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Research Article

Performance of fourteen genotypes of durum wheat under Eastern Mediterranean conditions

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Abstract

Durum wheat is used as raw material for many foods. Climate change might be responsible for larger or smaller changes in crop yields. For the combined assessment of climate and crop, growing degree days (GDDs) have a crucial role. Two experimental lines and twelve commercial wheat (*Triticum durum*) varieties from diverse backgrounds were cultivated to compare their crop properties, yield, and protein content in terms of GDDs. The experiment was established in typical Mediterranean environment, using a randomized complete block design with blocks of varieties and lines for two growing seasons. For all varieties, GDDs to head emergence was affected by factor year, whereas GDDs from head emergence to harvest were influenced by both varieties and year. Protein content (%) was not affected by genotypes. Factor of variety and interaction variety × year had an impact on vitreousness; it was ranged from 79.75 % ('Makaras' variety) to 44.00 % ('Levante' variety). Yield had no statistically significant difference among varieties/lines. In durum wheat cultivation, up to head emergence, when GDDs increased, yield would be declined in contrast to GDDs from emergence to harvest; with the increasing of GDDs to harvest, yield was climbed. Nowadays, the integrations of and interpretation of GDDs in the evaluation of crop performance seem vital.

Keywords: durum wheat varieties; GDDs; protein content; relative production efficiency; vitreousness

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Introduction

Wheat constitutes one of the most cultivated cereals around the world and possess second place after maize (Alfonzo *et al.*, 2020). The major importance of wheat among cereals attributed to its versatility of grain for the preparation of various foods (Peña-Bautista *et al.*, 2017) and to its nutritional value in the human diet (Pomeranz, 1987; Braun *et al.*, 2010). All European countries cultivate wheat (FAOSTAT, 2017), while the Mediterranean countries produce more than 38% of the global durum wheat production (IGC, 2017). Tetraploid durum wheat species are particularly important for the agricultural sector of the Mediterranean due to their economic impact on the global market. Furthermore, adaptation to special climatic and territorial conditions of the Mediterranean basin is essential. Now-adays, there is an increasing interest in durum wheat crop in virtue of serious abiotic threats on yields and quality of products which come from climatic change.

In many countries, main components of diets are derived from refined cereals and their derivatives. (Turnbull and Rahman, 2002). Durum wheat is customarily cultivated for pasta formation. Durum wheat semolina is considered the perfect raw material for making pasta due to its hardness and vitreousness (Vaquero *et al.*, 2017). In addition, durum wheat flour is used to produce flat breads, couscous, and bulgur mainly in the Middle East and North Africa (Beres *et al.*, 2020).

Most of these products are of utmost importance in human nutrition on account of calories and bioactive components, such as dietary fibers, phytochemicals, and micro-nutrients (Hernandez-Espinosa *et al.*, 2020). In addition, durum wheat grain is rendered as an important protein source. Quality of final food products is defined from grain protein content (Kaur *et al.*, 2015; Nigro *et al.*, 2020). The higher is protein content and gluten strength of semolina, the higher quality product will be produced (Beres *et al.,* 2020).

Although durum wheat is one of the earliest domesticated crops (Mefleh *et al.*, 2019), grain yield and quality are strongly affected by variability of environmental conditions during the growing season (Porter and Semenov, 2005). Size and nature of damage are determined by the development stage at which the durum wheat experiences the stress (Saini and Westgate, 1999). High air temperatures in the range of 30-40 °C during the key reproductive stages, i.e., anthesis and grain-filling are the major climatic limitation for durum wheat yield (Ferrise *et al.*, 2015). Regarding the typical climate of the Mediterranean, heat stress, which is provoked by drought, is usually sharpened by water scarcity, and causes even more negative results on yield (Asseng *et al.*, 2011); namely, rising temperatures during flowering could influenced yield components. In addition, heat stress leads to reduction of photosynthetic flux and augmentation of respiration. Thus, accumulation of stored reserves is restrained (Álvaro *et al.*, 2008). As a result, remobilization, and assimilation of stored reserves from the grain are limited during the grain-filling (Mendanha *et al.*, 2020).

In most self-pollinated crops, increased temperatures lead to pollen sterility, pollen germination losses, and floral asynchrony during anthesis (Dupuis and Dumas, 1990). Therefore, the grain number is reduced (Ji *et al.*, 2010), while heat stress during grain filling provokes the reduction in grain size (Abid *et al.*, 2016). Besides, starch deposition is affected by high temperature and grain weight is decreased. In particular, conversion of sucrose is impaired by heat stress and starch synthesis is restricted (Bhullar and Jenner, 1985). Concerning grain protein content, high temperature during grain filling causes decreases in kernel weight, while protein concentration rises (Jenner, 1994; Correll *et al.*, 1994). High temperature during grain filling also affects gluten strength (Corbellini *et al.*, 1997). Randall and Moss noticed that the strength of wheat gluten increased under heat stress (Randall and Moss, 1990). Increasing of drought is simultaneously occurred with grain filling in cereal crops during the late spring in the Mediterranean region (Araus *et al.*, 2002). Consequently, further yield improvement is needed through changes in crop development.

It is essential to determine the temperature demands in each phenological stage in order to account for losses of durum wheat yield under drought (Ayed *et al.*, 2016). Temperature could be used to estimate wheat yield (White and Reynolds, 2003; Tack *et al.*, 2015). Due to the interaction between temperature (environment) and plant growth stages, growing degree-days (GDDs) are regularly connected with crop growth estimation and performance. GDD differs through each growing stages and phenological stages., due to their sensitivity to drought and temperatures. For instance, temperature during head emergence has a crucial on flowering. If this critical threshold is overcome, yield will be negatively affected (Prasad *et al.*, 2017). In addition, GDD depends on genotype and are varied even in the same crop (Porter and Gawith, 1999; Trudgill *et al.*, 2005). Therefore, GDD is a useful indicator which allows estimation of the exact sowing date and growing stage in several areas (McMaster *et al.*, 2012).

