

Comparative Field Studies of Biochemical and Agro-physiological Parameters in semi-arid zone with rainfall Moroccan climate Of Durum wheat

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Abstract

Durum wheat production is highly unpredictable throughout the year because of uncertain rainfall and frequent dry spells, and it is absolutely necessary to characterize the impact of drought on grain yield. The objective in this research is to carry out a comparative analysis of biochemical and physiological responses and production parameters of durum wheat (*Triticum durum*) in semi-arid zone with rainfall in Morocco's climates. Thirteen durum wheat genotypes selected at INRA-Morocco and three control varieties were evaluated under Moroccan rainfed conditions for two growing seasons (2019/20 and 2020/21). The INRA-Morocco-Douyet Fez experimental field site was where the trials were conducted (34°2 N, 5°W, 416 m). Different parameters were studied: leaf area, leaf temperature, relative water content, chlorophyll content, proline, yield and yield components. Decreased rainfall significantly increased proline content, leaf temperature and decreased leaf area, seed yield, chlorophyll and relative water content ($P < 0.01$). Based on these results, field-induced rainfall variations resulted in inconsistencies in the response of the assessed traits to drought-related interactions between both growing seasons (2020–2021) in order to identify stable, high-yielding genotypes in the presence and absence of rainfall, which requires a strong association of drought-related traits.

Introduction

On a global scale, the cultivation of cereals is a significant source of food and nutrition feed in the farming system (Behnassi et al, 2021). On other hand, the production of cereals is further limited by a decreasing yield of intense agriculture and by the potentially catastrophic effects of climatic change (Royo et al, 2022; Amiri et al, 2021; *Chahbar et al, 2016*), the possible decrease in available water resources. Several studies have shown that the weather conditions in the adaptation zone of Mediterranean breeds are similar to those in durum wheat affect yield formation and development pattern (Royo et al, 2017; Royo et al, 2014). wheat worldwide development and growth is most affected by drought, which is the most important abiotic stress, particularly in the Mediterranean basin region in Morocco (Bouras et al, 2021). However, Morocco is still one of the major importers of durum wheat. Therefore, to meet local consumer demand, Moroccan breeding programs have to develop new wheat germplasm with higher yields and desirable end-use quality (Chegdali et al, 2020). The Moroccan climate, which is Mediterranean, is characterized primarily by intra- and interannual variability in rainfall and temperature. In fact, the shortage of available water is mainly due to higher frequency of droughts caused by increased variability in precipitation (Huang et al, 2014). These obstacles will negatively impact agricultural seed yields, employment opportunities, and consumer purchasing power. Therefore, sustainable agricultural practices must be adopted to adapt to and address drought (Abdelmajid et al, 2021). The productivity of rainfed wheat remains dependent on these climatic variations (Schilling et al, 2020). The strategies developed to improve wheat production include the search for stress-tolerant varieties and better use of rain water (Bouras et al, 2019). Tolerance is often linked to genetic factors that ensure the maintenance of the plant's vital functions under stress and adaptation to changes in its environment (Boussakouran et al, 2022). The total water requirement of wheat is 450 to 650 mm/year, provided that these quantities are well distributed during the development cycle of wheat. Wheat is cultivated mainly in areas that are prone to drought and is the most important factor limiting the Mediterranean zone (Erice et al., 2019). However, the development of drought-tolerant varieties is necessary to achieve appropriate agricultural production in these areas. In this regard, the aim of durum wheat selection is to create new genotypes with adaptive morphophysiological characteristics that can guarantee sustainability in the face of drought and its consequences. (Boussakouran et al, 2022). As water scarcity has limited durum wheat production in areas that are either arid or semi-arid (Akhtar et al, 2022), Wheat's metabolic activity is reduced, biomass accumulation is reduced, and photosynthesis is reduced by reducing the chlorophyll content of leaves (McAusland et al, 2019; Mathobo et al, 2017; McAusland et al, 2016), this ultimately resulted in a decrease in wheat grain yield (De Santis et al, 2021). Other research indicates that the timing and intensity of soil moisture deficiency is critical to wheat development and growth (Rea et al, 2022). Furthermore, a high moisture stress at the vegetative growth stage could seriously affect wheat plant growth, leaf area and decrease seed yield (Gizaw et al, 2016; Li et al, 2013). Moreover, a slight application of water stress at the onset of vegetative growth and at the end of wheat grain filling showed some tolerance to water stress due to the low water demand of wheat at these stages (Monneveux et al, 2012), although soil moisture is sub-optimal during these stages of vegetative growth and grain filling (González-Ribot et al., 2017). Despite this, optimal irrigation at the flowering stage would result in high wheat yields (Farooq et al., 2014). In this way, a better understanding of the water stress associated with wheat growth is essential for soil and crop management, as shown by many studies that have examined the impact of water stress on wheat growth and development (Parent et al., 2017; Farooq et al. 2014). To understand that such an influence is important for wheat yield forecasts under drought conditions, our present study combines different approaches to identify the agrophysiological and biochemical characteristics associated with a better genotypic growth performance of durum wheat under Mediterranean conditions in Morocco, that vary in rainfall availability and temperature, and estimate these conditions for two growing seasons in durum wheat. This research presents two years of field experience to gain a thorough understanding of the response of the different genotypes studied to the precipitation conditions of both assessment years to determine their effect on durum wheat production and development. The aims of this research was to evaluate the biochemical and agro-physiological parameters of the rainfall conditions of durum wheat in a semi-arid climate in Morocco and to identify the effect of genotypes, years, and how you interact with ten studied parameters, as well as to know their reaction in these two rainfall conditions. We highlighted the influence of drought during the flowering stage in durum wheat development and analysed the response of these impacts. The experiment was chosen

in the field at several places in various soil water conditions. Consequently, normal rainfall conditions over those two years were taken into account.

1. Material and methods

1.1. Material Plant

This study consisted of three control varieties and thirteen genotypes, with sixteen durum wheat (*Triticum durum* Desf.) genotypes being included (Table 1).

Table 1
List of the studied genotypes along with their pedigree and origin.

