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IMPACT OF HEAT STRESS ON YIELD POTENTIAL OF DURUM WHEAT GENOTYPES

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ABSTRACT

Heat stress during plant growing cycle is a critical factor affecting wheat production. The primary objective of this research is to assess the impact of heat stress on key agronomic traits of durum wheat, including grain yield, heading time, plant height, chlorophyll content (SPAD), leaf area index (LAI), normalized vegetation difference index (NDVI), and ground cover ratio. The study was conducted over two consecutive cropping seasons (2019 and 2020) under rain-fed conditions. Twenty durum wheat lines and varieties were used as the research materials. The genotypes experienced significant heat stress from vegatative to reproductive period. Heat stress during plant growth is critical for wheat grain yield and quality but heat stress effects vary between genotypes depending on their stress tolerance level. The study demonstrated the potential of NDVI as a reliable indicator that can be used to evaluate the crop yield performance under temperature stress conditions. This supported by strong relationships between grain yield and NDVI. The association of estimated maximum ground cover (EMC) with earliness indicates that early soil surface closure is related to rapid growth rate. According to ground cover estimations, early ground cover and fast plant growth were related to earliness and plant height, respectively. This study reveals significance of identifying and selecting durum wheat genotypes with good stability under heat stress, aiming to development of heat-tolerant varieties and ensuring more stable wheat production.

Keywords: Grain yield, NDVI, heat stress, plant growth rates

INTRODUCTION

The worldwide wheat production for the 2020-2021 season was 774 million tons, and production of durum wheat specifically amounted to 33.8 million tons (Anonymous, 2023). Durum wheat accounting for a small percentage, (4.4%). It significantly contributes to production and agricultural income due to its use making pasta, couscous, bulgur, and various traditional food products. The largest durum wheat producers in the world is in Canada, Italy, and Turkey (Anonymous, 2023).

Increasing wheat production, ensuring food security, and adapting to climate change are of great importance, particularly in the Mediterranean region, which is expected to be significantly affected by the adverse impacts of global climate change (Habash *et al*., 2009). Limited water availability is a significant constraint on wheat production worldwide, especially in arid and semi-arid regions. Adaptation, selection, and breeding for stress-tolerant plants are the ultimate pathways to enhancing grain yield (Golabadi *et al*., 2011).

The inability to produce enough food in response to increase in human population poses a threat to future food security. Enhancing wheat yield and making food production sustainable are influenced by various factors, with heat stress being the one of environmental stresses (Trethowan *et al*., 2005). Heat stress, refers to the period when intense temperature stress occurs during the grain filling, and is a significant factor adversely affecting wheat production worldwide (Farooq *et al*., 2011).

Heat stress can adversely affect plant growth by impacting physiological processes such as leaf and root development, photosynthesis, and stomatal movement (Wahid *et al*., 2007). Furthermore, temperature stress during flowering and grain-filling stages are directly affecteds wheat grain yield. The examination of physiological and morphological characteristics of durum wheat in response to heat stress is of critical importance in understanding responses of stress on plant growth. Zarei *et al.* (2013) reported a significant decrease in grain yield of both durum and bread wheat genotypes under heat stress, with reductions of approximately 36.2% and 45.8% under conditions of drought and heat stress, respectively. Kumar *et al.* (2023) investigated the impact of temperature stress on wheat genotypes and found that temperature stress led to a 44% reduction in grain yield, and for genotypes exposed to prolonged temperature stress, the reduction was as high as 75.8%. In a similar study, Kumari *et al.* (2013) found that wheat genotypes exposed to heat stress in the years 2004, 2005, and 2006 experienced with a yield reduction of approximately 29%, 36%, and 22% for late sowing conditions, and 31%, 21%, and 31% for very late sowing conditions, compared to yields under normal sowing conditions of Karnal, India. In order to determine effect on wheat, the study carried out in normal and late sowing periods under rain-fed and irrigated conditions showed that yield losses varied between 5.5% and 18% in irrigated conditions and between 28% and 41% in dry conditions (Koç *et al.*, 2004).