An economic indicator is needed to evaluate completely crop success. Relative Production Efficiency (RPE) is one of these economic indicators. RPE indicates the possibilities of the cultivation compared to the existing data. This indicator compares crops and production systems and is mostly affected by yields. Besides, in case of experimental varieties and lines, RPE gives information on the potential profits (Kakabouki *et al.*, 2020).

The purpose of the present study is the evaluation of the effects of genotype and year on durum wheat crop under the East Mediterranean conditions. As there is a shortage of researches on the quality of durum wheat yield, this study focused especially on the yield and quality features of the crop in Greece. Fourteen advanced varieties and lines, in particular, were compared in order to distinguish the most high-yielding. Furthermore, correlation between growth characteristics and GDDs was investigated under the Mediterranean drought.

Materials and Methods

Experimental design

During the growing seasons 2018-2020, two field experiments were conducted in an experimental area located near Larissa (Latitude: 39° 29' 17.2" N, Longitude: 22° 21' 22.8" E, Altitude: 120 m) in Central Greece. The experimental year A refers to the vegetative season 2018-2019 and the experimental year B to the vegetative season 2019-2020. Two advanced lines ('APSD23' and 'APSD24') of wheat and twelve durum wheat varieties ('Svevo', 'Meridiano', 'Reale', 'Odisseo', 'Prospero', 'Levante', 'Normanno', 'SY Atlante', 'Marakas', 'Pigreco', 'SY Leonardo' and 'Iride') were compared regarding agronomic and quality traits. Soil properties (at 0-25 cm sampling depth) of the experimental plots are depicted in Table 1. The soil was clay (C) and the pH value was 7.4. The previous crop was cotton. The mean temperature and the cumulative precipitation per month are presented in Figure 1.

Table 1. Soil properties in the experimental site

Physical composition (%)		**Exchangeable bases (cmol kg^{-1})**	
Sand	23	Na	0.37
Silt	24	K	1
Clay	53	Ca	28
Textural class	C		
Chemical characteristics			
pH (H_2O 1:1) (25 °C)	7.4	Total N (Kjeldahl) (g/100g)	0.11
Organic Matter (%)	1.4	$CaCO_3$	1
EC	524	(P_{Olsen}) (mg/kg)	15

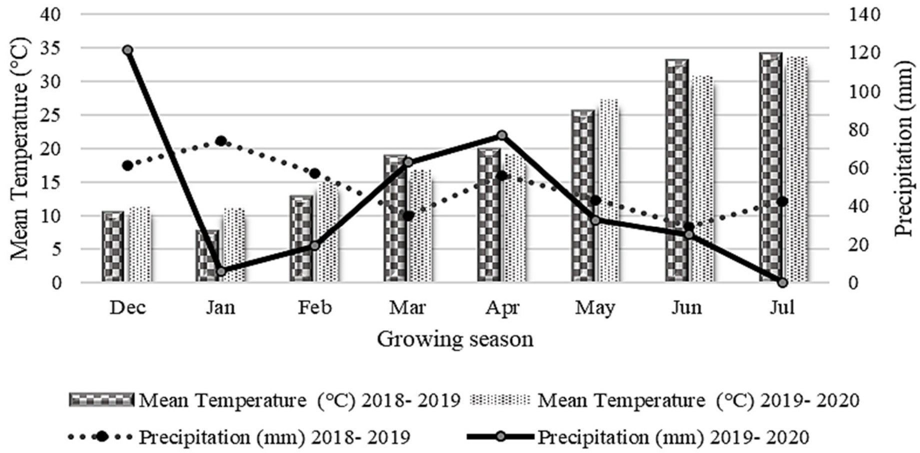

Figure 1. Meteorological data at the experimental area for growing seasons 2018-2019 and 2019-2020
Total annual precipitation was 399 mm and 343 mm for the two consecutive experimental years 2018-2019 and 2019-2020, respectively.

The field experiment was arranged in randomized complete block design, where blocks were varieties and lines. The total acreage of the experimental area was 1.680 m^2 divided in 4 blocks with 14 plots each (each plot was 1.5 m × 20 m). Sowing took place in 12th December 2018 and 19th December 2019 utilizing a HALDRUP SB-25 plot seeder (Haldrup USA Corp., Ossian, IN, USA) with a seeding rate adjusted to 420 viable seeds m^2. Each plot divided in 10 rows with 15 cm spacing between them. The soil tillage included a deep ploughing at a depth of 40 cm followed by a disc harrowing. The plots were properly fertilized with 230 kg ha^{-1} di-ammonium phosphate (18-46-0) as basic fertilization and 250 kg ha^{-1} of urea and ammonium sulfate (40-0-0) in top-dressing at tillering (20, BBCH scale). Additional irrigation was not applied. In both experimental years weed management was conducted through a single application with herbicide mixture of 2,4-D 28% and bromoxynil 28% (Brominal Nuevo/Bayer) at tillering stage of wheat. Head emergence of each variety/line in specific days after sowing (DAS) are presented in Table 2. A HEGE 140 plot harvester (Hege Company, Waldenburg, Germany) was used at harvest 215 DAS (2865.8 GDD in year A) and 201 DAS (2651.3 GDD at harvest in year B).

Table 2. Days After Sowing (DAS) to head emergence for each line and variety

Lines/variety	Days After Sowing	
	Year	
	2018	2019
‘Svevo’	130	129
‘Meridiano’	132	132
‘Reale’	132	132
‘Odisseo’	136	136
‘Prospero’	133	133
‘Levante’	130	130
‘Normanno’	134	134
‘SY Atlante’	133	133
‘Marakas’	131	132
‘Pigreco’	133	132
‘SY Leonardo’	131	131
‘APSD24’	135	135
‘Iride’	131	131
‘APSD23’	131	132

Plant materials

Field trials included twelve varieties and two advanced lines (‘APSD23’ and ‘APSD24’). ‘Svevo’, ‘Reale’, ‘Odisseo’, ‘Levante’, ‘Normanno’, ‘SY Atlante’, ‘Pigreco’, ‘SY Leonardo’ and ‘Iride’ are owned by Syngenta (Syngenta International AG, Basel, Switzerland). ‘Meridiano’ is owned by Alfa Seeds (Alfa Seeds SA, Larissa, Greece). ‘Prospero’ and ‘Marakas’ are owned by Florimont, while the two advanced lines of wheat are being developed by APSOV (APSOV sementi s.p.a., Voghera, Italia). ‘Meridiano’, ‘Svevo’ and ‘Iride’ are common varieties under Greek farming conditions and were used as check varieties to compare and estimate the productivity index of the remaining durum wheat varieties and lines.