Genotype	Pedigree	Origin
DYT1TAZI	Murlagost-2	INRA/Meknes/Morocco
DYT3TAZI	Arislahn-9	INRA/Meknes/Morocco
DYT4TAZI	Aristan/3/Lahn//Gs/Stk/4/Brch	INRA/Meknes/Morocco
DYT5TAZI	Stk/Hau//Heca-1	INRA/Meknes/Morocco
DYT6TAZI	Gsbl-1/4/D68-1-93A-1A//Ruff/Fg/3/Mtl-5	INRA/Meknes/Morocco
DYT7TAZI	Gsbl-1/4/D68-1-93A-1A//Ruff1/Fg/3/Mtl-5	INRA/Meknes/Morocco
DYT9TAZI	Gcn/4/D68-1-93A-1A//Ruff/Fg/3/Mtl-5	INRA/Meknes/Morocco
DYT10TAZI	Ossl-1/4/MrbSH/3/Rabi//Gs/Cr/5/Hna	INRA/Meknes/Morocco
DYT11TAZI	Ossl-1/4/MrbSH/3/Rabi//Gs2/Cr/5/Hna	INRA/Meknes/Morocco
DYT12TAZI	Quarmal/Gbch-2	INRA/Meknes/Morocco
DYT13TAZI	Gcn//Stj/Mrb3	INRA/Meknes/Morocco
DYT14TAZI	F4 13 J.S/3/Arthur71/Lahn//Blk2/Lahn/4/Quarmal	INRA/Meknes/Morocco
DYT15TAZI	Lgt3//Bcr/Sbl5	INRA/Meknes/Morocco
FERRAHI	T1V1-2016 FERRAHI	Variety registered in 2011 INRA/Meknes/Morocco
FARAJ	T2 FARAJ	Variety registered in 2007 INRA/Meknes/Morocco
LOUIZA	T3 LOUIZA	Variety registered in 2011 INRA/Meknes/Morocco

1.2. Field Experiment Design

The experiments have been carried out in the field in two campaigns (2019–2020 / 2020–2021) at National Institute of Agronomic Research of field Experimental site in Douyet Fez (5°W, 34°2 N, 416 m) starting on 10/12/2019. The site is situated in a semi-arid Mediterranean area, with an average annual precipitation of 500mm (over 40 years old), characterized by a loam soil, poor in organic matter and alkaline Ph. The configuration of the experimental design was carried out in two blocks as a completely random scheme for the precipitation tests. The experimental blocks were planted on 16 plots (16 genotypes x 2 replicates), each plot being planted in four four-metre (6 m) rows, of which 4 m²/plot area. The seeding rate has been adjusted to 30 g/m.

1.3. Environmental requirements

Growing seasons were different in terms of amount and distribution of precipitation and mean air temperature (Table 2). The distribution of precipitation varies considerably between growing seasons. Both seasons are characterized by 221.1 and 400.54 mm of precipitation for the 2019-20 and 2020-21 seasons, respectively (Table 2). During the 2019/20 crop year, high temperature and drought become the key stress during flowering stage, with the potential impact on crop yield, which has often shortened the grain filling period, reduction in the weight of cereals and thus loss of yield in the wheat experiments during the drought in Morocco.

Table 2
Variation of monthly patterns of the average temperature of air (T_{air}) and rainfall in douyet-Fès meteorology station during 2019/20–2020/21 growing seasons.

Year	Season 2019/2020							Season 2020/2021						
Month	Nov	Dec	Jan	Fev	Mar	Apr	Mai	Nov	Dec	Jan	Fev	Mar	Apr	Mai
Rainfall (mm)	62,2	33,4	18	0	40	67,5	0	47	19,5	101	25,2	68,04	113,8	26
Avg (T_{air}) (°C)	14.4	14.2	12.4	17.2	15.6	17.3	24.6	12,9	12,6	10,4	12,7	14,1	16,6	18,7
T. Cumul (mm)	221,1 (dry season)							400,54 (rainy season)						

1.4. Parameters measured

Physiological, morphological, and agronomic traits were measured or determined on all the plants experimented.

1.4.1. Agro-physiological parameters

Measurements of the physiological traits were performed during three growth stages, namely, vegetative, 50% flowering and 100% pod formation, prior to irrigation, from 12.00 to 15.00 PM. The following parameters were determined on the same healthy leaves. The leaf Relative Water Content (RWC) of the drought and control leaves has been measured using the Clarck and McCaig (1982) method. The cut leaves of the analysed plants were weighed immediately to obtain their fresh weight (FW). These leaves were then kept in distilled water for 24 hours, after which they were weighed to obtain the turgid weight (TW). The leaves were finally oven dried at 80°C for 48 hours and weighed again to determine their dry weight (DW). The relative water content was calculated using the following formula: $RWC (\%) = [(FW - DW)/(TW - DW)] \times 100$. The chlorophyll (C_{lc}) content determined by a SPAD-502Plus chlorophyll content meter (Model CCM-502Plus, ADC Bioscientific Ltd, UK), which was used to assess the nitrogen content in leaves. Three measurements were taken at three different levels of the leaf (top, middle, and base). Finally, the average of the three values, expressed in SPAD units, is considered. Leaf stomatal conductance (Gs) was measured using an automatic porometer type AP4 version 3.1, 2014. For each leaf of the plant three measurements were made. Data regarding stomatal resistance (Rs) were expressed in cm s⁻¹. Leaf area (LA), expressed in cm², was determined by the Portable Leaf Area Meter (LI-3000C-USA). It is a simple and accurate technique that consists of placing the leaf on the planimeter plate and determining the leaf area value. Finally, leaf temperature (LT°), expressed in °C, was determined by using a testo AG thermometer (Lenzkirch, Germany). The optical lens of the device captures the energy emitted, reflected and transmitted by the object. This energy is collected and concentrated towards a detector, and the electronics of the device translate this information into a temperature that is then displayed on the device screen. Plant height (PH, cm) and 1000-seed weight (TSW, g) were determined using a precision balance in the laboratory. The number of spikes per m² and yield per m² were collected in productivity per square meter (m²).

1.4.2. Biochemical parameters

The proline content (ProC), expressed as µg/100 mg MF (fresh matter), and has been measured using the methods of Monneveux and Nemmar (1986). One hundred milligrams of fresh matter was collected from the average third of the various genotypes studied and placed in test-tube, which were numbered according to the treatments studied. Two milliliters of 40% methanol was added to the different test tubes, which were then hermetically sealed. All test tubes were placed in an 85°C water bath for one hour, then removed from the water bath and cooled in an ice tray for 30 minutes. A mixture (solution A) consisted of 120 ml distilled water, 300 ml acetic acid and 80 ml orthophosphoric acid (H4P2O5). 1 ml of the treated tubing solution was injected with 1 ml of acetic acid and 25 mg of ninhydrin. The tubes were then left for 30 minutes in a 100°C water bath. The contents of the tubes turned red and were then removed from the bath and left to cool in an ice tray. After that, to each tube 5 ml of toluene were added and stirred vigorously until it separated into two superimposed phases, one clear supernatant and the other denser, darker phase forming the deposit. The supernatant solution carrying the proline was collected in a new set of clean test tubes and dehydrated by adding anhydrous Na₂SO₄. This solution was pipetted into polished glass cuvettes, at a wavelength of 528 nm, the optical density was read with a spectrophotometer. The concentration of proline corresponding to optical density read was deduced from the relationship between the optical density and the proline concentration of the standard samples used to construct a calibration curve with the formula $y = 0.1766 \times x + 0.0027$ ($R^2 = 0.9973$)

y: optical density (nm)

x : proline concentration (µg/mL).