In this study, different durum wheat genotypes were examined under heat stress conditions to understand their impact on yield-related traits, yield, and growth rates. The research aimed to investigate how durum wheat genotypes responses to stress and which characteristics positively affects performance under heat stress. The study also explored the variability of durum wheat genotypes to heat stress conditions.

MATERIALS AND METHODS

This investigation was conducted during two consecutive cropping seasons (2019 and 2020) under rain-fed conditions at Dicle University, Diyarbakır, Türkiye. Twenty durum wheat varieties including 17 lines were used in this study (Table 1).

Soil, Climatic, Design and Data Analysis: The soil was clay loam and low salinity. Organic matter and phosphorus ($H_2PO^-{}_4$) contents were very low, while potassium (K^+) was very high. Magnesium content was at the middle level (616 ppm). The soil contains lime between 10.0-11.0% at a depth of 0-60 cm.

The average temperature, total precipitation, and relative humidity were 12,93 ℃, 479,6 mm and 67,18%, respectively (2019), while the same climate traits for the 2020 growing season were 12,75 ℃, 461,2 millimeters, and 64,77 %, respectively (Table 2). In April-May, which covers the pre-heading and milk dough periods, there was more rainfall in the first year compared to the second year.

The experiments were set up in a randomized complete block design with three replications. Seeds were sown on February 5-2019, and February 26-2020, employing a 6-row configuration and plot dimensions of 4.8 m² (4 m x 1.2 m), adhering to a seeding density of 500 seeds/m². The fertilization rates for all plots were applied as 60 kg ha^{-1} pure N and P at sowing time and 60 kg ha^{-1} pure N at the end of tillering stage. The herbicide application for weed control was manually carried out when the weed plants were at the 3-4 leaf stage. On June 9, 2019, and June 25, 2020, by plot combine harvester.

Table 1. Information of line and variety used in the study

Genotype	Varieties/Lines	Origin
41 IDSN 7007	Line	International Maize and Wheat Improvement Center
46 IDSN 7153	Line	International Maize and Wheat Improvement Center
46 IDSN 7190	Line	International Maize and Wheat Improvement Center
46IDSN 7201	Line	International Maize and Wheat Improvement Center
47 IDSN 7015	Line	International Maize and Wheat Improvement Center
47 IDSN 7027	Line	International Maize and Wheat Improvement Center
47 IDSN 7031	Line	International Maize and Wheat Improvement Center
47 IDSN 7037	Line	International Maize and Wheat Improvement Center
47 IDSN 7050	Line	International Maize and Wheat Improvement Center
47 IDSN 7060	Line	International Maize and Wheat Improvement Center
47 IDSN 7067	Line	International Maize and Wheat Improvement Center
47 IDSN 7075	Line	International Maize and Wheat Improvement Center
47 IDSN 7097	Line	International Maize and Wheat Improvement Center
47 IDSN 7143	Line	International Maize and Wheat Improvement Center
48 IDSN 7048	Line	International Maize and Wheat Improvement Center
48 IDSN 7055	Line	International Maize and Wheat Improvement Center
48 IDSN 7114	Line	International Maize and Wheat Improvement Center
FIRAT-93	Variety	GAP International Agricultural Research and Training Center
SENA	Variety	Dicle University Faculty of Agriculture
SVEVO	Variety	Tasaco Agricultural industry and trade inc.

Table 2. Climate-related Meteorological Data for the Study Period

	Years	Jan.	Feb.	March	April	May	June	Mean/Total
Mean Temperature (°C)	2019	3,8	5,4	8,2	11,8	20,1	28,3	12,93
	2020	3,7	3,6	10,5	13,5	19,2	26,0	12,75
	Long years	1,7	3,70	8,3	13,8	19,3	26,0	12,13
Total Rainfall (mm)	2019	67,6	77,4	135,2	152,6	45,8	1,0	479,6
	2020	89,4	58,6	164,8	92,6	55,2	0,6	461,2
	Long years	70,9	67,7	65,6	69,5	44,2	8,8	326,7
Moisture (%)	2019	81,7	77,0	75,0	78,4	58,5	32,5	67,18
	2020	77,6	75,1	72,4	70,98	57,45	35,1	64,77

