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Full Length Research Paper

Sorghum stem yield and soluble carbohydrates under different salinity levels

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The aim of this study was to select the most suitable cultivar for salty land in this geographical area. Two sweet sorghum cultivars (Keller and Sofra) and one grain sorghum cultivar (Kimia) were grown in greenhouse benches under four salinity levels of 2, 4, 8 and 12 dSm^{-1} to evaluate the effects of salinity on stem yield and soluble carbohydrate (sucrose, glucose and fructose). The results showed that in all cultivars as salinity increased, the amount of stem yield and soluble carbohydrate decreased. In all salt concentrations, Keller and Kimia had the highest and the lowest stem yield and sucrose, respectively. At the highest salt concentration (12 dSm^{-1}), Keller had the lowest stem yield reduction (less than 1%) and the highest sucrose content while Kimia had the highest stem yield reduction (more than 18%) and the lowest sucrose content. Therefore, Keller and Kimia can be considered as salt tolerance and salt sensitive cultivars, respectively. As salinity increased, the amount of glucose and fructose in Keller decreased while they increased in Sofra. Increasing glucose and fructose in Sofra is not an indication of its salt tolerance. At the physiological maturity stage, the plant has the highest stem yield and sucrose content while it has the lowest glucose and fructose content than flowering stage. Base on the results, Keller is recommended to be planted under soil salinity conditions and harvested at physiological maturity stage.

Key words: Sweet sorghum, grain sorghum, salinity, stem yield, sucrose, glucose, fructose.

INTRODUCTION

Soil salinity is one of the main problems for agriculture, especially in countries where irrigation is an essential aid to agriculture (Ahloowalia et al., 2004). Saline soils are estimated about 5 – 10% of the world's arable land (Szabolcs, 1994), and the area affected by salinity is increasing steadily (Ghassemi et al., 1995). There are vast areas in Iran with salinity-affected soils and as Kehl (2006) reported, moderate saline soils occupy approximately 25.5 million ha and strong saline soils cover about 8.5 million ha. Soil salinity reduces yield production of most crops (Munns et al., 2002). Therefore, there is a need to improve salinity tolerance of important crops. Sorghum [*Sorghum bicolor* (L.) Moench] is a potential crop for moderately saline areas (Almodares and Sharif, 2007) and shown to contain intraspecific variability for salinity (Igartua et al., 1995). However, Salinity reduced sorghum growth and biomass production (Ibrahim, 2004). Nevertheless, the development of high-yielding salinity-tolerant sorghums is the best option to increase the productivity in such soils (Igartua et al. 1994). Krishnamurthy et al. (2007) reported that there are large genotypic variations for tolerance to salinity in sorghum. Ibrahim (2004) reported that in sorghum, total soluble sugar increased with increasing salinity level. Sucrose content of sorghum could be an indicator for its salt tolerance (Juan et al., 2005). In sorghum, the fructose level was always higher than that of the glucose in response to various salinity treatments (Gill et al., 2001). The present study was conducted to determine how salinity affects stem yield, sucrose and invert sugars (glucose and fructose) of two sweet and one grain sorghum cultivars.

MATERIALS AND METHODS

Experimental location, plant material and experimental design

This experiment was conducted in the Isfahan University green

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house benches (3 m long, 1.2 m length and 0.5 m depth) in 2006. Seed of two popular sweet sorghum and one grain sorghum [*Sorghum bicolor* (L.) Moench] cultivars were provided from Isfahan University Research Station in Iran. The experimental design was split-split plot in complete randomize block with three replications. Four levels of salinity (2, 4, 8 and 12 dSm^{-1}) were assigned to the main plots. Two sweet sorghum (Keller and Sofra) and grain sorghum (Kimia) cultivars were assigned to the subplots. Two harvesting dates (flowering and physiological maturity) were assigned to the sub-subplots. Each sub-subplot consisted of 3 rows 3 m long and 0.4 m apart. The inter-row space was 0.1 m.