1.4.3. Statistical assessment

This is a statistical evaluation of the data collected and analyzed by SPSS 25 (IBM SPSS Statistics 25, Inc., Chicago, Illinois; USA), was used to test the effects of genotype, year and interaction on all the traits assessed. In order to reveal the relationships between seed yield and the

parameters evaluated, the Pearson correlation was performed using the same statistical set.

2. Results

2.1. Environmental conditions

The growing seasons were different in terms of the amount and distribution of precipitation and average air temperature (Table 2), resulting in contrasting growing conditions and therefore a range of yield potential in rain conditions. The distribution of precipitation varied considerably between growing seasons and genotypes exposed to different levels of water stress, becoming a limiting factor in Morocco's Mediterranean regions. The two seasons have more different precipitation (221.1 and 400.54 mm, respectively, in 2019-20 and 2020-21) during this experiment. In addition, a large variation in minimum air temperature was observed between growing seasons, and the 2019–2020 season was warmer than the following season. During 2019/20 season, drought with high temperatures is considered a key stress factor after flowering stage, which could have a significant effect on yield production due to the impact of drying on the grain filling period, which reduces the weight of cereals and therefore the yield loss of wheat in Morocco. The results of the combined ANOVA for genotypes, cereal yield and nine agro-physiological traits are presented in Table 3, indicating very significant differences ($p < 0.5$).

Table 3

Analysis of variance (mean squares) for physiological, biochemical and yield traits in durum wheat genotypes evaluated under different rainfall conditions during 2019/20–2020/21 growing seasons.

Source of Variation	DF	RWC (%)	LA (cm ²)	Rs (cm ² /s)	Chc (SPAD)	LT°(°C)	ProC (µg/100mg)	PH(cm)	Ns/m ² WTS(g)	Y/m ² (g)
Genotypes (G)	15	19.09***	18.5***	24.2***	27.8***	21.66***	23.15***	20.1***	26.1*** 26.16***	29.63***
Year (Y)	1	233.7***	131.7***	289.6***	189.7***	709.3***	1271.6***	321.3***	277.12*** 257.7***	1170.2***
(G) × (Y)	15	13.36***	8.36***	6.33***	10.47***	11.33***	12.11***	10.61***	12.04*** 13.2***	22.4***
*, **, *** Significant at 0.05; 0.01 and 0.001 probability levels, respectively.										
Y: Year; G: Genotype, RWC (%): relative water content, LA (cm ²): leaf area, Rs (cm ² /s): Stomatal resistance, Chc (SPAD): Chlorophyll content, LT° (°C): leaf temperature, ProC (µg/100 mg): proline content, PH (cm): Plant height, Ns/m ² : Number of spike per square meter, WTS(g): Weight of 1000 seeds, Y/m ² (g): yield per square meter.										

2.2. Effects of rainfed conditions and season on physiological and biochemical parameters

Variance analysis (ANOVA) revealed very significant differences between durum wheat genotypes and between rainfed conditions and seasons ($P < 0.001$) for all parameters studied (leaf area, stomatal resistance, chlorophyll content, leaf temperature, relative water content and proline content). However, the two years of this study were comparable (Table 3). Additionally, there was a very strong effect of the interaction between the genotype- year season and all of those parameters. During the first season (2019–2020), stomatal resistance increased significantly under rainfed conditions compared to the second season (2020–2021). A higher value was observed in genotype DYT1TAZI (6.4 cm²/s; $p < 0.05$) during the 2019-20 season; on the other hand, in the 2020-21 season, the lowest value was observed during the 2020-21 season in two genotypes, DYT1TAZI (0.9 cm²/s) followed by DYT14TAZI (0.8 cm²/s) with a reduction of 15% compared to the first season (2019–2020) (Table 4). Significant relative water content (RWC) values were recorded during the 2020–2021 season., with a maximum value of 85% ($p < 0.001$) observed in DYT11TAZI and DYT1TAZI and a minimum value of 75.8% ($p < 0.001$) in DYT7TAZI (Table 4). A decrease in the RWC was noted in all genotypes studied during the 2019-20 season compared to second year in which the highest RWC (78%) observed in genotype DYT1TAZI, while the lowest RWC (44.7%; $p < 0.001$) was found in the genotype DYT13TAZI. Regarding the rainfed conditions, DYT1TAZI and DYT11TAZI had the highest RWC, while DYT13TAZI had the lowest RWC. Similarly, the highest chlorophyll content values were observed during the 2020-21 season, whereas the lowest values were recorded in the 2019-20 year (Table 4). Under these conditions, the DYT1TAZI genotype showed the highest value (59.7 SPAD; $p < 0.001$) in 2020-21 and (54.1 SPAD; $p < 0.001$) in the 2019-20 season, with a reduction of 11%, while the DYT13TAZI genotype showed the lowest value (20.5 SPAD; $p < 0.001$), with a reduction of more than 50% compared to the 2020-21 season (41.2 SPAD; $p < 0.001$). A significant reduction in foliar area (LA) of the various genotypes tested was observed during the 2019–2020 season compared to 2020-21 season due to rainfall conditions, and the significance of such a decrease

was associated with the dry season. DYT1TAZI showed the largest leaf area, with a maximum value of 45.1 cm² ($p < 0.001$), with a reduction of more than 12% compared to the second season (51.2 cm²; $p < 0.001$). The smallest leaf area, with a minimum value of 10.2 cm² ($p < 0.001$), was recorded in DYT7TAZI during the 2019-20 season, with a reduction of more than 64% compared to the second season (28.3 cm²; $p < 0.001$) (Table 4). Leaf temperature (LT) increased with the drought stress level in all genotypes during the 2019-20 season compared to the 2020-21 season (Table 4), with an overall increase of 40% in comparison to the rainy season (2020-21 season). The highest leaf temperature (32°C) was recorded in DYT3TAZI, DYT6TAZI, DYT7TAZI and DYT12TAZI, while the lowest leaf temperature (26°C) was registered in DYT1TAZI, DYT5TAZI, DYT11TAZI, DYT14TAZI and LOUIZA under drought conditions (2019-20 season). During the 2020-21 season, LT varied from 17.8°C (DYT1TAZI) to 21.9°C (DYT3TAZI). During the 2019-20 season, the results demonstrated a remarkable increase in proline content due to this year's drought stress. The highest proline content values were recorded in plants during the dry season, with a variation from 603.1 µg/100 mg in DYT1TAZI to 282.5 µg/100 mg in DYT10TAZI. During the rainy season, the values registered were much lower than those during the dry season, ranging from 107.5 µg/100 mg in DYT4TAZI to 82.9 µg/100 mg in DYT11TAZI (Table 4). We observed a drastic increase in proline with the level of water deficit, i.e., 6 times for DYT1TAZI, DYT5TAZI, DYT11TAZI, DYT14TAZI, FERRAHI, FARAJ, LOUIZA and 3 times for the rest of genotypes tested.