Sampling and analytical methods

Total protein content (%), moisture content (%) and grain specific weight (kg hl^{-1}) were determined using the Infratec™ 1241 Grain Analyzer (FOSS, Eden Prairie, MN, USA, Serial no.:12417239) after harvest with moisture content 13%. Scanning temperature was set between 21-25 °C. The absorption wavelength range of the samples was 850-1050 nm. Thousand kernel weight (TKW) was determined by using a subsample of the harvested grain from each plot. Vitreousness was measured by using a 50-socket seed cutter and counting the number of seeds with vitreous endosperm, expressed as percentage. Ratio of vitreousness and protein content was also calculated.

Yield measurements included total protein yield (t ha^{-1}) and total grain yield (t ha^{-1}). Tillering, fungi infection and vigour were recorded according to visual estimations and ratings and their range was: 1=low, 5=high. These initial assessments were based on colour distribution, size, and shape comparisons between healthy and poor plants. The rating system was assigned by a researcher with experience in cultivation. Tillering was measured at 60 DAS, while fungi infection and vigour were measured at 60, 75, and 90 DAS, respectively, and the values refer to the mean value of all three observations.

Calculations and statistical analysis

Head emergence was recorded in both years of investigation during the growth stages of durum wheat, based on growing degree days (GDDs) which were calculated by using Equation (1) on a daily basis (Peterson, 1965) with a base temperature of 0°C (Al-Karaki, 2012; Fatima *et al.*, 2020).

$$GDD = \left(\frac{T_{max}+T_{min}}{2}\right) - T_b \qquad (1)$$

Tmax & Tmin = Maximum and minimum daily air temperature respectively in °C

Tb = Minimum base temperature (threshold temperature) for durum wheat (°C), Tb = 0.0 °C

GDDs recordings conducted both from sowing to head emergence and from the latter growth stage to harvest.

Relative production efficiency (%) was used as index of productivity by comparing the durum wheat varieties yield with the mean yield of check varieties, using Equation (2).

$$Relative\ Prod.Efficiency\ (\%) = \left(\frac{Yield\ wheat - Yield\ check\ varieties}{Yield\ check\ varieties}\right) * 100 \qquad (2)$$

Yield wheat = mean yield for each line and wheat variety

Yield check varieties= mean yield of most common cultivated varieties ‘Meridiano’, ‘Svevo’, ‘Iride’ (7.11 t ha^{-1}) in the first experimental year and 4.94 t ha^{-1} in the second experimental year)

Analysis of variance was conducted for all data using Statistica software (2011) logistic package as RCBD. Fisher’s least significant difference (LSD) test was used. Correlation coefficients and linear regression were carried out using the Statistica software and were set at two levels with significance (p= 0.05) and remarkable significance (p= 0.01).

Results

Head emergence varied significantly among genotypes in both experimental years, but the effect of year was not significant, since head emergence was ranged between 129 and 136 DAS (Table 3). 'Svevo' and 'Levante' varieties showed the earliest head emergence in both experimental years. The highest values were recorded in 'Odisseo' variety; this variety had statistically significant differences in almost all varieties and one advanced line.

Regarding GDDs until head emergence, values during vegetative season 2019-2020 (year B) were remarkably higher than the values being recorded in previous experimental year. This fact is indicated that mean monthly temperature was higher in the second year (Table 1). Nevertheless, no statistically significant differences were observed between years (Table 3). 'Svevo' and 'Levante' varieties had statistically significant differences among varieties/lines in two consecutive growing periods, marking the lowest values 1016-1018.9 °C days in year A and 1105.4-1118.1 °C days in year B, respectively. 1102.7 °C days and 1229.2 °C days was required from 'Odisseo' variety in order to reach head emergence in year A and year B, respectively. Concerning GDDs from head emergence to harvest, it is observed that values in the first experimental year were statistically higher than those in second year at $p<0.001$ significance level (Table 3).

In year A, the highest value was recorded in variety 'Svevo' with 1849.8 °C days and the lowest was reported in 'Odisseo' variety, 1763 °C days. The same pattern was observed in the second experimental year. Rest of varieties and advanced lines showed moderate variance between years regarding GDDs until head emergence and then, until harvest.

Thousand kernel weight was measured for each variety/line and statistically significant differences were noticed between experimental years and among varieties/lines (Table 3). The highest values were attributed to 'SY Leonardo' variety in first year, re-cording 58.2 g, and to 'Marakas' variety in second year with 48.32 g per one thousand kernels. On the contrary, the lowest values were recorded in Levante variety in year A (39.93 g) and 'SY Atlante' in year B (33.95 g). Some high yielding varieties in the first experimental year ('Svevo', 'Reale', 'SY Atlante') faced high reductions in thousand kernels weight in contrast to second experimental year. The advanced lines APSD23 and APSD24 relatively maintained standard values in both years.

