

Novel Insight into The Role of Date Molasses in Enhancing Durum Wheat Tolerance to Water Stress

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Abstract

Purpose: Crop production is severely limited in dry and semi-arid environments due to poor soil fertility and water scarcity. In this context, the use of date molasses as an organic amendment may enhance agronomic productivity under such conditions. This study investigates the response of two durum wheat varieties, Ofanto and Bousselam, to application of date molasses under water deficit conditions.

Methods: Morphological traits and biochemical parameters of plant development were assessed under different treatments.

Results: Water stress significantly inhibited wheat growth by markedly reducing seminal root length, leaf area index (LAI), shoot and root dry biomass, and chlorophyll (a+b) content. Additionally, a decrease in adventitious root formation was observed. However, application of date molasses effectively maintained higher chlorophyll and soluble sugar contents, and enhanced activities of key antioxidant enzymes including superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT).

Conclusions: Date molasses application under water deficit conditions efficiently mitigated water stress effects in durum wheat. Our findings emphasize the potential of this organic amendment to reduce the negative impacts of abiotic stress on crop plants.

Keywords: Triticum durum, water deficit, organic amendment, antioxidant enzymes, semi-arid, root architecture.

1. Introduction

Durum wheat (*Triticum durum* Desf.) holds significant economic importance as a major cereal crop worldwide, particularly in the Mediterranean region (Zargar et al., 2017). Its cultivation extends across Southern Europe, North Africa, the Middle East, Central Canada, and the Northwestern United States. Together, these regions contribute to approximately one-quarter of global wheat production (FAO, 2023). In Algeria, durum wheat represents a major component of the agricultural sector (Zargar et al., 2017; Zemour et al., 2024).

Water deficit is a critical constraint limiting crop development and yield, especially in dry and semi-arid environments (Zou et al., 2021). Wheat plants are highly sensitive to water availability, with productivity declining by 50–90% under drought conditions (Chennafi,

2012). Moreover, climate change and unsustainable farming practices exacerbate water scarcity and soil fertility degradation, further threatening crop sustainability (Li et al., 2013).

Understanding crop responses to drought and developing effective mitigation strategies are vital for securing food production. Water deficit disrupts many physiological and biochemical processes in plants, reducing growth and reproduction (Yousaf et al., 2025). Plants exhibit diverse drought tolerance mechanisms, including avoidance and tolerance strategies regulated by complex physiological, biochemical, and molecular networks (Du et al., 2020). Antioxidant enzymes play a key role in mitigating oxidative damage induced by drought in crops such as maize and wheat (Altansambar et al., 2024; Isgandarova et al., 2024).

Organic by-products from agro-food industries, rich in nutrients, present promising options for improving soil fertility and enhancing drought tolerance in crops. In particular, molasses has shown ameliorative effects under abiotic stress in plants like spinach (Pyakurel et al., 2019).

In this study, we aimed to evaluate the effects of date molasses, a nutrient-rich organic by-product, on the growth and physiological responses of two durum wheat genotypes under water deficit conditions. This research provides novel insights into the potential of date molasses as an organic amendment to promote wheat growth and stress tolerance in semi-arid environments.

2. Material and Methods

The experiment was conducted at Ibn Khaldoun University, Tiaret (Algeria) under controlled glasshouse conditions in 2023. The temperature was maintained at 20 °C during the day and 15 °C at night, with relative humidity set at 70%. A photoperiod of 15 hours per day was provided, supplemented with light intensity of 85 W·m⁻².

Two durum wheat (*Triticum durum* Desf.) varieties were selected for this study: Ofanto (locally known as Ouarsenis from Italy) and Bousselam (originating from ICARDA-CIMMYT, Aleppo, Syria).

2.1 Extraction of Date Molasses

Low-market-value dates were washed and pitted. Two kilograms of dates were macerated in 1 L of water at 70 °C (solid-to-liquid ratio 2:1) for 60 minutes in a water bath with agitation to ensure thorough homogenization and efficient extraction of soluble components. The macerate was filtered through muslin to remove impurities, then concentrated using a vacuum evaporator to preserve nutritional quality. The physicochemical composition of the extracted date molasses is presented in Table 1.

Table1. Physical-chemical Composition of molasse date

Constituants	Date molasse
Moisture (%)	18
pH	5.7
Total sugars (%)	74
Soluble sugars(%FW)	42

Saccharose(%FW)	30
K(mg/100mLFW)	250
P(mg/100mLFW)	7
Ca(mg/100mLFW)	225
Mg(mg/100 mLFW)	6.5
Na(mg/100 mLFW)	15
Zn(mg/100mLFW)	0.1
Cu(mg/100mLFW)	0.03
Fe(mg/100mLFW)	78
Mn(mg/100 mLFW)	0.05
Protein (%)	0.87
Density	1.31

2.2 Experimental Setup

Seeds were sterilized and germinated on moistened absorbent paper in Petri dishes incubated at 25 °C. After one week, seedlings were transplanted into PVC cylinders (5 cm diameter, 60 cm length) filled with a substrate mixture of sand, soil, and organic matter in an 8:3:1 ratio, with a water retention capacity of 27% (see Fig. 1). Thirty cylinders were divided into three groups and irrigated to field capacity. One group received a solution of date molasses (1 mL pure molasses per 1 L water), while the others received water only until the tillering stage (Zadoks scale 22). Thereafter, water regimes were adjusted as follows: (i) continuous irrigation (control), (ii) water deficit (WD), and (iii) water deficit with date molasses application (WMD). Each treatment was replicated six times with random distribution of genotypes.