Table 4
Effects of rainfall conditions and season on physiological and biochemical parameters of 16 durum wheat genotypes evaluated for two years 2020 and 2021.

Parameters	Rs (cm ² /s)		LA (cm ²)		ChC (Spade)		LT (C°)		RWC (%)		ProC (µg/100mg)	
Y G	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
DYT1TAZI	6,4 a	0,9 a	45,1 a	51,2 a	54,1 a	59,7 a	26,5 a	17,8 a	78,4 a	85,3 a	603,1 a	92,4 b
DYT3TAZI	3,1 d	1,6 b	15 d	21,7 d	35,9 c	44 b	32,1 e	21,9 c	59,3 c	77,1 c	340,8 d	100,8 a
DYT4TAZI	3,5 d	1,9 b	23,2 c	35,6 c	36,9 c	45 b	31,1 de	19,6 b	60,8 c	76,6 c	322,2 d	107,5
DYT5TAZI	6,1 a	1,3 b	41,9 a	50,7 a	50,8 ab	58,7 a	26,9 a	19,3 b	74,1 ab	84,1 a	550,7 b	93,2 b
DYT6TAZI	2,3 e	1,7 b	14 d	31,03 c	26,3 d	39,7 c	32,2 e	21,8 c	59,23 c	76,18 c	334,1 d	101,7 a
DYT7TAZI	3,2 d	1,8 b	10,2 e	28,3 cd	24,8 de	40,4 c	32 e	20,8 bc	50,3 d	75,8 c	332,7 d	104,5 a
DYT9TAZI	2,8 e	1,6 b	14 d	29,1 cd	27,8 d	46 b	30,3 d	19,4 b	57,7 cd	76,8 c	322,4 d	103,5 a
DYT10TAZI	3,1 d	1,4 b	11,4 e	25,7 d	30,3 cd	41,1 c	29,9 d	20,1 b	54,8 cd	77,2 c	282,5 e	105,2 a
DYT11TAZI	5,6 b	1,7 b	40,4 a	50,7 a	50,9 ab	58,6 a	26,6 a	18,2 ab	75,1 ab	85,5 a	528,4 b	82,9 c
DYT12TAZI	3,9 cd	1,9 b	15 d	37,8 bc	24,9 de	42 bc	32 d	20,6 bc	54,1 cd	81,9 b	457,1 c	106,2 a
DYT13TAZI	2,6 e	1,8 b	15 d	32,2 c	20,5 e	41,2 c	31,4 d	20,3 bc	44,7 e	76,5 c	318,6 d	100,7 a
DYT14TAZI	5,6 b	0,8 a	41,9 a	50,6 a	52,6 ab	57,7 a	26,5 a	19,5 b	74,2 ab	84,5 a	527,7 b	93,3 b
DYT15TAZI	4,3 c	1,7 b	14 d	35,9 bc	28,05 d	43 bc	28,9 c	20,1 bc	59,24 c	77,8 c	328,8 d	103,3 a
FERRAHI	4,7 c	1,4 b	24,8 c	39,9 b	47,9 b	54 ab	27,6 ab	18,4 ab	69,18 b	82,1 b	513,5 b	92,9 b
FARAJ	4,8 c	1,7 b	24,9 c	40,8 b	49,8 b	57,4 a	27,3 ab	19,7 b	69,44 b	82,4 b	484,4 c	106,3 a
LOUIZA	5,4 b	1,4 b	36 b	41,5 b	46,2 ab	54 ab	26,8 a	18,5 ab	69,06 b	83,9 ab	525,1 b	105,7 a
Values are expressed as the means $\pm$ standard deviation (SD) of three independent assays. Means in each column and for each season with similar letters are significantly different at $p < 0.05$ according to DMRT. Y: Year; G: Genotype, RWC (%): relative water content, LA (cm ²): leaf area, Rs (cm ² /s): Stomatal resistance, ChC (SPAD): Chlorophyll content, LT° (°C): leaf temperature, ProC (µg/100 mg): proline content.												

2.3. Effects of rainfed conditions and season on grain yield and agronomic component parameters

ANOVA results showed very large differences between genotypes and between years ($P < 0.001$) in plant height (PH) weight of 1000 seeds (WTS), spikes number per square meter (Ns/m²) and seed yield per m² (y/m²); however, the two years of this study were comparable (Table 3). Additionally, one could observe an extremely important impact of the interaction between the genotype year and all of these

parameters. PH, WTS, Ns/m², and Y/m² decreased with decreasing precipitation in all the studied durum wheat genotypes in the 2019-20 season (Figs. 1, 2, 3, and 4). DYT1TAZI had the highest values for PH, WTS, Ns/m², and Y/m² in the two cropping seasons, but the highest values observed in the 2020-21 season decreased by 32.63%, 24.48%, 31.64% and 34.5%, respectively. The lowest Y/m² and PH were registered in DYT13TAZI (143 g; 50.5 cm; p < 0.001, respectively) during the 2019-20 season, with reductions of more than 82.24% and 46.85%, respectively, compared to the second season (805 g; 95 cm; p < 0.001) (Fig. 4, 1). The lowest Ns/m² was registered in DYT10TAZI (86; p < 0.001) during the 2019-20 campaign, 78% less than in the 2020-21 second campaign (390; p < 0.001) (Fig. 3). For WTS, the lowest values were observed in DYT6TAZI (14.5 g; p < 0.001) during the 2019-20 season, with a reduction of more than 57.85% compared to the second season (34.4 g; p < 0.001) (Fig. 2).