Table 3. Agronomic and grain quality characteristics of each variety and line

Variety / Line	Head emergence (DAS)	GDDs to head emergence	GDDs head emergence to harvest	1000 kernel weight (g)	Grain Specific Weight (kg hl^{-1})
Year A					
'Svevo'	129.50^{cd}	1016^{f}	$1849,8^{d}$	47.00^{bc}	80.45^{ab}
'Meridiano'	132.25^{b}	$1051,6^{d}$	$1814,2^{b}$	41.97^{c}	78.05^{c}
'Reale'	132.25^{b}	$1051,4^{d}$	$1814,3^{b}$	49.1^{b}	81.72^{a}
'Odisseo'	135.5^{a}	$1102,7^{a}$	1763^{a}	44.1^{c}	79.1^{b}
'Prospero'	132.75^{b}	1058^{cd}	$1807,8^{ab}$	43.45^{cd}	78.9^{bc}
'Levante'	129.75^{cd}	$1018,9^{f}$	$1846,9^{cd}$	39.93^{d}	79.3^{b}
'Normanno'	134.25^{a}	$1081,1^{b}$	$1784,7^{a}$	45.6^{c}	78.3^{c}
'SY Atlante'	132.75^{b}	$1059,6^{c}$	$1806,1^{ab}$	48.05^{bc}	77.72^{d}
'Marakas'	130.75^{c}	$1031,5^{e}$	$1834,3^{c}$	54.1^{a}	78.53^{c}
'Pigreco'	132.75^{b}	$1061,4^{c}$	$1804,3^{ab}$	44.87^{c}	76.15^{d}
'SY Leonardo'	130.5^{c}	$1029,1^{e}$	$1836,7^{c}$	58.2^{a}	78.8^{c}
'Iride'	130.75^{c}	$1031,5^{e}$	$1834,3^{c}$	42.45^{cd}	77.95^{cd}
'APSD23'	132.25^{b}	$1051,6^{d}$	$1814,2^{b}$	48.02^{b}	79.22^{b}
'APSD24'	134.75^{a}	$1090,1^{a}$	$1775,6^{a}$	46.95^{bc}	78.3^{c}

Variety / Line	Head emergence (DAS)	GDDs to head emergence	GDDs head emergence to harvest	1000 kernel weight (g)	Grain Specific Weight (kg hl^{-1})
Year B					
'Svevo'	129.00^{d}	1105,4^{f}	1545,9^{d}	41.05^{c}	79.72^{c}
'Meridiano'	132.25^{bc}	1162,5^{d}	1488,7^{c}	39.95^{c}	78.55^{d}
'Reale'	132.25^{bc}	1162,6^{d}	1488,6^{c}	41.95^{bc}	81.18^{a}
'Odisseo'	136^{a}	1229,2^{a}	1422^{a}	46.05^{a}	78.35^{d}
'Prospero'	133.25^{b}	1180,9^{c}	1470,4^{c}	37.3^{d}	78.05^{d}
'Levante'	129.75^{cd}	1118,1^{f}	1533,2^{d}	37.02^{d}	79.30^{c}
'Normanno'	134.25^{b}	1198,8^{c}	1452,4^{b}	39.67^{c}	78.90^{d}
'SY Atlante'	132.75^{bc}	1171,6^{b}	1479,7^{c}	33.95^{d}	80.10^{b}
'Marakas'	131.75^{bc}	1153,7^{d}	1497,6^{d}	48.32^{a}	78.42^{d}
'Pigreco'	131.75^{bc}	1154,2^{de}	1497,1^{de}	39.75^{c}	76.62^{e}
'SY Leonardo'	130.5^{b}	1131,6^{e}	1519,7^{e}	42.20^{bc}	81.20^{a}
'Iride'	130.75^{c}	1135,2^{e}	1516,1^{e}	40.97^{c}	80.52^{b}
'APSD23'	132.25^{bc}	1162,5^{d}	1488,7^{c}	46.57^{a}	78.80^{cd}
'APSD24'	135.00^{a}	1211,6^{ab}	1439,7^{ab}	44.62^{b}	77.78^{e}
$F_{variety}$	11.54***	12.25***	11.856***	1064.21***	8.30***
F_{year}	ns	ns	6203.971***	7604.38***	ns
$F_{variety \times year}$	ns	ns	ns	450.48***	2.36*

F-test ratios are from ANOVA. Different letters within a column and growing season indicate significant differences between varieties and lines according to Fisher's LSD test. Significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns, not significant ($p > 0.05$).

Concerning hectolitre weight, in 'Reale' variety was showed the highest record in the first year (81.72 kg hl^{-1}), while it had statistically significant differences with the remaining varieties and lines in both years, except of 'Svevo' variety in year A and 'SY Leonardo' variety in year B, which marked the highest value (81.20 kg hl^{-1}) (Table 3). The lowest values per year were recorded in 'Pigreco' variety (76.15 and 76.62 kg hl^{-1} in the first and second year, respectively) which had statistically significant differences in the rest of durum wheat genotypes.

Moisture content (%) of kernels at harvest ranged 8.5-9.50 % in year A and 8.67-9.22 % in year B, displaying statistically significant differences among varieties/lines (Table 4). In Levante variety was recorded the identical moisture content in both years (9.22%). The lowest values were attributed to check varieties 'Iride' (8.5%) in the first growing season and 'Meridiano' (8.67%) in the second growing season.

Vitreousness recordings revealed significant differences at p=0.001 significance level among wheat genotypes (Table 4). In year A, 'Marakas' variety had the highest vitreous content (79.75%), whereas in year B 'Svevo' variety performed 79.5% vitreousness. Protein content was not statistically differed across years and wheat genotypes (Table 4). The lowest values were recorded in 'Odisseo' variety (12.48%) in the first experimental year and in 'Iride' variety (11.75%) in the second experimental year. During this two-year study 'Svevo' variety had the highest grain protein content; 14.05% and 13.88%, respectively. The ratio of vitreousness/protein differed among varieties (Table 4). In the first year, 'Normanno' variety had the highest ratio (6.02), while in the second year this was observed in 'Iride' variety (6.36).

