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Effects of water stress on seed yield and essential oil content of dill genotypes

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Abstract

Water stress may alter essence content of medicinal plants. Thus, a split plot experiment based on RCB design with three replications was conducted in 2015, to evaluate the effects of different irrigation treatments (I_1, I_2, I_3, I_4: irrigation after 70, 100, 130 and 160 mm evaporation, respectively) on seed yield and essential oil content of three dill (*Anethum graveolens* L.) genotypes (Isfahan, Malayer, Varamin). Irrigation treatments and genotypes were allocated to the main and sub-plots, respectively. The essential oil of seeds was extracted by hydro distillation. Means of seeds per plant and seed weight were decreased due to water deficit, which led to significant reduction in seed yield per unit area under severe water stress. Although essential oil percentage of dill seeds increased with decreasing water availability, the highest essential oil yield per unit area was obtained under mild (I_2) and moderate (I_3) water stress. However, severe water deficit significantly reduced essence yield as a result of a large reduction in seed yield per unit area. Malayer with the greatest number of seeds per plant and Varamin with the largest seeds were the high yielding cultivars, with no significant difference in seed yield per unit area. Consequently, seed essence yield of Varamin and Malayer genotypes was about 25% higher than that of Isfahan genotype.

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Introduction

Medicinal and aromatic plants are very importance because of the increasing demand for their products. Dill (*Anethum graveolens* L.) is an annual and sometimes biennial herb that is used as a vegetable, a carminative, an aromatic and an antispasmodic (Hornok, 1992; Sharma, 2004) and also as an inhibitor of sprouting in stored potatoes (Score *et al.*, 1997). Dill seed is usually sown at early spring for seed and essential oil production. The dill fruit is a schizocarp with paired carpels that split apart at maturity to release two pericarps, commonly referred to as "seed" (Bouwmeester, 1998).

Constituents of dill include essential oils, fatty acids, proteins, carbohydrates, fiber, ash and mineral elements such as calcium, potassium, magnesium, phosphorous, sodium, vitamin A and niacin (Kaur and Arora, 2010). The dill vegetative tissues, flowers and seeds contain essential oil, most of which accumulated in two latter organs (Ghassemi-Golezani *et al.*, 2008, 2011, 2015). The main constituents of dill essential oil are carvone and limonene (Bailer *et al.*, 2001; Singh *et al.*, 2005; Callan *et al.*, 2007).

In a large part of the agricultural areas in the world, water deficit is limiting crop productivity (Micheletto *et al.*, 2007). Photosynthesis and cell growth are the primary processes which are affected by water stress (Munns *et al.*, 2006). The flowering stage appear to be the most sensitive stage to drought stress (Nayyar *et al.*, 2006). Water stress during flowering and seed filling caused 50-80% reductions in seed yield due to restrictions in photosynthesis (Leport *et al.*, 1999). Coincidence of water stress with reproductive stages reduces duration of flowering and seed filling and consequently lowers the number of seeds per plant, mean seed weight and seed yield per unit area (Ghassemi-Golezani and Mazloomi-Oskooyi, 2008; Ghassemi-Golezani *et al.*, 2010). The effect of water deficit on growth and yield depends on function of genotype, duration of stress, weather conditions, growth and developmental stages of crops (Robertson and Holland, 2004).

Secondary metabolites in the medicinal and aromatic plants are strongly influenced by genotypes and environmental conditions (Yazdani *et al.*, 2002). Environmental stresses bring about a wide range of responses in medicinal plants from the changes in growth and yield to the changes in secondary metabolites (Ghassemi-Golezani *et al.*, 2008, 2011). This may be associated with the function of secondary metabolites as self-defense components against stress conditions. In other words, the stress conditions accelerate the biosynthesis of essential oils (El-Din *et al.*, 2009). Among the different environmental constraints, drought is an important abiotic factor limiting plant productivity (Ghassemi-Golezani *et al.*, 2014, 2015). Depending on the plant growth stages, drought stress influences morphology, anatomy, physiology and biochemistry of plants (Upadhyaya and Panda, 2004). The adaptability and responses to water stress depend on duration and magnitude of stress and developmental stage of plant (Kramer, 1983). The experiments with Cymbopogons have demonstrated that water stress alters the oil biogenetic capacity without any change in the oil gland count, as observed in the excised systems subjected to short-term stress conditions (Baher, 2002). It was found that essential oil content of dill organs increased with decreasing water availability during plant growth and development, but essence yield declined as a result of a large decrease in organs yields (Ghassemi- Golezani *et al.*, 2015).