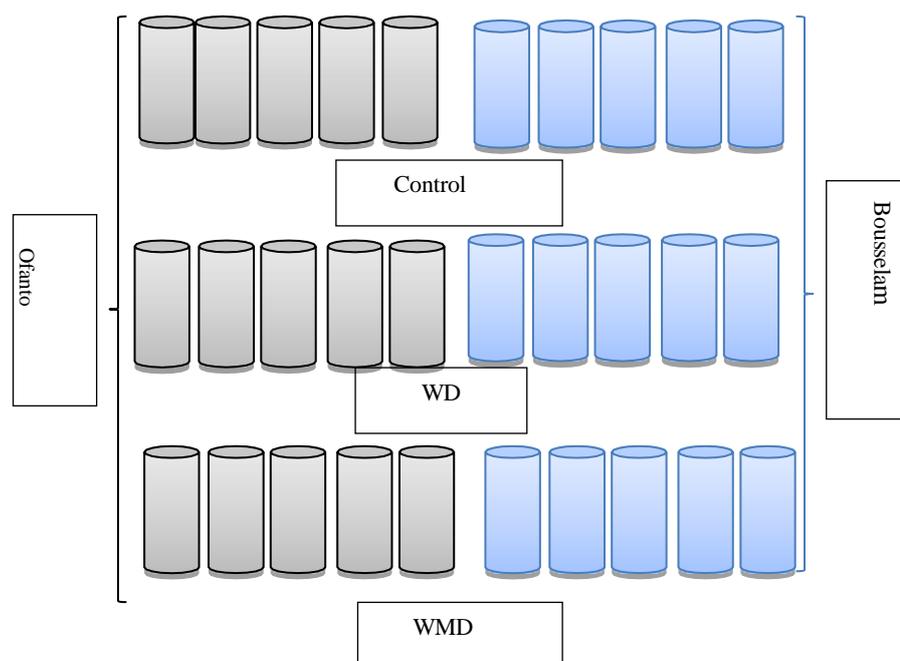


Fig1 Experimental dispositive of the study. WD:Water deficit; WMD: With date molasse

2.3 Measurements

One month after initiating water deficit treatments, the following parameters were measured on the youngest fully developed leaves:

Relative Water Content (RWC): Measured following Schonfeld et al. (1988) by weighing fresh leaf samples to determine fresh weight (FW), turgid weight (TW, after 12 h in darkness at 4 °C), and dry weight (DW, after drying at 80 °C for 48 h). Calculated as $RWC (\%) = [(FW - DW) / (TW - DW)] \times 100$.

Chlorophyll (a+b) Content: Determined according to Barnes et al. (1992) using leaf extracts.

Leaf Area Index (LAI): Measured with a leaf area meter (model QCJ-2A).

Root and Shoot Morphological Traits: Length of seminal roots and number of adventitious roots were recorded. Samples were oven-dried at 80 °C for 48 h for measurement of dry biomass.

Antioxidant Enzyme Activities: Activities of peroxidase (POD) and catalase (CAT) were assayed using the methods of Chance and Maehly (1955), while superoxide dismutase (SOD) activity was determined following Giannopolitis and Ries (1977). Leaf samples were extracted in potassium phosphate buffer.

Total Soluble Sugars: Quantified by the Anthrone method (Gomez et al., 2002). After appropriate dilution, samples were incubated at 92 °C for 8 minutes, and absorbance was measured at 585 nm.

2.4 Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) with SPSS version 20. Duncan's multiple range test at 5% significance was used to compare genotype means within each water treatment.

3. Results

3.1 Relative Water Content (RWC)

RWC, an indicator of plant hydration status reflecting the balance between water availability and transpiration (Jin et al., 2017), was significantly affected by cultivar and drought stress ($p < 0.01$). Under well-watered conditions, both genotypes exhibited high RWC values, with 91.5% and 91% observed in Ofanto and Bousselam, respectively (Fig. 2).

Water deficit caused a significant reduction in RWC in both genotypes, with values declining to 82% for Ofanto and 75% for Bousselam. However, treatment with date molasses significantly ameliorated this reduction, maintaining RWC at approximately 88% in Ofanto and 85% in Bousselam (Fig. 2).

Table 2 Effect of water treatment on growth, chlorophyll and antioxidant enzymes.

Trait	Effect		
	Water treatment (df=2)	Genotype (df=1)	genotype x water treatment (df=2)

Chlorophyll (a+b)	245.32**	118.82**	79.29**
LAI	28.32**	0.563	3.422*
SOD	7.322*	118.935**	15.337**
POD	495.08**	165.76**	81.007**
CAT	62.472**	91.982**	16.23**
Root adventitious number	6.2*	5.4*	1.8
Seminal root lenght	0.641	11.256*	0.33
Shoot dry weight	5.621*	0.731	0.248
Root dry weight	3.889*	1.607	1.504
Sugars	93.86**	4.936*	0.728
N Tillers	3.545	0.364	0.91

ns : non significant, * : significant at p=0.05, ** : significant at p=0.01 level.

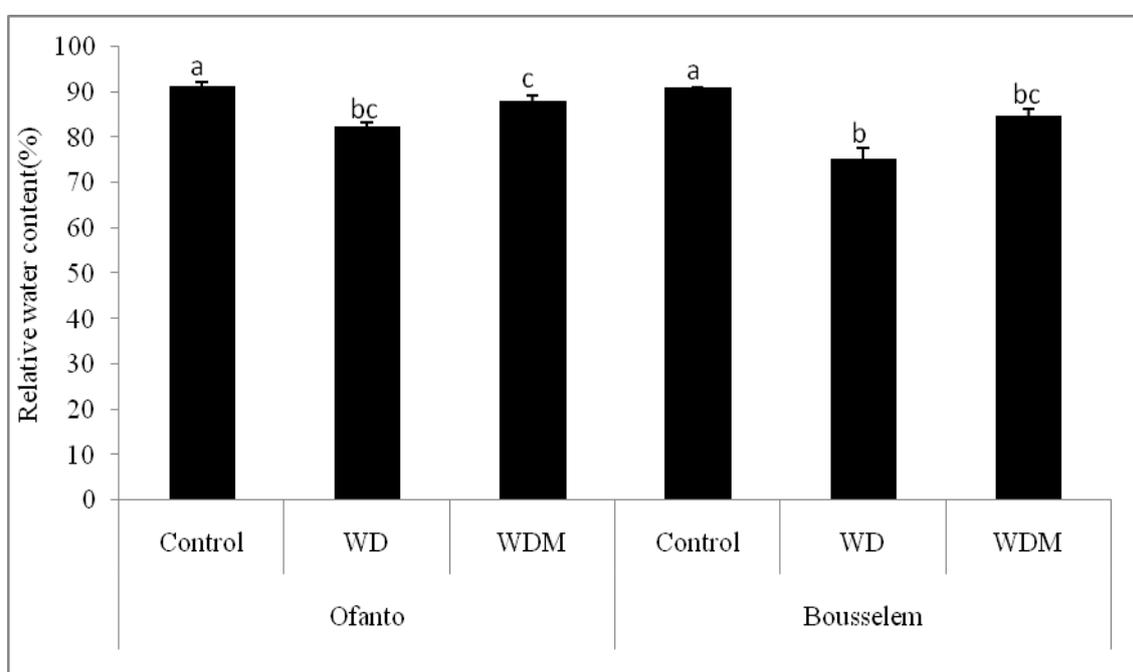


Fig.2 Relative water content (RWC) measured in two durum wheat genotypes grown

Fig. 2 Relative water content (RWC) measured in two durum wheat genotypes grown under three water regimes (Control, WD:With drought, WDM:with date molasse) within the same water treatment and assigned different letters are significantly different (at 0.05 probability level) by Duncun's Test.