Table 4. Quality characteristics of grain of each variety and line

Variety/Line	Moisture content (%)	Vitreousness (%)	Protein (%)	Vitreousness/Protein (ratio)
Year A				
'Svevo'	8.52^{d}	75^{b}	14.05	5.34^{bc}
'Meridiano'	8.82^{c}	77.25^{ab}	12.93	5.98^{d}
'Reale'	8.90^{b}	70.75^{c}	13.05	5.42^{c}
'Odisseo'	9.22^{ab}	65^{d}	12.48	5.21^{b}
'Prospero'	9.50^{a}	75.25^{b}	13.05	5.77^{cd}
'Levante'	9.22^{ab}	69^{c}	13.30	5.19^{b}
'Normanno'	9.37^{ab}	76.5^{b}	12.70	6.02^{d}
'SY Atlante'	9.05^{b}	75.75^{b}	12.83	5.91^{d}
'Marakas'	9.30^{ab}	79.75^{a}	13.34	5.98^{d}
'Pigreco'	9.37^{ab}	79.25^{a}	13.30	5.96^{d}
'SY Leonardo'	9.05^{b}	71.00^{c}	12.68	5.60^{cd}
'Iride'	8.50^{d}	61.25^{d}	13.00	4.71^{a}
'APSD23'	8.97^{b}	69.75^{c}	13.28	5.25^{b}
'APSD24'	8.7^{0c}	64.00^{d}	13.20	4.85^{a}
Year B				
'Svevo'	8.80^{c}	79.50^{a}	13.88	5.73^{b}
'Meridiano'	8.67^{d}	75.50^{c}	12.55	6.02^{b}
'Reale'	8.95^{bc}	69.75^{e}	12.45	5.60^{b}
'Odisseo'	9.10^{ab}	77.5^{b}	13.20	5.87^{b}
'Prospero'	8.85^{c}	73.00^{de}	13.08	5.58^{b}
'Levante'	9.22^{a}	44.00^{f}	13.35	3.30^{a}
'Normanno'	9.07^{b}	77.50^{b}	13.50	5.74^{b}
'SY Atlante'	9.15^{a}	75.75^{c}	12.28	6.17^{c}
'Marakas'	9.07^{b}	71.50^{d}	13.30	5.38^{b}
'Pigreco'	8.92^{bc}	76.00^{bc}	13.43	5.66^{b}
'SY Leonardo'	9.00^{b}	78.50^{a}	13.03	6.03^{bc}
'Iride'	8.97^{bc}	74.75^{b}	11.75	6.36^{c}
'APSD23'	9.12^{ab}	73.50^{e}	12.25	5.42^{b}
'APSD24'	8.95^{bc}	65.00^{e}	12.00	6.00^{bc}
$F_{variety}$	2.11*	26.26***	ns	7.599***
F_{year}	ns	ns	ns	ns
$F_{variety \times year}$	ns	16.37***	ns	6.236***

F-test ratios are from ANOVA. Different letters within a column and growing season indicate significant differences between varieties and lines according to Fisher's LSD test. Significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns, not significant ($p > 0.05$).

Table 5. Yield, protein yield and relative production efficiency in each variety and line

Variety/ Line	Yield (t ha^{-1})	Protein yield (t ha^{-1})	Relative Production Efficiency
Year A			
'Svevo'	6.99^{a}	0.98^{a}	
'Meridiano'	7.18^{a}	0.93^{a}	
'Reale'	7.86^{a}	1.03^{a}	10.61^{a}
'Odisseo'	7.043^{a}	0.88^{a}	-0.94^{a}
'Prospero'	7.54^{a}	0.98^{a}	6.06^{a}
'Levante'	7.14^{a}	0.95^{a}	0.41^{a}
'Normanno'	7.36^{a}	0.93^{a}	3.53^{a}
'SY Atlante'	6.90^{a}	0.89^{a}	-2.93^{a}
'Marakas'	6.55^{a}	0.87^{a}	-7.87^{a}
'Pigreco'	6.75^{a}	0.90^{a}	-5.07^{a}
'SY Leonardo'	7.09^{a}	0.90^{a}	-0.33^{a}
'Iride'	7.17^{a}	0.93^{a}	
'APSD23'	6.61^{a}	0.88^{a}	-6.92^{a}
'APSD24'	7.40^{a}	0.98^{a}	4.11^{a}
Year B			
'Svevo'	4.87^{b}	0.68^{b}	
'Meridiano'	5.21^{b}	0.65^{b}	
'Reale'	4.44^{b}	0.55^{b}	-10.17^{b}
'Odisseo'	4.24^{b}	0.56^{b}	-14.23^{b}
'Prospero'	5.19^{b}	0.68^{a}	5.01^{b}
'Levante'	4.83^{b}	0.64^{b}	-2.31^{b}
'Normanno'	4.38^{b}	0.59^{b}	-11.26^{b}
'Sy Atlante'	5.00^{b}	0.61^{b}	1.13^{b}
'Marakas'	4.59^{b}	0.61^{b}	-7.09^{b}
'Pigreco'	4.23^{b}	0.57^{b}	-14.34^{b}
'SY Leonardo'	4.58^{b}	0.60^{b}	-7.33^{b}
'Iride'	4.74^{b}	0.56^{b}	
'APSD23'	4.50^{b}	0.55^{b}	-8.87^{b}
'APSD24'	4.29^{b}	0.51^{b}	-13.25^{b}
$F_{variety}$	ns	ns	ns
F_{year}	422.69***	291.41***	10.649**
$F_{variety \times year}$	ns	ns	ns

F-test ratios are from ANOVA. Different letters within a column and growing season indicate significant differences between varieties and lines according to Fisher's LSD test. Significance levels: * p < 0.05; ** p < 0.01; *** p < 0.001; ns, not significant (p > 0.05).

Yield had no statistically significant difference among varieties/lines, as opposed to the year that had a statistically significant effect to the yield (Table 5). The highest value was 7.86 t ha^{-1} in 'Reale' variety, in year A, while 'Meridiano' presented the highest value (5.21 t ha^{-1}) during year B. The lowest values were recorded in 'Marakas' (6.55 t ha^{-1}) and 'Pigreco' (4.23 t ha^{-1}) varieties in year A and year B, respectively.

Moreover, protein yield showed a non-significant trend in response to varieties/lines, whereas it was significantly ($p<0.05$) affected by years (Table 5). In 'Reale' variety was reported the highest values (1.03 t ha^{-1}) in year A, while during the year B, in 'Prospero' and 'Svevo' was noticed the highest protein yield (0.68 t ha^{-1}) but with no significant differences with 'Meridiano' variety.