2.4. Correlations among physiological, biochemical and yield parameters

The mean correlation coefficients among the physiological, biochemical and yield parameters investigated under unstressed and stressed water conditions show that the yield parameters are significantly (p < 0.01) associated with most physiological and biochemical parameters (Table 5). Yield per square meter (y/m²) was positively and significantly correlated with relative water content (+ 0.885), leaf area (+ 0.860), chlorophyll content (+ 0.827), plant height (+ 0.644), spikes number per square meter (+ 0.898), and weight of 1000 seeds (+ 0.882), indicating that these are the parameters that mainly explain the high yield in all the genotypes tested under contrasting water conditions. In contrast, seeds yield have been negatively affected by the correlation with leaf temperature (-0.901), stomatal resistance (-0.459) and proline content (-0.646). Our findings suggest that high grain yield under contrasting water conditions would be conditioned by high osmoregulator accumulation (proline content), high stomatal conductance and low leaf temperature.

Table 5
Correlation coefficients among physiological, biochemical and yield traits in 16 durum wheat genotypes evaluated under rainfall conditions conditions for two years 2020 and 2021.

	LA (cm ²)	Chc (Spade)	LT (°C)	RWC (%)	ProC (µg/100mg)	PH (cm)	Ns/m ²	WTS (g)	Y/m ² (g)
Rs	-0.197	-0.140	0.562**	-0.343**	0.876**	-0.261*	-0.498**	-0.211	-0.459**
LA		0.832**	-0.674**	0.804**	-0.337**	0.516**	0.730**	0.897**	0.860**
Chc			-0.723**	0.871**	-0.316**	0.500**	0.727**	0.866**	0.827**
LT				-0.842**	0.756**	-0.606**	-0.860**	-0.761**	-0.901**
RWC					-0.518**	0.577**	0.831**	0.855**	0.885**
ProC						-0.483**	-0.648**	-0.339**	-0.646**
PH							0.514**	0.521**	0.644**
Ns/m ²								0.731**	0.898**
WTS									0.882**
*, **, Significant at 0.05 and 0.01 probability levels, respectively.									
RWC (%): relative water content, LA (cm ²): leaf area, Rs (cm ² /s): Stomatal resistance, Chc (SPAD): Chlorophyll content, LT° (°C): leaf temperature, ProC (µg/100 mg): proline content, PH (cm): Plant height, Ns/m ² : Number of spike per square meter, WTS(g): Weight of 1000 seeds, Y/m ² (g): yield per square meter.									

3. Discussion

Significant genotype variation between rainfall conditions and both years may reflect changes over time that may impact plant firming in drought conditions in response to interannual variations in rainfall and temperature, resulting in changes in seed yield (Ruane et al, 2016). High inheritance and predicted genetic progress as a percentage of average were observed during the 2019-20 and 2020-21 seasons, with a 48% reduction in grain yield due to first-year drought this will become more prevalent and more seriously going forward (Yan et al., 2016). That it is essential to understand plant biochemical, physiological and yield reactions to droughts (Sallam et al., 2019). The notable impact of water deficit on plants include reduced rates of cell expansion and division, reduced germination rates, foliar areas, disordered stomata responses and a reduction in chlorophyll content (Zhao et al., 2020; McAusland et al., 2019). Furthermore, plants can get around the lack of water by reducing water exhaustion, also may inhibit the characteristics of gaseous exchanges and consequently influence the

photosynthetic ability. (Zendonadi, et al., 2021; Mathobo et al., 2017). Plants retain water levels in cells, which are generated by hydropassive or hydroactive processes by the closure of the stomata, which plays a major role in the physiological reaction of the plants to lack of water with the reduction of transpirational water losses (Zhao, et al., 2020; Murata et al., 2014). Under deficit stress, wheat photosynthesis can be impacted by the stomatal process. This study, showed that stomatal conductance was reduced by water stress, limiting photosynthesis by stomatal resistance that controlled water loss through stomatal closure, considered an early plant response to water deficit. (Nakhforoosh, et al., 2016). The stomata stay closed longer in case of water stress, which reduces carbon absorption and water loss, leaving carbon absorption at the expense of limited water supply. Closure of the stomata can also improve sensitivity to photolesions. Which are the carbon-water exchange doors takes place, stomatal conductivity and perspiration, which leads to a decrease in metabolism and agricultural production. (Muhammad, et al., 2021; Saeidi, et al., 2018). Stomatal conductance and chlorophyll content at the grain filling stage are strongly associated with superior performance (Blum, 2016). The improvement in R_s and the increase in RWC in plants could be responsible for maintaining improved net photosynthesis in restricted irrigation and mitigating the adverse impacts of water shortage stress. In this current study, drought-restricted irrigation resulted in a significant reduction in chlorophyll, LA, RWC, and R_s contents compared to those in the rainy season during the two growing periods. In addition, higher crops chlorophyll content, LA, RWC, and R_s contents were more drought resistant (Table 4). Decreased transpiration results in increased TL (Table 4). In the event of a water stress, the reduction of the foliar RWC leads to stomatal closure, which leads to a decrease in the efficacy of CO_2 , resulting in decreased transpiration. Our results show negative correlations between R_s -RWC ($r = -0.343^{**}$; Table 5), Ns/m^2 ($r = -0.498^{**}$; Table 5), Y/m^2 (-0.459^{**} ; Table 5) were observed, suggesting that RWC, Ns/m^2 , and Y/m^2 have been strongly affected by the stomatal regulation of durum wheat. Similar findings were observed in wheat subject to water deficit (Pour-Aboughadareh, et al., 2019; Arjenaki, et al., 2012). This suggests that stomatal closure with reduced photosynthesis are common plant reactions to drought (Radzikowska, et al., 2022; Pamungkas, et al., 2022). whose variation in photosynthesis may be ascribed to changes in relative water content, chlorophyll content, leaf area and leaf temperature (Khayatnezhad, et al., 2021; Balfagón, et al., 2020; Sattar, et al., 2019; Khakwani, et al., 2013). Though, we observed an important variation among genotypes for this parameter in the case of water deficiency and genotypes DYT1TAZI, DYT5TAZI, DYT11TAZI exhibited the best relative water content and stomatal conductance. Nevertheless, most interesting genotype are those having appropriate water use regulation by maintaining in dry weather, optimum stomata conductance to reduce the loss of water by transpiration without impairing the photosynthesis pathway. This would be the case for the DYT1TAZI, DYT5TAZI, and DYT11TAZI genotypes. The proline content increased significantly in the durum wheat leaves during the drought in the genotype DYT1TAZI which can be drought tolerant genotype, than in DYT10TAZI, a drought-sensitive genotype (Table 4). The higher level of proline is crucial for resistance to stress on account of the strong role played in osmotic control, enzyme structure cover, membrane stabilisation and fender of hydroxyl radicals, participates in a variety of signalling routes and ensures good growth under water stress which helps plants adapt to stress (Ghodke et al. 2018; Sourour et al. 2017) and recovery of reactive oxygen species (ROS) from the cell without interfering with normal cellular bioprocesses (Habib, et al., 2020). Thus, it protects the cell from ROS-induced cell damage and keeps proteins structure inside the cell. Our findings are identical to those for Qaseem (2019) and Du (2022). It has also been demonstrated that proline acts as a molecular manipulator, protect protein integrity and improve enzyme activities (Ghodke et al. 2018). Several researchers have noted that proline plays a positive role in osmoregulation. (Murmur et al., 2017). Du (2022) suggested that proline accumulation in plants can be implicated in several cellular processes and contribute to wheat drought tolerance.