3.2 Chlorophyll Content

Both water stress and date molasses treatments significantly influenced chlorophyll (a+b) content in leaves (Table 2). Under control conditions, chlorophyll content ranged from 65 $\mu\text{g}\cdot\text{g}^{-1}$ FW in Bousselem to 73 $\mu\text{g}\cdot\text{g}^{-1}$ FW in Ofanto (Fig. 3).

Water deficit reduced chlorophyll content in Ofanto by 68%, while Bousselem showed an increase under drought. Importantly, date molasses application significantly restored

chlorophyll levels in both genotypes, with Bousselem reaching $69 \mu\text{g}\cdot\text{g}^{-1}$ FW, comparable to control values (Fig. 3).

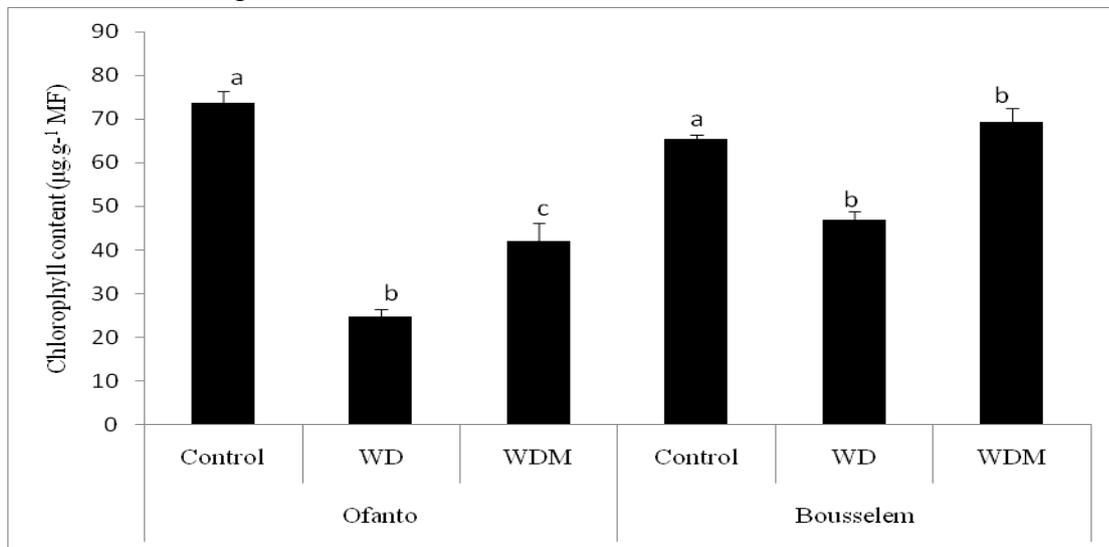


Fig. 3 Chlorophyll content measured on two durum wheat genotypes grown under three water regimes (Control, WD, WDM) within the same water treatment and assigned different letters are significantly different (at 0.05 probability level) by Duncun's Test.

3.3 Leaf Area Index (LAI)

LAI differed significantly across water treatments and genotypes (Table 2). Water stress reduced LAI, notably under the WD treatment (Fig. 4), with values between 0.12 and 0.13 for both genotypes, compared to 0.19–0.22 under control conditions. Application of date molasses increased LAI, especially in Ofanto, which recorded a maximum value of 0.20 (Fig. 4).

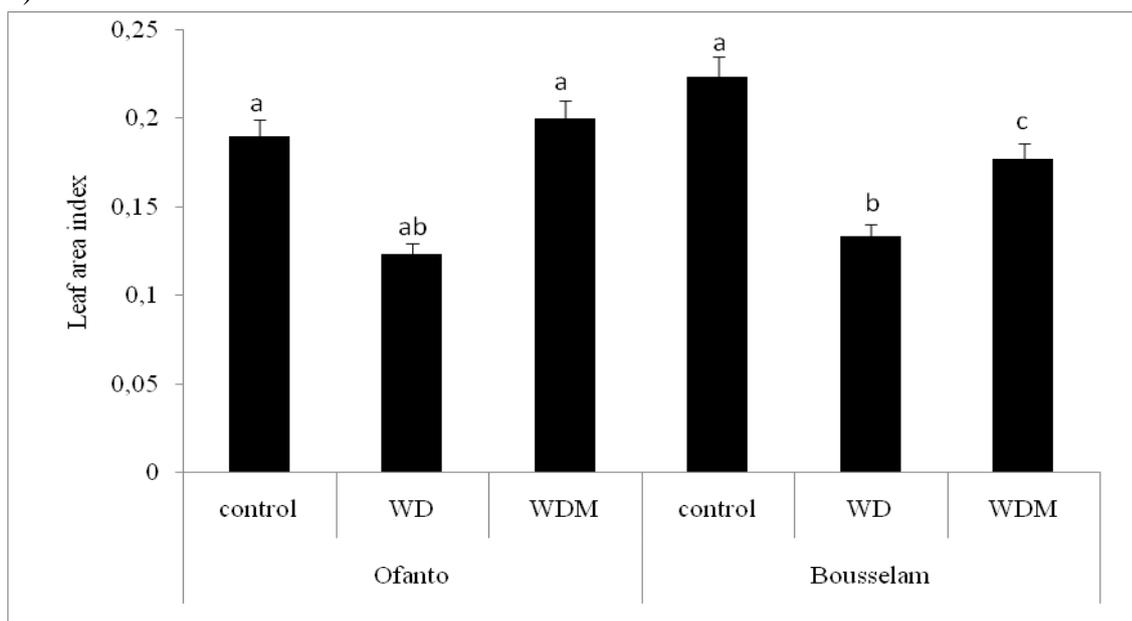


Fig. 4 Leaf area index (LAI) measured on two durum wheat genotypes grown under three water regimes (Control, WD, WDM) within the same water treatment and assigned different letters are significantly different (at 0.05 probability level) by Duncun's Test.