Table 6. Tillering, fungi infection, and vigour in each variety and line

Variety/Line	Tillering (1=low, 5=high)	Fungi Infection (1=low, 5=high)	Vigour (1=low, 5=high)
Year A			
'Svevo'	4^{a}	1.75^{c}	4.25^{f}
'Meridiano'	4^{a}	1.25^{a}	4.50^{g}
'Reale'	4^{a}	1.75^{c}	3.50^{c}
'Odisseo'	3^{b}	1.25^{a}	3.75^{d}
'Prospero'	4^{a}	1.25^{a}	3.75^{d}
'Levante'	3^{b}	1.75^{c}	3.75^{d}
'Normanno'	4^{a}	2.00^{d}	3.50^{c}
'SY Atlante'	3^{b}	2.50^{e}	3.25^{b}
'Marakas'	3^{b}	1.75^{c}	3.00^{a}
'Pigreco'	3^{b}	1.25^{a}	3.75^{d}
'SY Leonardo'	4^{a}	1.50^{b}	4.00^{e}
'Iride'	4^{a}	1.75^{c}	4.25^{f}
'APSD23'	4^{a}	1.25^{a}	4.00^{j}
'APSD24'	4^{a}	1.75^{c}	3.75^{d}
Year B			
'Svevo'	5^{a}	1.50^{b}	4.25^{d}
'Meridiano'	5^{a}	1.25^{a}	4.50^{e}
'Reale'	4^{b}	1.75^{c}	3.50^{a}
'Odisseo'	4^{b}	1.25^{a}	4.00^{c}
'Prospero'	4^{b}	1.25^{a}	4.00^{c}
'Levante'	4^{b}	1.75^{c}	4.00^{c}
'Normanno'	4^{b}	2.25^{e}	3.75^{b}
'SY Atlante'	4^{b}	2.00^{d}	4.00^{c}
'Marakas'	4^{b}	1.75^{c}	3.75^{b}
'Pigreco'	4^{b}	1.25^{a}	4.25^{d}
'SY Leonardo'	4^{b}	1.25^{a}	4.5^{e}
'Iride'	4^{b}	1.75^{c}	4.25^{d}
'APSD23'	3^{c}	2.75^{f}	3.00^{a}
'APSD24'	4^{b}	2.25^{e}	3.5^{a}
$F_{variety}$	1.94*	1.93*	2.44**
F_{year}	ns	ns	ns
$F_{variety \times year}$	ns	ns	ns

F-test ratios are from ANOVA. Different letters within a column and growing season indicate significant differences between varieties and lines according to Fisher's LSD test. Significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns, not significant ($p > 0.05$).

Referring to Relative Production Efficiency (RPE), it was not significantly ranged among wheat genotypes, whereas year had a statistically significant effect in RPE. The highest records were obtained at 'Reale (10.61) in year A and 'Meridiano' genotype (5.56) in year B (Table 5). The lowest value was noticed in 'Pigreco' variety in year B but it did not significantly differ with' Odisseo', 'Reale' and 'Normanno', while 'Marakas' variety had the lowest value of 7.87 in year A.

According to Table 6, tillering presented a statistically significant difference among varieties and lines, fluctuating between the genotypes from 3 to 4 tillers in first year and 3-5 tillers in the second year. Year had nonsignificant effect in tillering. 'Svevo', 'Meridiano', 'Reale', 'Prospero', 'Normanno', 'SY Leonardo', 'APSD24', 'Iride' and 'APSD23' had the same number of tillers (4) in year A and these varieties presented significant differences with all remaining genotypes that noted the lowest tillering (3). The highest tillering was reported in 'Svevo' and 'Meridiano' varieties (5 tillers) in year B, that they presented a significant difference with the other varieties and lines. 'APSD23' was the only variety that presented 3 tillers in year B, possessing the lowest number for the second year.

Consistent with significant genotypic differences, the genotypic variance was significant for the fungi infection characteristic (Table 6). The highest value was observed in 'APSD23' (2.75), which significantly differed with the rest of varieties in the second year. 'SY Atlante' noted the highest value (2.50) for year A, with statistically significant difference with the other genotypes. The lowest value was marked as 1.25 in the 'Meridiano', 'Odisseo', 'Prospero', 'Pigreco' and 'APSD23' varieties in year A and in the 'Meridiano', 'Odisseo', 'Prospero', 'Pigreco', 'SY Leonardo' genotypes in year B. The factor of year turned out to have no significant effect in fungi infection.

With regards to vigour, statistically significant differences revealed among varieties/ lines (Table 6). In 'Svevo' and 'Meridiano' were recorded the same earliest vigour (4.25 and 4.50, respectively). These varieties were significantly differed with the rest of varieties in both years, with the only exception 'Iride' genotype in 2019-2020, which presented the same value (4.25). The lowest values were 3 in both growing seasons, while were attributed to 'Marakas' (year A) and 'APSD23' (year B).

Discussion

The relative duration of the first growth and the post-flowering phase is crucial for defining the adaptation of crops to growing conditions (Sandras and Connor, 1991; Mitchell *et al.*, 1996). In this study, marked differences were observed in the duration of the growth phase up to head emergence for both cultivars and lines. More specifically, in 'Odisseo' variety and 'APSD24' line were recorded the highest duration of the growth phase in the two growing seasons. This result consists an indication of adaptation for both 'Odisseo' and 'APSD24' genotypes under East Mediterranean conditions. Early maturing varieties are preferred over late maturing to avoid June heat wave that diminishes quantity and quality (Sadras and Monzon, 2006).

The effect of temperature on the phenological stages was depicted with the de-termination of GDDs. As the daily temperature is the major factor for GDDs, different GDDs derive from years conditions. The results of our study are in accordance with our original hypothesis. In particular, the values of GDDs until head emergence were noticeably higher in the 2019-2020 growing year than the values recorded in the former experimental year. That fact is justified by the raised temperatures during the first months of the growing phase. The values recorded at the stage of head emergence are close enough to the 592 °C days mentioned in the literature (Miller *et al.*, 2001). Despite the high values of GDDs, the difference between the years was not significant. On the other hand, in 'Svevo' was noticed important differences among varieties and the lowest values in both years.