Source: Directorate of the Diyarbakr Meteorology Station (2020)

Measurements: In the study, physiological maturity (days), heading time (days), plant height (cm), grain yield (kg/da), chlorophyll content (SPAD value), leaf area index (LAI), normalized vegetation difference index (NDVI) and ground cover ratio (Canopeo) traits were investigated. Canopeo is an automatic color threshold image analysis tool using color values in the red–green–blue (RGB) system. The physiological maturity (PM) was calculated using the GS87 scale for the plants in the plot in the 2nd year of the experiment, based on the developmental periods described by Zadoks (Zadoks *et al.,* 1974). Heading time was calculated as the total number of days when ½ of spike (GS55) was visible in half of the plot. The leaf chlorophyll content was recorded by SPAD 502 chlorophyll meter (Minolta SPAD-502, Osaka, Japan), ranging from 0-100 on flag leaves of ten randomly selected plants during the heading. Leaf area index (LAI) was determined on area covered by plants leaves in the plot in the 2nd year of the experiment using the LAI-2000 (LI-COR, Lincoln, NE). Normalized vegetation different index (NDVI) was measured with a Trimple GreenSeeker Handheld Crop Sensor during the heading period in the range of 0.00-0.99 values. SPAD, LAI and NDVI measurements were recorded between 11:00 and 14:00 hours when there was no wind or cloud.

The ground cover percentage of vegetation in plot was precisely estimated by the Canopeo application using photographs captured by mobile phone cameras. These measurements were conducted at a height of 60 cm above the vegetation canopy on the 26th, 34th, 42th, 49th and 54th days after emergence during the second year of the experiment. It should be noted that Canopeo's estimations exhibit a 100% accuracy rate in assessing ground cover (Patrignani and Ochsner 2015). This method allowed for monitoring the growth and development of the vegetation cover within the plot and determining the extent to which it covered the soil surface. Our analysis relied on a cubic and quadratic polynomial curve to establish the relationship between maximum ground cover and the time passed since sowing. The average growth rate, highest growth rate and the day of maximum ground cover were determined using the formula in the Excel program (Eliş and Yıldırım, 2023).

Statistical analysis of the acquired data was conducted using the JUMP Pro 13 statistical package program and The Excel program. Genotypic differences were determined by ANOVA and correlation analyses were used to determine the relationship between investigated traits. Statistical differences between genotype means were established through LSD test. Biplot analysis was performed using the GenStat 12 statistical program to determine inter-trait relationships and the impact of traits on genotypes.

RESULTS AND DISCUSSION

Wheat grain production, growth, and development are increasingly affected by temperature variations, particularly in recent years in the semiarid regions of Northwest China (Guoju *et al.,* 2016). In particular, heat stress negatively impacts wheat grain development, restricting yield (Dubey *et al.,* 2020). According to Al-Karaki (2012) and Bahar *et al.* (2011), the optimal temperature range for growth and development of wheat crop varies between 18°C and 24°C. The period between heading and physiological maturity is critical for wheat grain yield, and genotypes that are sensitive to temperature often experience significant yield losses during this phase. The temperatures experienced during these periods are defined as heat stress (Rehman *et al.,* 2021; Yıldırım and Barutçular, 2021). According to Kingra *et al.* (2019), heat stress occurs when the average temperature during the grain-filling stage exceeds 31°C. When examining Figures 1 and 2, it is evident that in both years, durum wheat genotypes experienced intense heat stress during the flowering period (with temperatures ranging from 30-31°C/30-33°C in 2019 and 2020, respectively) and during the grain-filling to physiological maturity period (with temperatures ranging from 30-39°C in 2019 and 2020) (Yıldırım and Barutçular, 2021; Bhatti *et al.,* 2022).