3.4 Antioxidant Enzyme Activities

Drought stress significantly increased catalase (CAT) and superoxide dismutase (SOD) activities ($p < 0.01$) in both genotypes. Date molasses further enhanced CAT and SOD activities under water stress (Table 3). In Bousselam, SOD and CAT activities reached 8.44 and 76.76 $U \cdot mg^{-1}$ protein, respectively, following molasses treatment.

Peroxidase (POD) activity also increased markedly under drought, and was further elevated by date molasses application in both wheat cultivars (Table 3). Bousselam exhibited higher antioxidant activities overall compared to Ofanto.

Table 3 The mean values of antioxidant enzymes activity under water stress, with and without treatment of molasse date, are presented. Each value represents the mean of five replications for each trait. Values that share a common superscript letter are not significantly different at a significance level of $p < 0.05$.

	SOD ($U \cdot mg^{-1}$ protein FW)		POD ($U \cdot mg^{-1}$ protein FW)		CAT ($U \cdot mg^{-1}$ protein FW)	
	Ofanto	Bousselam	Ofanto	Bousselam	Ofanto	Bousselam
Control	5.17 ^a ±0.04	5.12 ^a ±0.1	23.52 ^a ±0.16	37.14 ^a ±0.94	3.15 ^a ±0.01	3.12 ^a ±0.02
WD	6.5 ^b ±0.5	6.10 ^b ±0.19	25.75 ^a ±0.31	40.85 ^b ±0.64	4.36 ^{ab} ±1.10	7.22 ^a ±0.06
Evolution (%)	25.86±10.6 7	19.28±2.33	9.49±0.63	10.07±4.29	38.19±34.9 6	131.66±2.27
WDM	7.67 ^c ±0.29	9.66 ^c ±0.77	31.21 ^b ±2.36	76.76 ^b ±5.39	5.6 ^b ±0.22	8.44 ^b ±0.54
Evolution (%)	48.49±6.9	88.69±12.1 5	32.67±9.37	106.93±18. 6	77.59±7.03	170.91±17.2 1

Each value represents the mean of five replications for each trait. Values that share a common superscript letter are not significantly different at a significance level of $p < 0.05$.

3.5 Number of Adventitious Roots

Adventitious root formation was significantly influenced by substrate water content and genotype (Table 2). Under control conditions, the average number of adventitious roots ranged from 3 (Ofanto) to 4 (Bousselam) (Fig. 5). Water deficit slightly decreased adventitious root production, with Ofanto showing a 50% reduction. Date molasses application enhanced adventitious root formation in Ofanto, averaging 3 roots compared to 2 in Bousselam (Fig. 5).

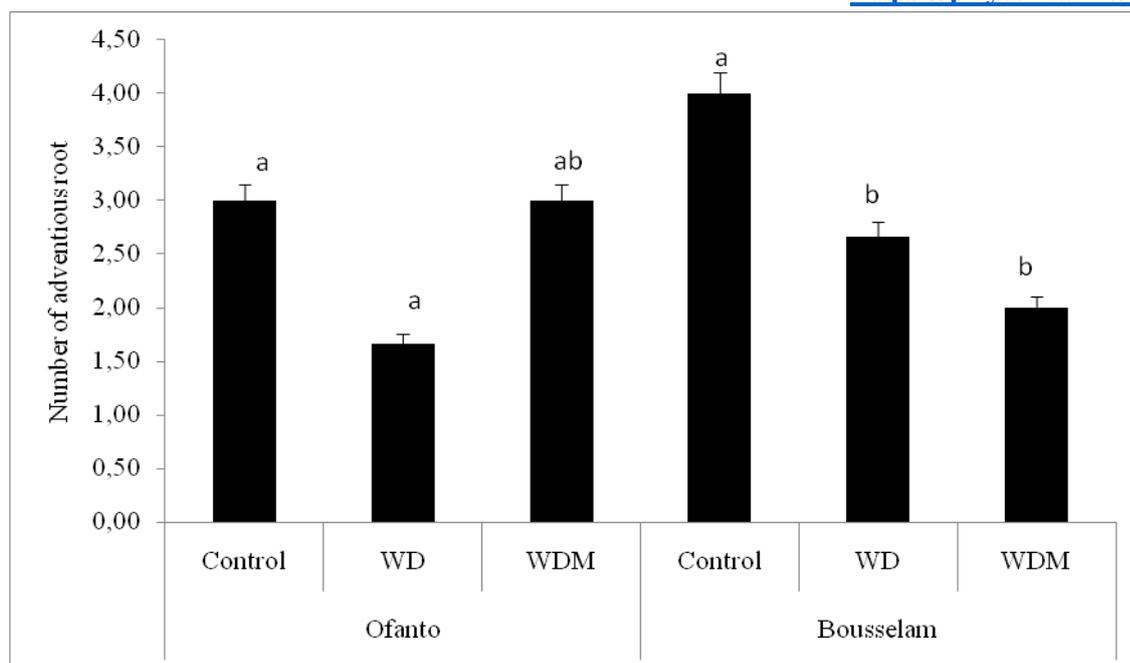


Fig. 5 Number of newly adventitious roots measured on two durum wheat genotypes grown under three water regimes (Control, WD, WDM) of genotypes within the same water treatment and assigned different letters are significantly different (at 0.05 probability level) by Duncan's Test.

3.6 Seminal Root Length

Root system development is critical for water and mineral uptake, especially under drought. Genotypes differed significantly in seminal root length (Table 2). Under control conditions, Ofanto and Bousselam exhibited average root lengths of 58 cm and 59.66 cm, respectively. Water deficit increased root length slightly, with Ofanto reaching 61.66 cm. Date molasses application further increased seminal root length, with Bousselam reaching 63 cm (Table 4).