However, when water stress occurred during reproductive stages of dill, both essence percentage and yield enhanced due to stress and the highest essence yield per unit area was recorded under mild water deficit (Ghassemi- Golezani *et al.*, 2008).

Although the secondary metabolite production is believed to be stimulated by stressful environment, the extent of this effect is not unique. Therefore, this research was carried out to assess the effects of water limitation on seed yield and essential oil content of dill genotypes.

Materials and methods

Location and experimental design

This experiment was conducted in 2015 at the Research Farm of the Faculty of Agriculture, University of Tabriz, Tabriz, Iran (Latitude 38°05´N, Longitude 46°17´E, Altitude 1360 m above sea level) to evaluate the effects of different irrigation intervals on seed and essential oil production of dill.

The climate is characterized by mean annual precipitation of 245.75 mm per year and mean annual temperature of 10°C. The experiment was arranged as split plot based on RCB design in four replications with irrigation treatments (I_1, I_2, I_3 and I_4: irrigation after 70, 100, 130 and 160 mm evaporation from class A pan, respectively) in main plots and dill genotypes (Isfahan, Malayer, Varamin) in sub-plots. Each plot consisted of six rows of 4 m length with 25 cm apart.

Seed sowing and seedling establishment

Seeds were treated with Benomyl at a rate of 2 g kg^{-1} and were sown by hand on 4 may, 2015, in 1.5 cm depth of a sandy loam soil. Sowing density was 80 seeds m^{-2}. All plots were irrigated immediately after sowing. After seedling establishment, plants in each plot were thinned to keep 56 plants m^{-2} and irrigations were carried out according to the treatments. Weeds were controlled by hand during crop growth and development as required.

Seed yield and essence extraction

At maturity, plants from 1 m^2 of each plot were harvested and seeds per plant, 1000 seed weight and seed yield per unit area for each treatment at each replicate were determined. A sub-sample of 20 g seeds from each plot was mixed with 500 ml distilled water and essential oil was extracted by hydro-distillation for 3 hours, using a Clevenger apparatus at 250°C (Darzi *et al.*, 2012).

Analyses of variance

Analyses of variance of the data were carried out by SPSS software and means of each trait were compared by Duncan test at $p \leq 0.05$. Excel software was used to draw Fig.s.

Results and discussion

Analysis of variance of the data (Table 1) showed that the effects of irrigation intervals on seeds per plant, 1000 seed weight and seed yield per unit area, essential oil percentage and essential oil yield were significant. Genotypic differences also had significant effects on 1000 seed weight and seed yield, but not on seeds per plant and essential oil percentage and yield. The interaction of irrigation × genotype was only significant for 1000 seed weight (Table 1).

Table 1. Analyses of variance of the effects of water supply on yield components, seed yield, essential oil content and yield of dill genotypes.

Treatment	df	Seeds per plant	1000 seed weight	Seed yield	Essential Oil	Essential oil yield
Replicate	2	57969.9^{ns}	0.001^{ns}	69.68^{ns}	0.031^{ns}	0.022^{ns}
Irrigation (I)	3	1585465.2*	0.532**	13770.79**	0.974**	2.376*
Ea	6	190000.0	0.014	987.88	0.035	0.321
Genotype (G)	2	101608.6^{ns}	0.145**	2635.57*	0.024^{ns}	0.518^{ns}
I×G	6	39805.7^{ns}	0.041*	196.33^{ns}	0.009^{ns}	0.078^{ns}
Eb	16	123325.3	0.025	493.83	0.063	0.264
CV	-	22.12	12.24	17.934	15.475	28.371

ns, *, **: No significant and significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Mean number of seeds per plant and 1000 seed weight were decreased as a result of water limitation, which led to significant reduction in seed yield per unit area under severe water stress (Table 2). Reduction in seed number was due to a decrease in flower formation and an increase in flower (Fang *et al.*, 2009; Ghassemi-Golezani *et al.*, 2012). Irrigation disruption during seed filling can decrease filling duration and photosynthate mobilization to seeds, thereby decreasing seed weight (Ghassemi-Golezani *et al.*, 2009).

In general, water stress during vegetative growth has the greatest impact on plant biomass, while during reproductive development it has the most limiting effect on seed yield (Ghassemi-Golezani *et al.*, 2008).

Malayer genotype produced about 1% and 12% more seeds per plant, compared with Varamin and Isfahan. However, these differences in seeds per plant were not statistically significant. In contrast, Varamin had the largest seeds, followed by Malayer and Isfahan (Table 2).