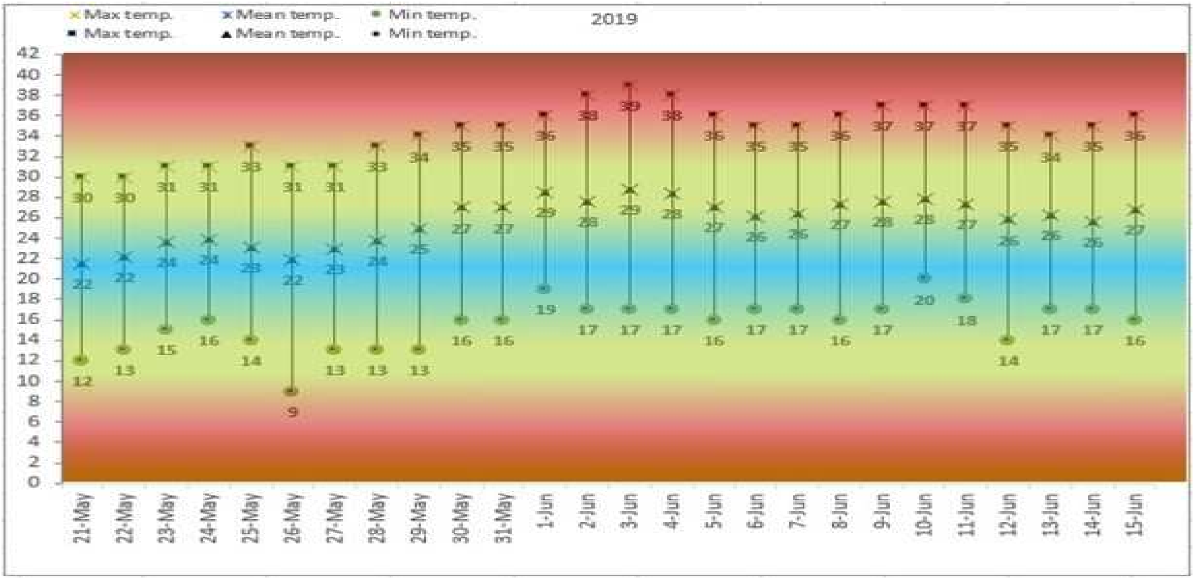


Figure 1. Presentation of average temperature values during the 2019 heat stress period and their representation with a color scale indicating optimum (blue), moderate to high-level stress (yellow), and temperatures (°C) at which the plant cannot survive (red) for wheat development

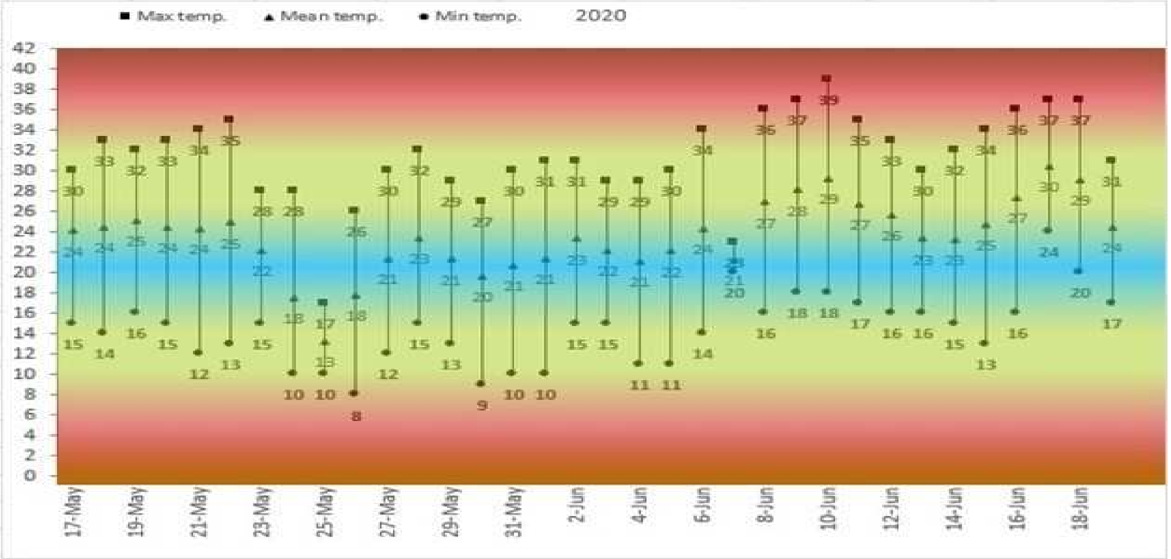


Figure 2. Presentation of average temperature values during the 2020 heat stress period and their representation with a color scale indicating optimum (blue), moderate to high-level stress (yellow), and temperatures (°C) at which the plant cannot survive (red) for wheat development.

