (*Sesamum indicum* L.) subjected to foliar-applied salicylic acid. Photosynthetica, *55(4):* 611-622.

PATH ANALIZA ZA PRINOS ZRNA SUSAMA (*Sesamum indicum* L.) INOKULISANOG/NEINOKULISANOG MIKORIZALNIM GLJIVAMA U USLOVIMA STRESA SUŠE

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Izvod

Da bi se utvrdile efektivne osobine poboljšanja prinosa semena kod susama (*Sesamum indicum* L.), eksperiment sa faktorijalnim split plot dizajnom je postavljen u tri ponavljanja u eksperimentalnom polju Poljoprivrednog istraživačkog centra, Zapadni Azerbejdžan (stanica Saatloo) u 2015 i 2016 godini. Glavne parcele (faktor A i B) sastojale su se od tri različita nivoa navodnjavanja (normalno navodnjavanje: navodnjavanje posle evaporacije useva od 70 mm ili ETc, umereni stres suše: navodnjavanje posle 90 mm ETc i jak stres suše: navodnjavanje posle 110 mm ETc i faktor B uključivao je tri nivoa: dve vrste mikoriznih gljiva *Glomus mosseae*, *Glomus intraradices* i ne-inokulirane (kontrola). Pod-parcele (faktor C) sastojalo se od osam komercijalnih sorti susama. Rezultati su pokazali visoku heritabilnost većine proučavanih osobina pod različitim nivoima stresa suše, osim za produktivnost. Procena komponenata varijanse pokazala je da su u optimalnim uslovima sva proučavana svojstva imala visoku heritabilnost i da su bila pod manjim uticajem sredine. *Path* analiza pokazala je pozitivne značajne korelacije prinosa zrna i svih proučavanih osobina. Poboljšanje komponenti prinosa može, dakle, povećati prinos semena susama. Istraživanje je pokazalo da je broj semena po kapsuli jedan od najvažnijih pokazatelja prinosa susama pod optimalnim navodnjavanjem. Takođe svojstva kao što su težina 1000 semena i broj kapsula po biljci mogu se koristiti kao opcioni indeks u programima oplemenjivanja na povećanje prinosa semena i selekciju genotipova pod optimalnim uslovima navodnjavanja, zbog visokog pozitivnog direktnog uticaja na prinos semena. Pod umerenim i jakim stresom suše, efektivne osobine prinosa semena bile su različite kod različitih vrsta mikoriznih gljiva.

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