The superiority of Varamin in seed weight was more evident under I_1 and I_2 and considerably reduced under I_3 and I_4 (Fig. 1). The lowest seed yield per unit area was recorded for Isfahan genotype, due to the production of the least number of seeds per plant with the smallest sizes. Malayer with the greatest number of seeds per plant and Varamin with the largest seeds produced the highest seed yield per unit area, with no significant difference between them (Table 2). Variation in yield components and seed yield among dill genotypes were directly related with their genetic constitution, which classified Varamin and Malayer as high yielding genotypes.

Table 2. Means of the yield components, seed yield and essential oil content and yield of dill for different irrigation treatments and genotypes.

Treatments	Seeds per plant	1000 seed weight (g)	Seed Yield g/m²	Essential oil (%)	Essential oil yield g/m²
Irrigations					
I1	1591 a	1.622 a	144.20 a	1.1778 c	1.6889 b
I2	1954 a	1.270 b	138.77 a	1.6056 b	2.2309 a
I3	1806 a	1.237 b	125.29 a	1.7511 ab	2.1909 ab
I4	999.2 b	1.038 c	59.49 b	1.9544 a	1.1353 c
Genotypes					
G1	1609 a	1.397 a	127.18 a	1.5708 a	1.8942 a
G2	1487 a	1.177 c	99.94 b	1.6458 a	1.5752 a
G3	1667 a	1.301 b	124.96 a	1.66 a	1.9651 a

Different letters in each column indicate significant difference at P ≤ 0.05. I_1, I_2, I_3, I_4: irrigation after 70, 100, 130 and 160 mm evaporation, respectively. G_1, G_2, G_3: Varamin, Isfahan and Malayer genotypes, respectively.

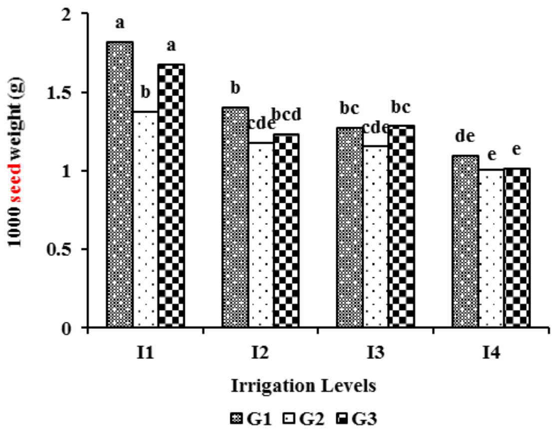

Fig. 1. Mean 1000 seed weight of dill genotypes under different irrigation treatments

Different letters indicate significant difference at P ≤ 0.05. I1, I2, I3, I4: irrigation after 70, 100, 130 and 160 mm evaporation, respectively.

Essential oil percentage increased with decreasing water availability. However, the differences in essential oil percentage between I_2 and I_3 and also between I_3 and I_4 were not significant (Table 2). In contrast, seed essential oil yield were considerably improved when plants were subjected to mild (I_2) and moderate (I_3) water deficit, but it was significantly diminished under severe water stress (I_4) (Table 2). Seed essential oil yield of all dill seeds genotypes were statistically similar (Table 1).

Holtzer *et al.* (1998) have pointed out that water stress can increase, decrease or have no effect on the levels of metabolites, depending upon the plant species. Ghassemi-Golezani *et al.* (2008, 2015) reported that the essence percentage of dill significantly improved, when plants were subjected to water stress during reproductive stages. Drought stress increases the essential oil content of medicinal and aromatic plants, in order to prevent oxidization within the plant cells (Aliabadi *et al.*, 2009). The results of this research showed that although essential oil percentage of dill seeds increased with increasing irrigation intervals (Table 2), the highest essential oil yield per unit area was obtained under mild (I_2) and moderate (I_3) water stress (Table 2). However, severe water deficit significantly reduced essence yield as a result of a large reduction in seed yield per unit area (Table 2).

Although seed essence percentage and yield among dill genotypes was not statistically significant (Table 1), essence yield of Varamin and Malayer genotypes was about 25 % higher than that of Isfahan genotype (Table 2).

No significant interaction between irrigation and genotype (Table 1) suggest that the superiority of two previous genotypes to the latter genotype in seed and essence yields were occurred under all irrigation intervals.

Conclusion

The highest essential oil yield per unit area was obtained under mild and moderate water stress, due to less reduction in seeds per plant, seed weight and seed yield and greater oil percentage in comparison with well watering. Seed and essence yields of Varamin and Malayer genotypes were more than those of Isfahan genotype. This superiority was consistent under all irrigation intervals.

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