Regarding agronomic traits, there was a remarkable effect of dryness on seed yield per m^2 with increased water deficit. What is shown by different study in wheat (Esaulko et al., 2023; Saeidi et al., 2018). Decline observed in all yield parameters in the first year, as a result of drought stress caused by low rainfall, can be explained by the reduction of the seed at filling stage and acceleration in leaf senescence. However, the tested genotypes reacted differently to drought condition, exhibiting significant variation in the extent to which damage has been caused. During the 2019-20 season, there was a 34.5-82.24% decrease in yield per square meter and a 24.4-57.85% reduction in TSW compared to the 2020-21 season. In a recent study on wheat, the drought-induced decreases in Kernels/ears, number of kernels and weight of 1000 kernels (TSW) ranged from 20–58% (Ehsanzadeh et al., 2021). The strong correlation between yield/ m^2 and Ns/m^2 and TSW indicates that the yield decrease under drought conditions is explained by the decrease induced both by the spikes number per plant and their weight. However, Zhao et al., (2020) noted that seed yield was mainly associated when a decrease in TSW. In our study, the best weight of 1000 seeds was registered in DYT1TAZI, followed by the genotypes DYT14TAZI and DYT5TAZI in the 2020-21 season (rainy season). For yield, these three genotypes have achieved better results than other genotypes not only during drought but also under well-watered conditions, suggesting their genetic potential as relevant germplasm for durum wheat breeding in environments with contrasting water conditions. Analysis correlation indicated that the performance was strongly related to RWC. ($r = .885$), leaf area ($r = .860$), chlorophyll content ($r = .827$), while it was adversely related to leaf temperature, proline content and stomatal resistance. Taking into account the ability to rapidly pinpoint these three parameters in field experiments using appropriate scientific equipment, we can suggest the same breeding indices for use in durum wheat selection for drought tolerance in semiarid climates.

4. Conclusion

Dry conditions reduced the studied physiological parameters and increased biochemical parameters. Physiological and metabolic responses differ considerably from genotype to genotype. Considering on overall physiological and metabolic responses, there was an increasing tendency to fill water scarcity with greater potential for resistance to water stress observed in DYT1TAZI, followed by genotypes DYT14TAZI and DYT5TAZI. The present findings suggest that while the commonly wheat genotypes used have a relatively close genetic variation, they can use various metabolic strategies to adjust to water stress situations. That could provide useful information for durum wheat in future selection programs for drought tolerance.

Declarations

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Conflict of interests

The Submitters have pointed out that they have no conflict of interests.

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Authors' contributions statements

Imane Saghour el idrissi, Rajae Kettani, Moha Ferrahi, Abdelghani Nabloussi, Rabea Ziri and Najiba Brhadda contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors reviewed the final manuscript.