Plant growth and salt treatment

Seeds of the above cultivars were planted in the benches. Salt treatments were started six weeks after germination following plant establishment (Almodares et al., 2008). The plants were irrigated with NaCl solution based on the experimental design once a week. Plants were grown under stress conditions until physiological maturity stage. Plants were harvested at flowering and physiological maturity.

Measurement of stem yield and carbohydrate content

Three plants samples were taken at flowering and physiological maturity. After the leaves and panicle were removed, stalk was weighed and immediately placed into 100°C oven. They were kept at that temperature for 1.5 h, and then dried at 70°C. After oven drying, the samples were ground and passed through 0.05 mm screen, mixed and stored for carbohydrates analysis. Sucrose and invert sugar were extracted with 80% ethanol from 100 mg of sample by AOAC method (1975). Sucrose content was determined according to Varma (1988) and invert sugar according Lane-Eynon method (1970). The amount of glucose was determined by Pearson (1970) method. Fructose content was determined by subtracting glucose from invert sugar (total of glucose and fructose).

Statistical analysis

Statistical analysis was performed using Statistical Analysis System (SAS) computer program. The means were compared according to Duncan multiple rang test.

RESULTS AND DISCUSSION

The effect of salinity on the stem yield and sucrose was significant at 1% level and on glucose and fructose at 5% level. As salt concentration increased, the stem yield decreased (Figure 1). It was 54.07 t h^{-1} at 2 dSm^{-1} and 50.65 t h^{-1} at 12 dSm^{-1}. El-Sayed et al. (1994) reported that sorghum growth was significantly reduced from 50 to 150 mM NaCl. Also, Almodares and Sharif (2007) indicated the salinity of water has an adverse effect on sweet sorghum biomass. They reported that sweet sorghum cultivar SSV108 and Rio had the lowest and the highest biomass under water qualities of 2, 5, and 8 dS m^{-1}. In addition, Silva et al. (2003) showed that salt stress reduced root and shoot dry matter. Therefore, it seems that as Netondo et al. (2004) mentioned, sorghum grown in salt affected soils may suffer from drought stress, ion toxicity, and mineral deficiency leading to reduced growth and productivity. As salt concentration increased, the amount of sucrose, glucose and fructose decreased (Figure 2). The amount of sucrose was 17.4% at 2 dSm^{-1} and 12.8% at 12 dSm^{-1}. The amount of glucose and fructose was not significantly different at 2 dSm^{-1} and 4 dSm^{-1}. However, they deceased significantly at 8 dSm^{-1} and 12dSm^{-1}. Almodares et al. (2008) reported that in sweet sorghum, as salinity increased, the amount of sucrose and glucose in Sofra cultivar decreased. Also, Anjum (2008) reported that concentrations of sugars i.e. sucrose, glucose and fructose in the leaves of Cleopatra mandarin and both leaves and roots of Troyer citrange in seedling stage decreased with increase in salinity level in the irrigation water containing 0, 40 or 80 mM NaCl for 12 weeks. On the contrary, Serraj and Sinclair (2002) reported that salt-stressed sorghum plants additionally accumulate sugars but its accumulation can be due to a reduced utilization during salt stress period. However, reduction in carbohydrates concentrations has been related to tissue re-hydration during stress recovery by some authors (Lacerda et al., 2005). Therefore, the increases of carbohydrate content under salt stress have not been detected here under the experimental conditions used. It seems that carbohydrates reduction

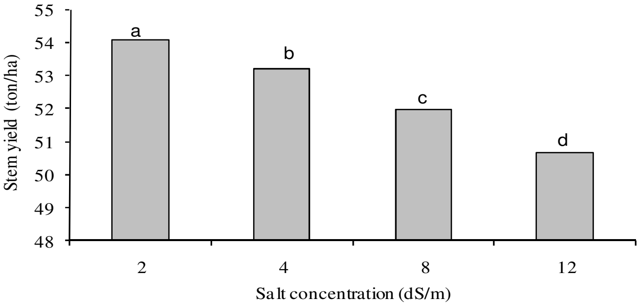

Figure 1. Mean comparisons* among salt concentrations for stem yield in sweet sorghum cultivars. Values within each column followed by the same letter are not significantly different at 5% level, using Duncan multiple rang test.