Regarding GDDs in the crucial stage from head emergence to harvest, elevated temperatures were indicated in both years. In particular, the highest temperatures were recorded in the first experimental year and specifically during June and July. Consequently, GDDs increased and were significant for the experimental years. The low precipitation during this period exacerbated the drought as well. Besides, important differences mentioned among the varieties and lines. The check variety 'Svevo' presented the higher values 1849.8 °C days, while the 'Odisseo' variety appointed the lowest 1763 °C days. Furthermore, a negative correlation was observed between GDDs from head emergence to harvest and days after sowing of head emergence ($r = -0.204$, $p < 0.05$; Table 7).

Table 7. Pearson correlation matrix between agronomic and quality characteristics in each variety and line

Crop properties	GDDs to head emergence	GDDs head emergence to harvest	1000 seed weight	Grain specific weight	Moisture content	Vitreous-ness	Protein	Ratio vitreousness / protein	Yield	Protein yield	Relative production efficiency	Tillering	Fungi Infection	Vigour
Head emerge (DAS)	0.42*	-0.20*	0.002ns	-0.19*	0.20*	0.032 ns	-0.06ns	0.06ns	-0.07ns	-0.08ns	-0.14ns	-0.11ns	-0.04ns	-0.02ns
GDDs to head emergence		-0.97*	-0.46*	0.01ns	0.02ns	0.027ns	-0.13ns	0.10ns	-0.83*	-0.80*	-0.32*	0.08ns	0.04ns	0.09ns
GDDs head emergence to harvest			0.51*	-0.06ns	0.02ns	-0.018ns	0.13ns	-0.09ns	0.88*	0.85*	0.30**	-0.13ns	-0.05ns	-0.11ns
1000 seed weight (g)				-0.04ns	0.03ns	0.13ns	0.041ns	0.08ns	0.39*	0.38*	-0.02ns	-0.16ns	0.04ns	-0.25**
Grain specific weight (kg/ hl)					-0.12ns	-0.05ns	-0.23*	0.08ns	-0.02ns	-0.08ns	0.13ns	0.13ns	0.07ns	0.09ns
Moisture content (%)						0.12ns	-0.11ns	0.18ns	-0.13ns	-0.16ns	-0.34*	-0.29**	0.02ns	-0.11ns
Vitreousness (%)							0.03ns	0.83*	-0.05ns	-0.03ns	-0.08ns	-0.05ns	-0.07ns	-0.008ns
Protein (%)								-0.51*	0.11ns	0.38*	0.04ns	0.094ns	-0.16ns	0.04ns
Ratio vitreousness / protein									-0.11ns	-0.24**	-0.11ns	-0.10ns	0.025ns	-0.03ns
Yield (t/ ha)										0.96*	0.68*	-0.01ns	-0.11ns	-0.03ns
Protein yield (t/ ha)											0.65*	0.011ns	-0.15ns	-0.01ns
Relative production efficiency												0.21*	-0.15ns	0.12ns
Tillering													-0.21*	0.56*
Fungi Infection														-0.46*

Significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns, not significant ($p > 0.05$).

Thousand kernel weight was significant differed between experimental years and among varieties and lines. Levante variety recorded the lowest values in both growing seasons, which can be attributed to the highest GDDs recorded in the period between head emergence to harvest. More specifically, heat stress negatively affects the grain filling. Besides, one thousand grain weight was positively correlated with the GDDs from head emergence to harvest (r=0.511, p< 0.05; Table 7). Previous studies verify the reduction of the grain weight under high temperatures as a result of limitation in the starch deposition (Bhullar and Jessen, 1985).

Grain specific weight is a major quality feature of cereals that measures the density of grain (Hoyle *et al.*, 2019), namely the weight of the grains per unit volume (Jenner, 1994). The present study revealed the important effect of variety and interaction between variety and growing season on grain specific weight. Higher values marked in 'Svevo' check variety in year A and SY Leonardo variety in the following year. As shown in Table 5, grain specific weight had a negative correlation with days after sowing of head emergence (r= -0.19, p< 0.05; Table 7).

Concerning grain moisture content, the highest values of 9.5% were recorded in the 'Prospero' variety in the first experimental year. That fact is contradictory with the high values of GDDs during the grain-filling of the year of 2018-2019. Despite the heat stress in the crucial stage, the availability of water is higher in comparison with the subsequent year. It is assumed that the greater precipitation during the first growth stages and grain filling is the reason for high grain moisture content. Moreover, a positive correlation between days after sowing of head emergence and grain moisture content was noticed (r= 0.20, p< 0.05; Table 7).

Vitreousness records noticed significant differences among wheat genotypes. More specifically, varieties appeared almost similar to higher values in both experimental years. Literature mentions that vitreousness is known to be affected by the environment (Pomeranz and Williams, 1990). Some studies also mention that irrigation can reduce the hardness of vitreous endosperm (Sissons *et al.*, 2014). Vitreousness is negatively affected by rainfall upon physiological maturing prior to harvest. In terms of grain protein content, previous studies have observed that the setting of protein in the grain is influenced by environmental conditions such as high temperatures. In particular, great temperatures during the grain filling can provoke thermal sock (Fernando *et al.*, 2012). Nevertheless, in our study no significant difference mentioned for the varieties/ lines and experimental year. According to Table 5, a negative correlation noticed between the grain-specific weight and the protein content (r= -0.235, p< 0.05). The literature identifies that regression as the elevated temperatures during grain filling result in reduced kernel weight without declining the protein content (Jenner, 1994; Correll *et al.*, 1994). The ratio of vitreousness/ protein recorded significant differences among varieties and a negative correlation with grain protein content (r= -0.51, p< 0.05; Table 7).