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Figures

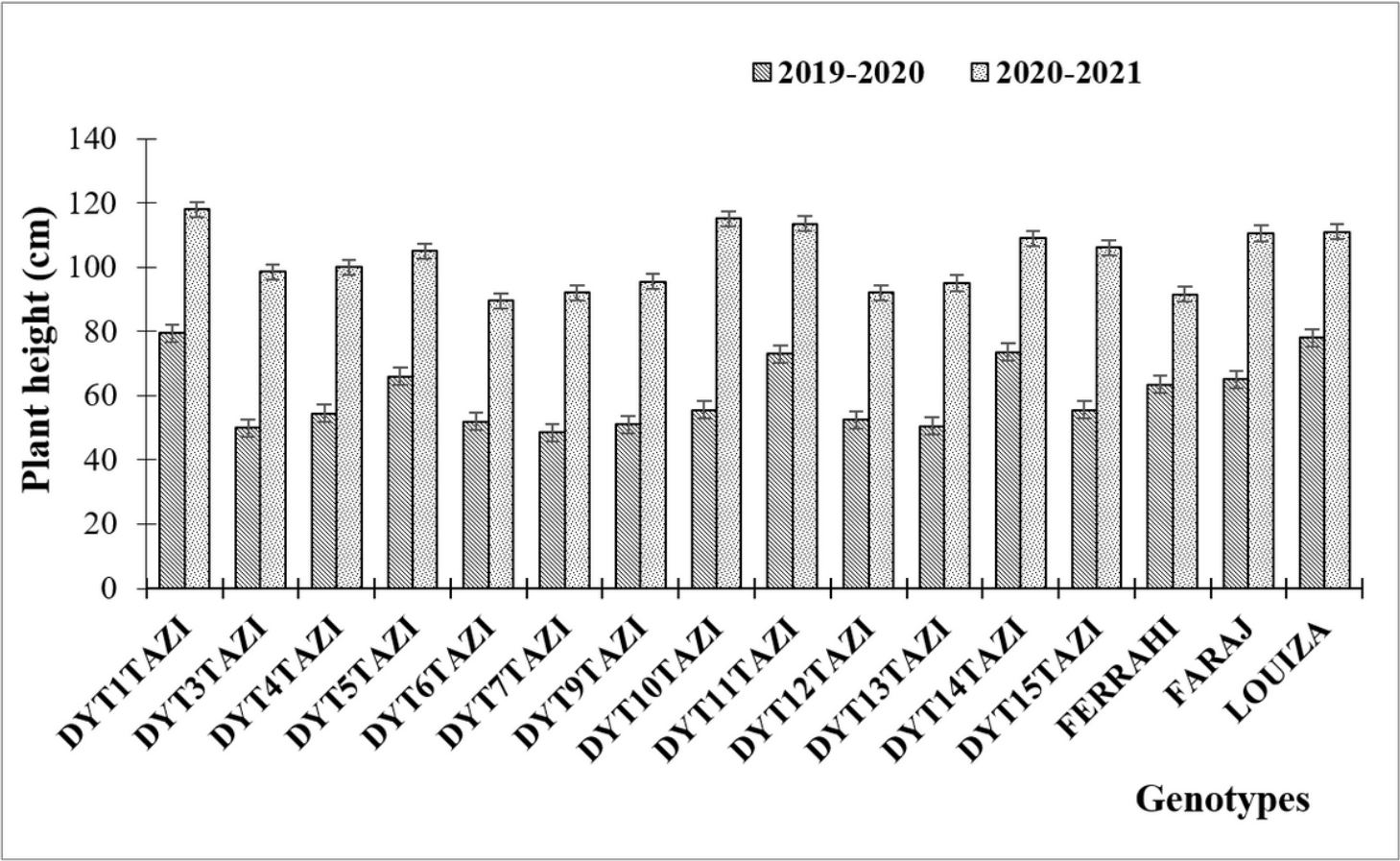


Figure 1

Effects of rainfall conditions and season on plant height (cm) in 16 durum wheat genotypes during 2019–2020 and 2020–2021 growing seasons

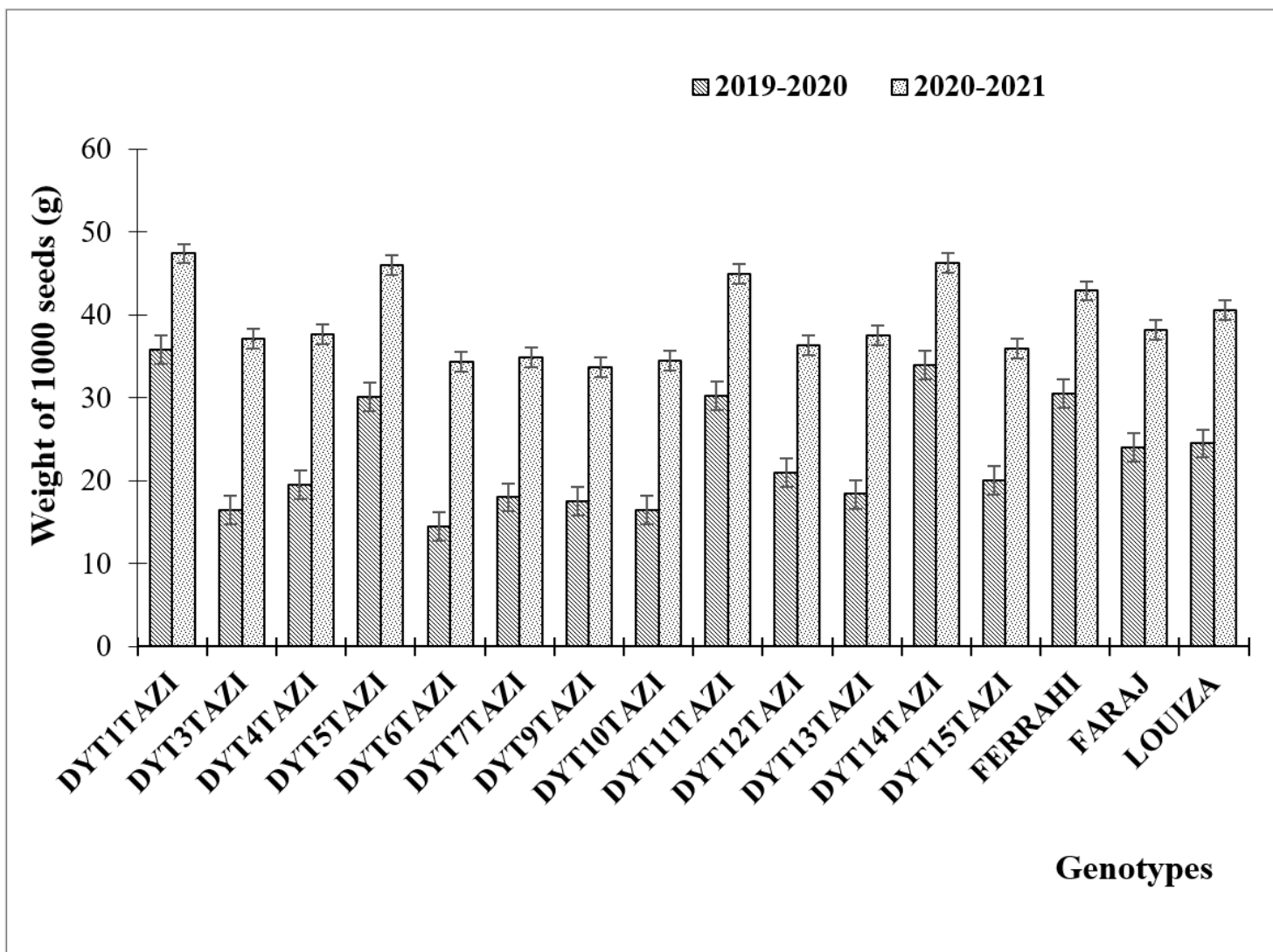


Figure 2

Effects of rainfall conditions and season on weight of 1000 seeds (g) in 16 durum wheat genotypes during 2019–2020 and 2020–2021 growing seasons