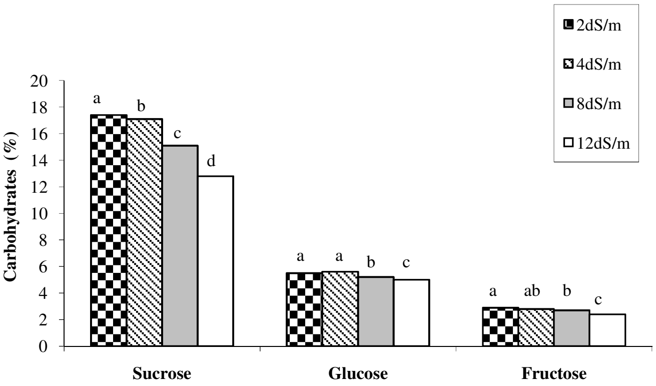

Figure 2. Mean comparisons* among salt concentrations for percent carbohydrates in sweet sorghum cultivars. Values within each carbohydrate column followed by the same letter are not significantly different at 5% level, using Duncan multiple rang test.

Table 1. Interaction* between salt concentrations and cultivars for measured characteristics in sweet sorghum.

Salt concentration (dSm^{-1})	Cultivar	Stem yield (t ha^{-1})	Sucrose (%)	Glucose (%)	Fructose (%)
2	Keller	67.43 ^{a}	21.73 ^{d}	6.50 ^{b}	3.06 ^{b}
	Sofra	56.00 ^{b}	18.66 ^{e}	5.70 ^{e}	3.66 a
	Kimia	39.20 ^{e}	12.03 ^{i}	4.56 ^{f}	2.16 ^{e}
4	Keller	67.60 ^{a}	22.26 ^{c}	5.86 ^{d}	2.86 ^{bc}
	Sofra	56.70 ^{b}	18.00 ^{f}	5.80 ^{de}	3.73 ^{a}
	Kimia	36.26 ^{f}	11.30 ^{j}	4.30 ^{g}	1.96 ^{e}
8	Keller	67.60 ^{a}	22.43 ^{b}	6.60 ^{c}	2.66 ^{cd}
	Sofra	53.67 ^{c}	15.80 ^{g}	6.40 ^{b}	3.73 ^{a}
	Kimia	34.40 ^{g}	7.20 ^{k}	4.43 ^{fg}	1.96 ^{e}
12	Keller	66.90 ^{a}	22.90 ^{a}	5.73 ^{de}	2.46 ^{d}
	Sofra	51.33 ^{d}	13.33 ^{h}	6.83 ^{a}	3.53 ^{a}
	Kimia	32.23 ^{h}	2.46 ^{l}	2.73 ^{h}	1.43 ^{f}

* Values within each column followed by the same letter are not significantly different at $P<0.05$.

could be due to the long time exposure of plants under salinity and or high concentration of salt.

Interaction between salt concentrations and cultivars were significant at 1% level for stem yield and sucrose; and at 5% level for glucose and fructose. Keller and Kimia had the highest and lowest stem yield at all salt concentrations (Table 1). At 12 dSm^{-1}, stem yield of Keller and Kimia was 66.90 t ha^{-1} and 32.23 t ha^{-1}, respectively.

De lacerda et al. (2003) compared seedlings of two forage sorghum genotypes (salt tolerance and salt sensitive) under salinity of 0 and 100 mM NaCl. They reported that biomass of salt sensitive plant was significantly reduced as salt concentration increased. Also, Sunseri et al. (1998) compared four sweet surghum cultivars under soil salinity. They reported that salt tolerant lines did not show significant differences in leaf dry weight and stem dry weight, with increasing level of soil salt stress. While, the salt sensitive lines showed a different behaviour; significantly reducing yield performances with increasing level of soil salt stress. Thereby, it seems that Keller is more salt tolerant than Sofra and Kimia. Sucrose content of Keller was the highest at the12 dSm^{1-}. As the amount of salt concentration increased, the sucrose content of Keller significantly increased.