Table 4 The mean values of Seminal Root Length (cm) under water stress, with and without treatment of molasse date, are presented. Each value represents the mean of five replications for each trait. Values that share a common superscript letter are not significantly different at a significance level of $p < 0.05$.

Genotypes	Treatment		
	Control	WD	WDM
Ofanto	58.33 ^a ±1.15	61.66 ^{ab} ±1.53	62.00 ^{ab} ±1.00
Bousselam	59.66 ^a ±1.15	60.00 ^b ±1.00	63.00 ^b ±1.25

In same column means with the same letter are not significantly different at $p > 0.05$

3.7 Shoot Dry Matter

Dry shoot biomass was significantly affected by water treatments (Table 2). Under control, Ofanto produced the highest shoot dry weight (1.12 g), while Bousselam exhibited lower biomass under drought (0.76 g). Molasses application significantly increased shoot biomass in both genotypes, reaching over 2 g (Table 5).

Table 5 The mean shoot dry matter values(g) under water stress, with and without treatment of molasse date, are presented. Each value represents the mean of five replications for each trait. Values that share a common superscript letter are not significantly different at a significance level of $p < 0.05$.

Genotypes	Treatment		
	Control	WD	WDM
Ofanto	1.12 ^a ±0.06	1.31 ^{ab} ±0.44	2.18 ^{ab} ±0.65
Bousselam	0.77 ^a ±1.04	0.76 ^a ±1.04	2.21 ^b ±0.82

In same column means with the same letter are not significantly different at $p > 0.05$

3.8 Root Dry Matter

Root dry weight varied similarly across genotypes and treatments (Table 2), with no significant genotype by treatment interaction. Bousselam had lower root biomass under favorable conditions but showed increased root dry matter under severe water scarcity (0.28 g). Date molasses enhanced root growth under water deficit, with root dry weights of 0.32 g and 0.36 g for Ofanto and Bousselam, respectively (Table 6).

Table 6 The mean values of Root dry matter under water stress, with and without treatment of molasse date, are presented. Each value represents the mean of five replications for each trait. Values that share a common superscript letter are not significantly different at a significance level of $p < 0.05$.

Genotypes	Treatment		
	Control	WD	WDM
Ofanto	0.38 ^a ±0.01	0.27 ^{ab} ±0.02	0.32 ^{ab} ±0.05
Bousselam	0.21 ^a ±0.05	0.28 ^a ±0.07	0.36 ^c ±0.13

In same column means with the same letter are not significantly different at $p > 0.05$

3.9 Soluble Sugars Content

Water deficit and molasses treatments significantly affected soluble sugar content ($p < 0.01$). Under control conditions, Ofanto had the lowest sugar content (4.15 $\mu\text{g}\cdot\text{mg}^{-1}$ FW), which increased dramatically with molasses to 48.61 $\mu\text{g}\cdot\text{mg}^{-1}$ FW in Ofanto and 66 $\mu\text{g}\cdot\text{mg}^{-1}$ FW in

Bousselam. Under drought without molasses, sugars ranged from 24.07 to 34.26 $\mu\text{g}\cdot\text{mg}^{-1}$ FW for Ofanto and Bousselam, respectively (Table 7).

Table 7 The mean values of soluble sugars content ($\mu\text{g}\cdot\text{mg}^{-1}$ FW) under water stress, with and without treatment of molasses date

Genotypes	Treatment		
	Control	WD	WDM
Ofanto	4.15 ^a ±1.08	24.07 ^{ab} ±1.41	48.61 ^{ab} ±1.17
Bousselam	6.11 ^a ±0.70	34.26 ^b ±0.07	66.00 ^c ±1.74

In same column means with the same letter are not significantly different at $p>0.05$

3.10 Number of Tillers

Genotype and interaction effects on tiller number were generally insignificant ($p < 0.01$), with genotype exhibiting minor influence ($p > 0.01$). Under control, both genotypes averaged about 4 tillers. Water deficit significantly reduced tillering to 2.33 (Ofanto) and 2.66 (Bousselam). Molasses application mitigated this decline, especially in Bousselam, which reached 3 tillers under drought (Table 8).

Table 8 The mean values of number of tillers under water stress, with and without treatment of date molasses

Genotypes	Treatment		
	Control	WD	WDM
Ofanto	3.66 ^a ±0.57	2.33 ^{ab} ±0.51	2.66 ^{bc} ±0.50
Bousselam	3.66 ^a ±1.52	2.66 ^a ±0.57	3.00 ^a ±0.54

In same column means with the same letter are not significantly different at $p>0.05$

Table 9 Correlation between the measured parameters of durum wheat cultivated under water stress and molasses date application

	Chl	RAN	SRL	SDW	RDW	LAI	RWC	SOD	POD	CAT	Sugar
Chl	1.00										
RAN	0.27	1.00									
SRL	-0.72**	-0.60*	1.00								
SDW	0.21	-0.30	-0.19	1.00							
RDW	0.43	-0.03	-0.32	0.63*	1.00						
LAI	0.57	0.21	-0.62*	0.08	-0.14	1.00					
RWC	-0.02	0.47	-0.42	-0.57	-0.26	0.15	1.00				

SOD	0.00	-0.41	0.37	0.62*	0.40	-0.16	- 0.96***	1.00			
POD	0.42	-0.28	0.17	0.46	0.24	0.06	-0.81**	0.75**	1.00		
CAT	0.06	-0.55	0.49	0.45	0.25	-0.31	- 0.87***	0.77**	0.78**		
Sugar	-0.23	-0.53	0.57	0.48	0.19	-0.30	- 0.91***	0.91***	0.61*	0.84***	1.00
N Tillers	-0.14	0.16	-0.11	-0.15	-0.29	0.51	0.31	-0.26	-0.36	-0.51	-0.37

Chl : Chlorophyll; RAN : Root adventitious number; SRL : Seminal root length; SDW: Shoot dry weight; RDW: Root dry weight; LAI: Leaf area index; SOD : Superoxyde dismutase; POD : Peroxydase; CAT : Catalase; N Tillers : Number of tillers

4. Discussion

Drought is a primary factor limiting crop development and yield (Tippayawat et al., 2025). It induces physiological responses such as stomatal closure, altered gas exchange, reduced CO₂ availability, and decreased photosynthesis (Grzesiak et al., 2019).