Table 3 provides the combined analysis of mean values based on variance analysis results for grain yield, heading time, plant height, SPAD, and NDVI of durum wheat lines and varieties. Genotype, year, and genotype x year interaction were found to be statistically significant at the level of $P < 0.01$ or $P < 0.05$ for grain yield, heading time, plant height and NDVI value. It was observed that SPAD values were significantly influenced by genotype and genotype x year interaction, but not affected by the year effect.

The average grain yield values for durum wheat lines and varieties for 2019 and 2020 growing seasons were 2165 and 3412 kg ha^{-1}, respectively. There was a significant difference between the two years for grain yield. Low grain yield potential was obtained in both years though sufficient rainfall. It can stem from temperature stress during the grain-filling period which disrupts photosynthetic activities (Wahid *et al.,* 2007; Sarkar *et al.,* 2001; Al-Karaki, 2012). In a study conducted by Li *et al.* (2013) under drought stress conditions, their average grain yield results (3307 kg ha^{-1}) were within our range of findings, while grain yield under heat stress conditions

(5348 kg ha^{-1}) was higher than our findings. In a study that found grain yield correlated with canopy temperature, its grain yield (5390 kg ha^{-1}) was higher than our results (Bahar *et al.,* 2008). Al-Karaki (2012), who obtained results similar to ours, reported that high temperatures resulting from late planting reduce average yield. In both years, the SVEVO variety exhibited the highest grain yield, with values of 3161 kg ha^{-1} in the year 2019 and 4389 kg ha^{-1} in the year 2020, respectively. The lowest grain yield was recorded in the first year, with a value of 1647 kg ha^{-1} for the 47 IDSN 7015 line, and in the second year, with a value of 2549 kg ha^{-1} for the 41 IDSN 7007 line. When considering the two-year average values, the 46 IDSN 7007 line had the lowest grain yield. It is widely acknowledged that environmental factors play a crucial role in determining crop yields. Therefore, it is important to identify superior genotypes with good stability in terms of tolerance to temperature stress and heat stress, which can lead to critical yield reductions (Mir *et al.,* 2012; Elbasyoni, 2018; Gautam *et al.,* 2023).

The heading time of genotypes varied between 79,0 and 102,5 days, according to two-year average values. Among the genotypes, 46 IDSN 7153 was the lates heading genotype, whereas 46IDSN 7201 and 48 IDSN 7055 were the earliest genotypes. Earliness and mid-earliness are important attributes in terms of selection and improvement of cereals, arising from the combined or separate effects of genetic and environmental interactions, such as different climatic conditions and locations (Motzo and Giunta, 2007; Al-Doss *et al.,* 2010; Gupta *et al.,* 2020). Earliness is a crucial factor enabling plants to escape from stress factors like drought, heat shock, and temperature (Kumar and Rai, 2014; Dubey *et al.* 2020; Elis and Yıldırım 2023). Genotypes that complete the grain filling period in the earlier phase of the period, as reported by some researchers, can have an advantage and minimal or no yield losses (Whan *et al.,* 1996; Dias and Lidon, 2009). The interaction of genetic and environmental diversity has highlighted the earliness and mid-earliness characteristics of certain genotypes, such as 47 IDSN 7037, 47 IDSN 7067, and Svevo. The heading day differences of genotypes were 22 days between the first and second year verage results, which was similarly reported in other studies (Al-Doss *et al.,* 2010; Kendal and Şener, 2015; Gautam *et al.,* 2023). The durum wheat genotypes, despite being planted earlier in the first year compared to the second year, exhibited delayed heading time in the first year. This delay can be attributed to ecological conditions occurring before the heading period. Indeed, in the first year, there was 49.2 mm more rainfall before the heading period compared to the second year (Table 1).