Silva et al. (2003) reported that in sorghum under salt stress, the salt-tolerant cultivar showed greater enhancement in soluble carbohydrate content. They suggested that the accumulation of soluble carbohydrates were significantly related to salt tolerance in relation to leaf osmotic adjustment and soluble carbohydrate contents of leaves were significantly correlated with the acclimatization to salt stress. Thus, these parameters may be used as physiological markers of salt tolerance in sorghum. Also as Juan et al. (2005) reported that in tomato, sucrose content of plant parts is an indicator of salt tolerance. Therefore, it seems that Keller is more tolerant than both Sofra and Kimia. On the other hand, as salinity increased, the amount of invert sugar in Keller decreased while the amounts of glucose and fructose of Sofra increased. Sofra had the highest amount of glucose and fructose at 12 dSm^{1-} (6.83 and 3.53 %, respectively). Balibera et al. (1997) reported that in tomato as salinity increased, plant accumulates more sucrose in its stalk, root and leaf whereas the amount of hexose such as glucose and fructose decreased in salt tolerant cultivars. Therefore, it seems that increasing glucose and fructose in Sofra is not an indication of its salt tolerance but rather as salt sensitive cultivars.

Also, invert sugar reduction in Keller could be due to hydrolysis inhibition of sucrose or as Barreto et al. (1995) showed that reduction of hexose in sorghum could be due to plant energetic cost for active exclusion of Na^+ as mechanism salt tolerance. The effect of harvesting stage on stem yield and carbohydrates were significant at 1% level (data not shown) and their interactions were significant at 1% for sucrose and at 5% for stem yield, glucose and fructose (Table 2). Stem yield and sucrose content of all cultivars were significantly higher at physiological maturity than flowering. In all salt concentrations Keller had the highest stem yield and sucrose at both flowering and physiological maturity. While, Kimia had the lowest stem yield and sucrose at both of the above stages. Almodares et al. (1994) reported that in sweet sorghum, biomass and carbohydrate content was higher at the physiological maturity than flowering. Tarpley and Vietor (2007) reported that amount of sucrose in sorghum culm is the highest at ripening stage (physiological maturity) and sucrose can be radially transferred to the intracellular compartment of mature ripening sorghum internode without being hydrolysed which is in agreement with our results. However, Tew and Cobill (2006) reported that in sorghum, mean sugar yields of M81E, Theis and Topper were not significantly different from each other at the each harvest date in July, August or September. Therefore, it seems that at the physiological

Table 2. Interaction between harvesting stage and cultivars for measured characteristics in sweet sorghum.

Harvesting stage	Cultivar	Stem yield (t ha^{-1})	Sucrose (%)	Glucose (%)	Fructose (%)
Flowering	Keller	65.63 ^{b}	17.70 ^{c}	6.10 ^{b}	3.76 ^{a}
	Sofra	51.33 ^{d}	11.73 ^{d}	7.53 ^{a}	3.96 ^{a}
	Kimia	33.80 ^{f}	7.10 ^{f}	5.13 ^{d}	2.73 ^{c}
Physiological maturity	Keller	69.10 ^{a}	26.93 ^{a}	5.93 ^{c}	1.73 ^{d}
	Sofra	57.46 ^{c}	21.16 ^{b}	4.83 ^{e}	3.36 ^{b}
	Kimia	37.20 ^{e}	9.40 ^{e}	2.83 ^{f}	1.03 ^{e}

* Values within each column followed by the same letter are not significantly different at $P<0.05$.

maturity stage the plant has the highest stem yield and sucrose content. In all cultivars, glucose and fructose at physiological maturity were lower than at flowering.

Lingle (1987) reported that in sorghum at physiological maturity stage, sucrose content increased while invert sugar decreased. The author indicated that at this stage, invert sugars (glucose and fructose) were converted to sucrose, which is in agreement with our results. Therefore, it seems that low sucrose content at flowering could be due high invertase activities which invert sucrose to glucose and fructose. In contrast, at physiological maturity due to low invertase activity, sucrose does not invert to glucose and fructose. Based on the above results, it seems than Keller is better adapted to salinity than others and it is recommended to plant Keller and harvest at physiological maturity in salty land.

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