Relative water content (RWC) is a critical indicator of plant water status and metabolic activity (Ievinsh, 2023). Water deficit significantly decreased RWC in both wheat genotypes, signaling impaired hydration and early water stress symptoms (Masheva et al., 2022). Date molasses application significantly improved leaf RWC under drought, consistent with findings that molasses enhances abiotic stress tolerance (Hatano and Yamatsu, 2018).

Chlorophyll degradation due to photooxidation is common under water stress (Afzal et al., 2014; Sibomana et al., 2013). Our results showed chlorophyll content reduction in Ofanto under drought, which was alleviated by molasses treatment. Molasses, rich in organic carbon, vitamins, and minerals, likely enhances soil fertility and nutrient availability, thereby improving chlorophyll content (Oldfield et al., 2020).

The leaf area index (LAI) is a key structural parameter reflecting plant growth and photosynthetic capacity (Allahverdiyev, 2015). Water stress-induced reductions in LAI observed here are consistent with previous studies (Khayatnezhad and Gholamin, 2020). Molasses application mitigated LAI decline, likely by enhancing water and nutrient availability.

Water deficit induces oxidative stress, prompting increased antioxidant enzyme activities to mitigate reactive oxygen species (ROS) damage (Das and Roychoudhury, 2014). Our findings revealed elevated activities of CAT, POD, and SOD under drought, further enhanced by molasses treatment. These results align with reports of molasses increasing antioxidant defenses under abiotic stress (Kara et al., 2023).

The results of the study highlighted a strong correlation between RWC and SOD, CAT, and sugar content. Moreover, the antioxidant activity showed a positive correlation with sugar content (Table 9).

Drought decreased vegetative growth and biomass accumulation, primarily due to impaired enzyme activities and reduced turgor pressure (Farooq et al., 2009; Taiz et al., 2014).

Molasses application significantly increased shoot and root biomass under drought, reflecting its growth-promoting effects.

Root system development is vital for water and nutrient uptake. Drought stress altered root morphology and biomass, with deeper root elongation likely representing hydrotropic adaptation (Schulze et al., 2019; Gul et al., 2023). Molasses enhanced root biomass under drought, supporting improved water extraction capacity.

Soluble sugars accumulated under drought serve as osmoprotectants (Zemour et al., 2024; Khan et al., 2024). Molasses application further increased sugar content, potentially aiding osmotic adjustment and stress tolerance (Abdou et al., 2024).

5. Conclusion

This study provides novel insights into the physiological and morphological responses of durum wheat to water deficit and the mitigating effects of date molasses. Drought induced significant reductions in growth, chlorophyll content, and leaf area, while promoting antioxidant enzyme activities and osmoprotectant accumulation. Application of date molasses effectively alleviated the adverse effects of water stress by enhancing relative water content, antioxidant defenses, root growth, and soluble sugar accumulation.

These findings highlight the potential of date molasses as a sustainable organic amendment to improve wheat tolerance to drought in semi-arid regions. Future research should explore its effects across different developmental stages and concentrations to optimize its use in crop improvement programs.

References

- Abbas, T.; Rizwan, M.; Ali, S.; Adrees, M.; Mahmood, A.; Zia-Ur-Rehman, M.; Ibrahim, M.; Arshad, M.; Qayyum, M.F., 2018. Biochar application increased the growth and yield and reduced cadmium in drought stressed wheat grown in an aged contaminated soil. *Ecotoxicology and Environmental Safety*, 148, 825–833. doi: 10.1016/j.ecoenv.2017.11.063.
- Abdou N.M., EL-Samnoudi I.M., Ibrahim A.EA.M., Abd EL-Tawwab A.R. (2024) Biochar Amendment Alleviates the Combined Effects of Salinity and Drought Stress on Water Productivity, Yield and Quality Traits of Sugar Beet (*Beta vulgaris* L.). *J Soil Science Plant Nutrition* 24: 2091–2110. <https://doi.org/10.1007/s42729-024-01754-5> 12 422
- Afzal A. , Gulzar I. , Shahbaz M. , Ashraf M. 2014. Water deficit-induced regulation of growth, gas exchange, chlorophyll fluorescence, inorganic nutrient accumulation and antioxidative defense mechanism in mungbean *Vigna radiata* (L.) Wilczek. *Journal of Applied Botany and Food Quality* 87, 147 – 156. DOI: DOI.org/10.5073/JABFQ.2014.087.
- Akensous, F.Z.; Anli, M.; Boutasknit, A.; Ben-Laouane, R.; Ait-Rahou, Y.; Ahmed, H.B.; Nasri, N.; Hafidi, M.; Meddich, A., 2022. Boosting Date Palm (*Phoenix*