Climate conditions were found to exert its largest influence on yield and protein yield (Tables 5). According to our results, yield for each variety was significantly affected by year. A strong negative correlation was noticed between Yield and GDDs to head emergence (r= -0.83, p<0.05; Table 7). Also, GDDs from emergence to harvest and yield had a strong positive correlation (r= 0.88, p<0.05; Table 7). Videlicet, in durum wheat cultivation, up to head emergence, if GDDs increased, yield would be declined in contrast to GDDs from emergence to harvest; with the increasing of GDDs to harvest, yield was climbed. Furthermore, a medium positive relationship between yield and 1000 kernels weight was observed (r= 0.39, p<0.05; Table 7). Many researchers mentioned that higher yield means higher number of seeds per spike at the same time smaller seeds (Sissons *et al.*, 2014; Preece *et al.*, 2017). Connecting our conclusions with Preece *et al.* (2017) it could be concluded that increased yield was noticed due to a larger seed size and not a higher number of seeds.

Protein content is one of the most important variables in predicting pasta cooking quality (Wang and Fu, 2020). Referring to protein yield, climatic condition of each year significantly affected it. This result was similar with many studies (Mariani *et al.*, 1995; Morari et al., 2018). As a matter of fact, environment has been a major factor in matching classes of wheat with location (Taha *et al.*, 2018). In protein yield, similar results as yield were obtained. Up to head emergence protein yield was decreased with the increase of GDDs (r= -0.80, p<0.05; Table 7), whereas protein yield was increased with the increase of GDDs from head emergence to harvest (r= 0.85, p<0.05; Table 7).

In relation to indicator relative production efficiency, year was influenced it. 'Reale' variety was yielded 10.6 % more than average of the most commercial varieties in first year, whereas in the second was yielded -10.6 % (Table 5). Relative production efficiency was negative influenced up to head emergence (r= -0.32, p<0.05; Table 7) whereas up to harvest was influenced positive (r= 0.30, p<0.01; Table 7). In first experimental year, GDDs total was 1785.76 °C days; five out of eleven varieties were yielded higher than the average value of the three commercial varieties. In second year, with 1641.26 °C days only 2 out of eleven were yielded higher. Hence, higher GDDs' values offered higher yield, and relative production efficiency. According to our results, with the increase of moisture content, relative production efficiency decreased (r=-0.34, p<0.05; Table 7). Contrariwise to our results, Kakabouki *et al.* (2020) was observed that relative production efficiency and had grain specific weight had a negative correlation.

Tiller number was the primary contributing component to increased grain yield of wheat (Arduini *et al.*, 2018). Indeed, in our outcome, tillering had a small positive correlation with relative production efficiency (r= 0.21, p<0.05; Table 6). Furthermore, tillering was significantly affected only by variety. The parameter of fungi infection depended on varieties. However, research highlighted that location, climate, cultural practices, relationships among microorganisms and environmental conditions are all factors influencing fungal diversity and distribution in plant ecosystems (Bellgard and Williams, 2011). Although, fungi infection was noticed low for all varieties. It is crucial that with the increase of number of tillers, fungi infection was decreased (r=-0.21, p<0.05; Table 7).

In wheat crops, vigour is crucial for weed growth in crop (Richards *et al.*, 2002). In addition, in pea crop was observed that early vigour avoids drought stress (Polania *et al.*, 2017). In recent years, the characteristic of early vigour is a goal for breeders (Mwendwa *et al.*, 2020). In this study, we have demonstrated that significant varieties differences existed in contrast to climatic conditions (Table 6). On the other hand, Botwright *et al.* (2002) observed that rainfall is a significant factor for wheat vigour. In our study, vigour and 1000 seed weight had a low negative correlation (r= -0.25, p< 0.01; Table 7). Greater vigour early offered an increased water- and nutrient-use efficiency, hence increasing crop yields (Austin, 1999). Furthermore, a strong positive correlation was observed with tillering (r= 0.56, p<0.05; Table 7). It is important that the stronger vigour, the lower fungi inflection (r= -0.46, p<0.05; Table 7).

Conclusions

Climate change has growing demand to re-evaluate crops in relation to climate and cultivated areas. For this purpose, utilization of GDDs is considered fundamental owing to variance of crops temperature base. GDDs aspects of local weather into account and allow farmers to predict the plants' pace toward maturity and define harvest date. Our study was founded on that; hence two experimental lines and twelve commercial durum wheat varieties were examined. ANOVA analysis revealed that grain yield, and protein yield were influenced only by factor year. Furthermore, a strong negative correlation was noticed between yield and GDDs to head emergence whereas GDDs from emergence to harvest and yield had a strong positive correlation. Index relative production efficiency was affected by year and had a small correlation with GDDs. In the first experimental year GDDs total was 1785.76 °C days; five out of eleven varieties were yielded higher than the average value of the three commercial varieties in contrast to second year, with 1641.26 °C days only 2 out of eleven were yielded higher. Hence, higher GDDs' values offered higher yield, and relative production efficiency. Observations of tillering, and fungi infection were affected only by variety. The trait of vigour is considered as notable for cereals. In our study, vigour was noticed high for most of the varieties. Although, vigour did not correlate with GDDs.

Authors' Contributions

The contributions of authors to the manuscript should be specified in this section; according to the type of contribution (choosing only the appropriate ones), the authors are mentioned by initials: Conceptualization: I.K. and D.B.; Data curation: I.K., D.B., E.T., I.R., A.M. and N.K.; Formal analysis: I.K., D.B., E.T., I.R., A.M. and N.K; Investigation: I.K, D.B., E.T., I.R., A.M., V.K., N.K., A.E., S.K., C.K., A.Z. and V.T.; Methodology: I.K, D.B., E.T., I.R., A.M., V.K., N.K., A.E., S.K., C.K., A.Z. and V.T.; Project administration I.K. and D.B; Resources I.K, D.B., E.T., I.R., A.M., V.K., N.K., A.E., S.K., C.K., A.Z. and V.T.; Supervision I.K. and D.B.; Validation: I.K, D.B., E.T., I.R., A.M., V.K., N.K., A.E., S.K., C.K., A.Z. and V.T; Visualization I.K. and D.B.; Writing - original draft: I.K., D.B., E.T., A.M. and V.K.; Writing - review and editing: I.K., D.B., E.T., I.R., A.M. and V.K. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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