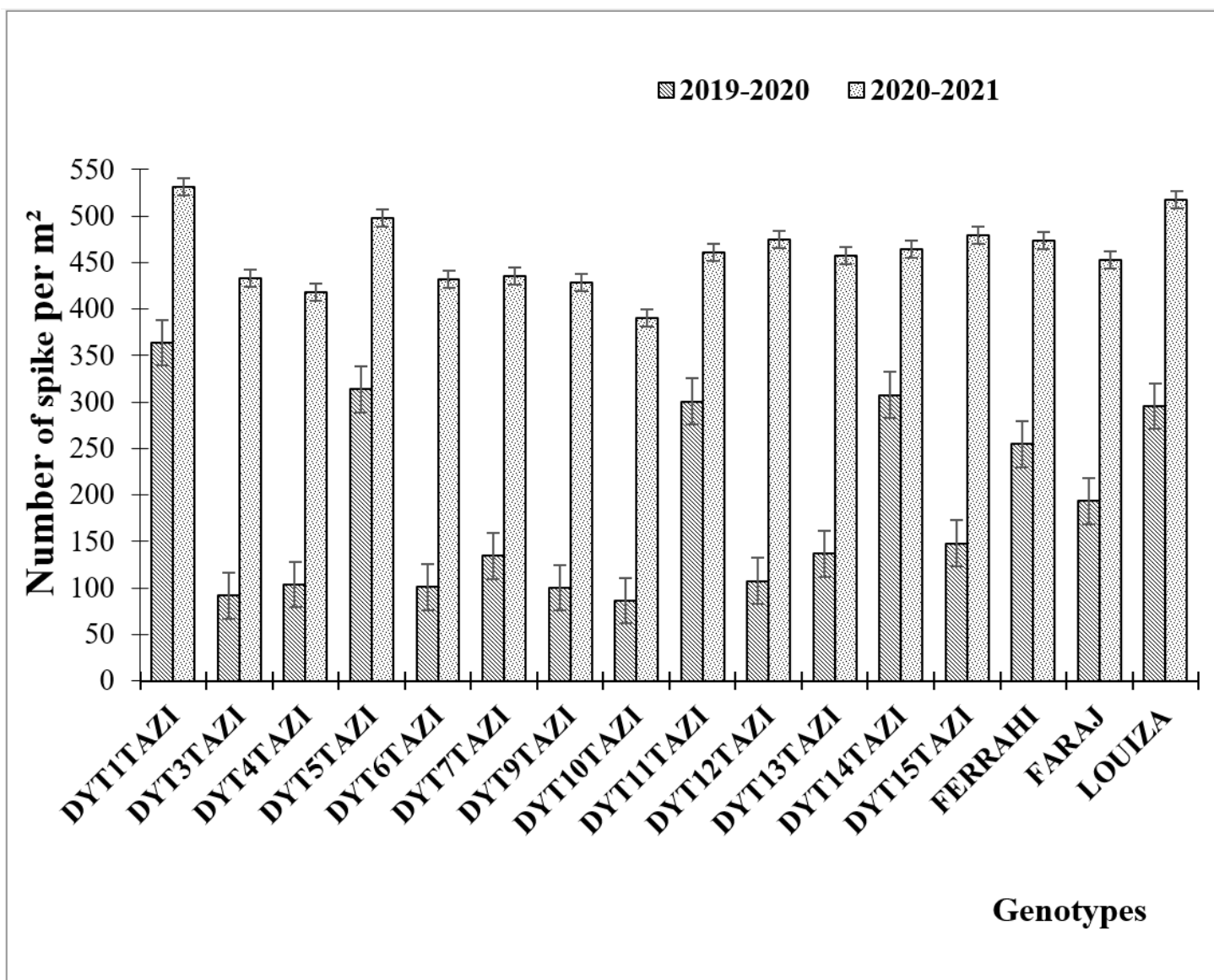


Figure 3
Effects of rainfall conditions and season on number of spike per m² in 16 durum wheat genotypes during 2019–2020 and 2020–2021 growing seasons

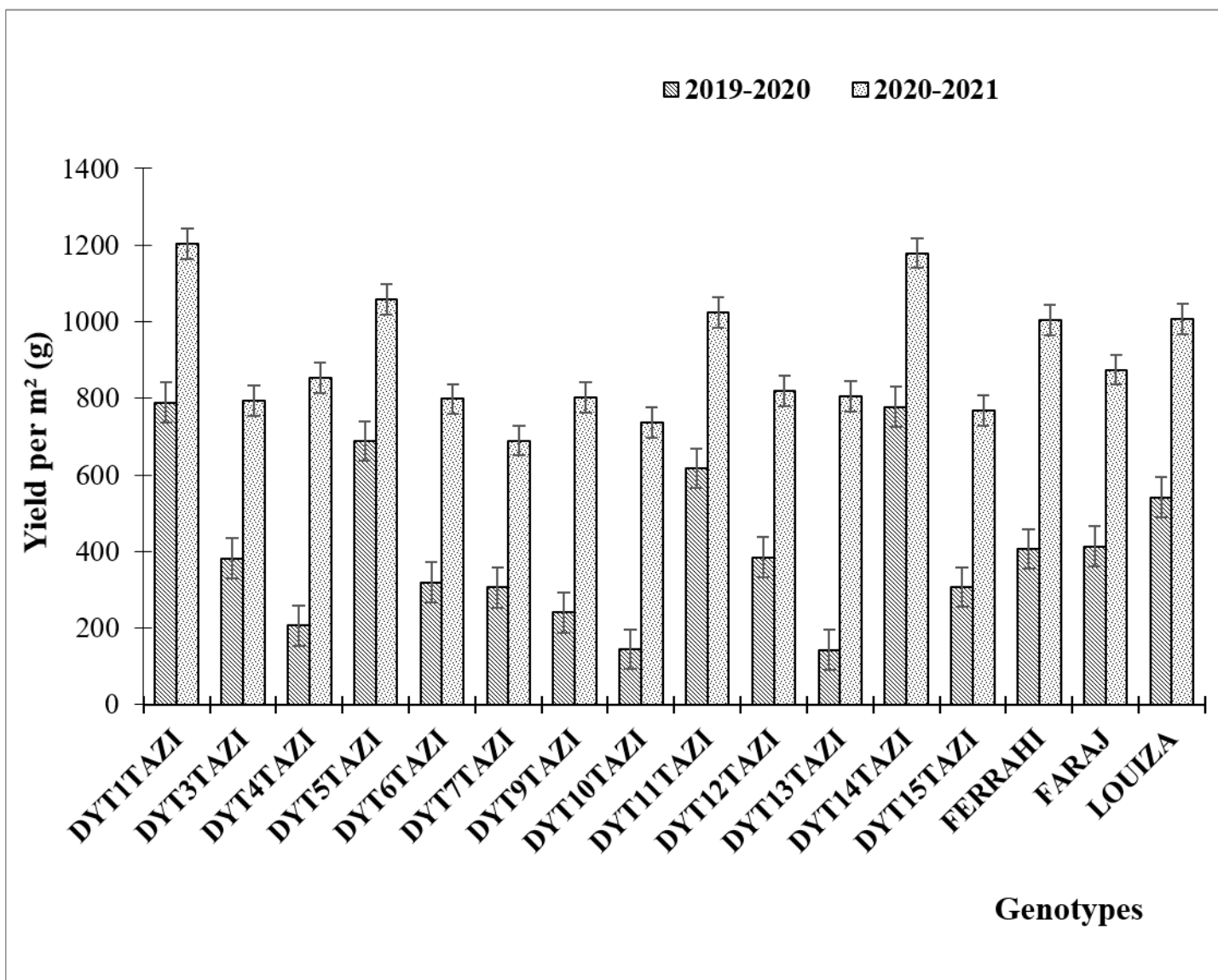


Figure 4

Effects of rainfall conditions and season on yield per m² (g) in 16 durum wheat genotypes during 2019–2020 and 2020–2021 growing seasons