- dactylifera* L.) Growth under Drought Stress: Effects of Innovative Biostimulants. *Gesunde Pflanz.*, 74, 961–982. DOI.org/10.1007/s10343-022-00651-0
- Alghabari F., Ihsan M.Z., Hussain S., Aishia G. Daur I (2015) Effect of Rht alleles on wheat grain yield and quality 429 under high temperature and drought stress during booting and anthesis. *Environ Sci Pollut Res* 22: 15506–15515. 430 <https://doi.org/10.1007/s11356-015-4724-z>
- Ali-Dinar H, Munir M, Mohammed M., 2023. Drought-Tolerance Screening of Date Palm Cultivars under Water Stress Conditions in Arid Regions. *Agronomy*; 13(11):2811. DOI:10.3390/agronomy13112811
- Allahverdiyev T. I., 2015. Physiological Traits of DurumWheat (*Triticum durum* Desf.) and BreadWheat (*Triticum aestivum* L.) Genotypes under Drought Stress. *Agriculture Science*, 6 :848-859. DOI: 10.4236/as.2015.68082
- Al-Taweil HI, Noura KMS, Ekhlash MT., 2015. Use of date syrup as alternative carbon source for microbial cultivation. *World Journal of Microbiology and Biotechnology*, 2(1): 022-025. DOI:10.22270/jddt.v11i5.4982
- Altansambar N., Sezgin Muslu A. Kadioglu A. (2024) The combined application of rutin and silicon alleviates osmotic stress in maize seedlings by triggering accumulation of osmolytes and antioxidants' defense mechanisms. *Physiol Mol Biol Plants* 30 : 513–525. <https://doi.org/10.1007/s12298-024-01430-z>
- Ashraf M (2009) Biotechnological approach of improving plant salt tolerance using antioxidants as markers. *Biotechnology Advances* 27, 84–93. doi:10.1016/j.biotechadv.2008.09.003
- Ashraf, M.A.; Rasheed, R.; Hussain, I.; Iqbal, M.; Haider, M.Z.; Parveen, S.; Sajid, M.A. 2014. Hydrogen peroxide modulates antioxidant system and nutrient relation in maize (*Zea mays* L.) under water-deficit conditions. *Arch. Agron. Soil Sci.*, 61, 507–523. doi: 10.1080/03650340.2014.938644.
- Barnes J. D., Balaguer L., Manrique, E. S., and Davison A. W., 1992. A Reappraisal of the Use of DMSO for the Extraction and Determination of Chlorophyll a and B in Lichens and Higher Plants', *Environmental and Experimental Botany.*, 32, 85-100. DOI.org/10.1016/0098-8472(92)90034-Y
- Caverzan, A.; Casassola, A.; Brammer, S.P. 2016. Antioxidant responses of wheat plants under stress. *Genet. Mol. Biol.*, 39, 1–6. doi: 10.1590/1678-4685-GMB-2015-0109.
- Chance, B.; Maehly, A. (1955). Assay of catalases and peroxidases. *Methods Enzymol.*, 2, 764–775. doi.org/10.1016/S0076-6879(55)02300-8
- Chennafi H., 2012. Decadal evaluation of durum wheat water requirements to improve rainfed agriculture under semi-arid conditions. *Energy Procedia.*; 18:896–904. DOI: 10.1016/j.egypro.2012.05.104
- Colombi, T.; Torres, L.C.; Walter, A.; Keller, T., 2018. Feedbacks between soil penetration resistance, root architecture and water uptake limit water accessibility and crop growth A vicious circle. *Science of The Total Environment.*, 626, 1026–1035. DOI: 10.1016/j.scitotenv.2018.01.129

- Das, K.; Roychoudhury, A. (2014). Reactive oxygen species (ROS) and response of antioxidants as ROS-scavengers during environmental stress in plants. *Frontiers. Environmental Science.*, 2, 53. doi.org/10.3389/fenvs.2014.00053
- Du, Y.; Zhao, Q.; Chen, L.; Yao, X.; Zhang, W.; Zhang, B.; Xie, F. 2020. Effect of Drought Stress on Sugar Metabolism in Leaves and Roots of Soybean Seedlings. *Plant Physiology and Biochemistry.* 146, 1–12. DOI: 10.1016/j.plaphy.2019.11.003
- Elnajar, M., Aldesuquy, H., Abdelmoteleb, M. 2024. Mitigating drought stress in wheat plants (*Triticum Aestivum* L.) through grain priming in aqueous extract of *spirulina platensis*. *BMC Plant Biology* 24, 233. DOI.org/10.1186/s12870-024-04905-z
- FAO, 2023. Crops and Livestock Products. 2023. Available online: <https://www.fao.org/faostat/en/#data/QCL> (accessed on 11 February). DOI.org/10.1787/f1b0b29c-en.
- Farooq, M., A. Wahid, N. Kobayashi, D. Fujita and S.M.A. Basra, 2009. Plant drought stress: effects, mechanisms and management. *Agronomy for Sustainable Development.*, 29 (1): 185-212. DOI:10.1051/agro:2008021
- Giannopolitis, C.N.; Ries, S.K., 1977. Superoxide dismutases: I. Occurrence in higher plants. *Plant Physiol.*, 59, 309–314. doi: 10.1104/pp.59.2.309
- Gomez L., Rubio E., Auge M (2002). A new procedure for extraction and measurement of soluble sugars in ligneous plants. *J. Sci. Food Agric.*, 82, 360–369. <https://doi.org/10.1002/jsfa.1046>
- Grzesiak MT, Hordyńska N, Maksymowicz A, Grzesiak S, Szechyńska-Hebda M., 2019. Variation Among Spring Wheat (*Triticum aestivum* L.) Genotypes in Response to the Drought Stress. II—Root System Structure. *Plants.* 8(12):584. DOI.org/10.3390/plants8120584.
- Gul M. U., Paul A., Manimurugan S., Chehri A. 2023. Hydrotropism: Understanding the Impact of Water on Plant Movement and Adaptation. *Water*, 15(3), 567. doi.org/10.3390/w15030567
- Hatano K., Yamatsu T (2018). Molasses melanoidin-like products enhance phytoextraction of lead through three Brassica species. *Inter J Phyto* 20: 552–559. <https://doi.org/10.1080/15226514.2017.1393397>
- Isgandarova T.Y., Rustamova S.M., Aliyeva D.R., Rzayev F.H., Gasimov E.K., Huseynova I.M (2024) Antioxidant and Ultrastructural Alterations in Wheat During Drought-Induced Leaf Senescence. *Agron*, 14(12): 2924. <https://doi.org/10.3390/agronomy14122924>
- Kara, M., Seçgin, Z., Arslanoğlu, Ş.F. (2023). Endogenous Food-Borne Sugar Beet Molasses Carbon Dots for Alleviating the Drought and Salt Stress in Tobacco Plant. *Journal of Plant Growth Regulation* 42, 4541–4556. <https://doi.org/10.1007/s00344-023-10923-2>
- Karimi M., Ahmadi A., Hashemi J., Abbasi A., Tavarini S., Guglielminetti L., Angelini L.G (2015) The effect of soil moisture depletion on Stevia (*Stevia rebaudiana* Bertoni) grown in greenhouse conditions: Growth, steviol glycosides content, soluble sugars and total antioxidant capacity. *Sci Horticu* 183: 93–99. 488 <https://doi.org/10.1016/j.scienta.2014.11.001>

- Khan M. A., Liu D.-H., Alam S. M., Zaman F., Luo Y., Han H., Ateeq M., Liu Y.Z (2023) Molecular physiology for the increase of soluble sugar accumulation in citrus fruits under drought stress. *Plant Physiol Biochem* 203: 108056. <https://doi.org/10.1016/j.plaphy.2023.108056>
- Khayatnezhad M., Gholamin R., 2020. Study of DurumWheat Genotypes' Response to Drought Stress Conditions. *Helix* : 10 (5): 98-103. DOI:10.29042/2020-10-5-98-103
- Li S, Di X, Wu D, Zhang J.,2013. Effects of sewage sludge and nitrogen fertilizer on herbage growth and soil fertility improvement in restoration of the abandoned open castmining areas in Shanxi, China. *Environmental Earth Sciences*. 70:3323–3333. DOI:10.1007/s12665-013-2397-9
- Molassiotis A, Sotiropoulos T, Tanou G, Diamantidis G, Therios I (2006) Boron-induced oxidative damage and antioxidant and nucleolytic responses in shoot tips culture of the apple rootstock EM9 (*Malus domestica* Borkh). *Environmental and Experimental Botany* 56, 54–62
- Oldfield, E.E.; Wood, S.A.; Bradford, M.A., 2020. Direct evidence using a controlled greenhouse study for threshold effects of soil organic matter on crop growth. *Ecological Applications*., 30, 02073. doi.org/10.1002/eap.2073
- Pyakurel A., Raj Dahal B., Rijal S., 2019. Effect of Molasses and Organic Fertilizer in Soil fertility and Yield of Spinach in Khotang, Nepal. *International Journal of Applied Science Biotechnology*. 7(1): 49-53. DOI: <https://doi.org/10.3126/ijasbt.v7i1.23301>
- Pour-Aboughadareh, A.; Mohammadi, R.; Etmnian, A.; Shooshtari, L.; Maleki-Tabrizi, N.; Poczai, P.n 2020. Effects of drought stress on some agronomic and morpho-physiological traits in durum wheat genotypes. *Sustainability* , 12, 5610. doi.org/10.3390/su12145610
- Rellán-Álvarez R. ; Lobet G., Dinneny J. R., 2016. Environmental Control of Root System Biology. *Annual Review of Plant Biology*, 29:67:619-42. DOI: 10.1146/annurev-arplant-043015-111848
- Saghouri el idrissi I, Kettani R., Ferrahi M., Nabloussi A., Ziri R., Brhadda N., 2023. Water stress effect on durum wheat (*Triticum durum* Desf.) advanced lines at flowering stage under controlled conditions. *Journal of Agriculture and Food Research*. 14 (2023) 100696. DOI:10.1016/j.jafr.2023.100696
- Schonfeld M.A., Johnson R.C., Carver B.F., Mornhinweg D.W (1988) Water relations in winter wheat as drought resistance indicators. *Crop Physi Metab*, 28(3): 526–531. <https://doi.org/10.2135/cropsci1988.0011183X002800030021x>
- Schulze, E.-D.; Beck, E.; Buchmann, N.; Clemens, S.; Müller-Hohenstein, K.; Scherer-Lorenzen, M.,2019. Water Deficiency (Drought). *Plant Ecology*. , 165–202. doi.org/10.55905/rcssv12n7-020
- Soar C.J. and Loveys B.R., 2007. The effect of changing patterns in soil-moisture availability on grapevine root distribution, and viticultural implications for converting full-cover irrigation into a point-source irrigation system. *Australian Journal of Grape and Wine Research*. 13, 1–13. doi.org/10.1111/j.1755-0238.2007.tb00066.x

- Sibomana I. C., Aguyoh J. N. and .Opiyo A. M., 2013. Water stress affects growth and yield of container grown tomato (*Lycopersicon esculentum* Mill) plants. Global Journal of Biochemistry and Biotechnology., 2 (4) 2013: 461-466 <https://api.semanticscholar.org/CorpusID:110548511>.
- Taiz, L., E. Zeiger, I.M. Møller and A. Murphy, 2014. Plant Physiology and Development. Sixth Edition, Sinauer Associates, Inc., Publishers, Sunderland, Massachusetts, USA, 761 pages. Doi.org/10.1093/hesc/9780197614204.001.0001
- Thind I., Hussain I., Ali S., Hussain S., Rasheed R., Ali B., Hussain H.A (2020) Physiological and Biochemical Bases of Foliar Silicon-Induced Alleviation of Cadmium Toxicity in Wheat. J Soil Sci Plant Nutr 20: 2714–2730. <https://doi.org/10.1007/s42729-020-00337-4>
- Tippayawat A., Jogloy S., Vorasoot N., Jongrunklang N., Kimbeng C.A. Jifon J.L., Khonghintaisong J., Songsri P (2025) Timing and Duration of Drought Differentially Affect Growth and Yield Components Among Sugarcane Genotypes. Plants 14(5): 796. <https://doi.org/10.3390/plants14050796>
- Yordanov I., Velikova V., and Tsonev T.,2003. Plant Responses to Drought and Stress Tolerance'. Bulgarian Journal of Plant Physiology., Special Issue (2003), 187-206. DOI:10.1023/A:1007201411474
- Yousaf M.M., Yasmeen A., Kareem S.H.S., Muhammad A., Alharby H.F., Alsamadany H., Alzahrani Y.M., Alamri A.M., Latif A., Rehman H (2025) Mitigating Terminal Drought in Chickpea (*Cicer arietinum* L.) Using Organic Manures; Effects on Yield, Potassium Uptake and Antioxidants Activity. Int J Plant Prod, <https://doi.org/10.1007/s42106-025-00342-6>
- Zargar, M.; Rebouh, N.; Pakina, E.; Gadzhikurbanov, A.; Lyashko, M.; Orskhanov, B., 2017. Impact of climate change on cereal production in the highlands of eastern Algeria. Research Crops , 18, 575–582. DOI:10.5958/2348-7542.2017.00098.5
- Zemour K., Adda A., Chouhim K.M.A., Labdelli A., Merah O (2024) Amylase activity and soluble sugars content of durum wheat seeds during germination under water stress. Agri Res 13: 676–683. <https://doi.org/10.1007/s40003-024-00742-6>
- Zou, Y.N.; Wu, Q.S.; Kuča, K. 2020. Unravelling the role of arbuscular mycorrhizal fungi in mitigating the oxidative burst of plants under drought stress. Plant Biology, 1–8. DOI: 10.1111/plb.13161. Epub 2020 Oct 12

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