FIRAT-93 variety had the highest plant height in the first year of the study, whereas 46 IDSN 7190 line had the highest plant height in the second year. Looking at the two-year average data, 46IDSN 7201 had the highest plant height of (83,2 cm). Some researchers' findings obtained at different environmental conditions were similar to ours (Al-Doss *et al.,* 2010; Kendal and Şener, 2015; Mohammadi *et al.,* 2019), while others have reported higher values than our findings (Pecetti and Annicchiarico, 1998; Sial *et al.,* 2005; Kumari *et al.,* 2013; Aberkane *et al.,* 2021).

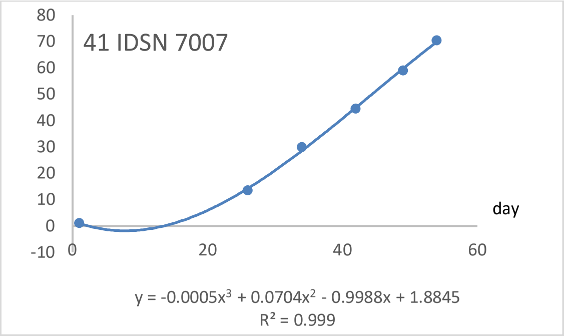
There are differences in leaf chlorophyll content (SPAD) among the genotypes in both 2019 and 2020. The SPAD and NDVI values were also observed to be higher in the second year. Genotypes 47 IDSN 7050 and 48 IDSN 7055 had the highest average SPAD values, while FIRAT-93 had the lowest SPAD value. Although leaf chlorophyll content is related to photosynthetic activity, it was found to have a positive but not significant relationship with grain yield parameters. The SVEVO and 47 IDSN 7037 varieties, notable for their impressive yields, exhibited SPAD values that exceeded the overall average. Zarei *et al.* (2013) noted that varieties with strong tolerance to high temperature conditions delayed senescence compared to sensitive varieties, thus maintaining yield by staying green. According to the model proposed by Reynolds *et al.* (2007), leaf chlorophyll content or staying green is involved in heat tolerance metabolism associated with transpiration efficiency. Therefore, it contributes to the improvement of water use and allows the plant to stay green.

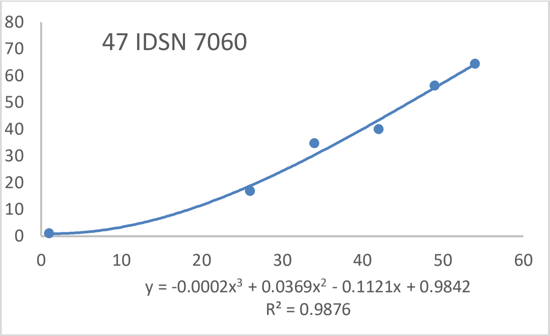
The genotype 48 IDSN 7048 had the highest average NDVI value, while genotypes 47 IDSN 7037, 46 IDSN 7190, and 47 IDSN 7015 had the lowest NDVI values. Many researchers have explained that NDVI determines the photosynthetic area over the plant canopy, provides estimated information for biomass growth, and can be used as a parameter to determine leaf angle and erectness (Wiegand *et al.,* 1991; Gong and McDonald, 2017). Some researchers consider NDVI values to be a crucial attribute for identifying genotypes that can adapt to drought and heat stress conditions. This is achieved by assessing the extent of greenness in plants experiencing stress. (Al Karaki, 2012; Kumar *et al.,* 2023). The NDVI values were lower in the first year compared to the second year, with average values of 0,58 and 0,76, respectively. Similar to the findings we obtained, as reported by Kumar *et al.* (2023), temperature stress conditions lead to a decrease in NDVI and a reduction in plant greenness. Considering the significance of each 1°C increase in heat stress, it is understandable that genotypes experienced higher heat stress in the first year, even though they encountered heat stress in both years. The two-year NDVI and yield values showed a positive and significant relationship in the same direction with this observation.

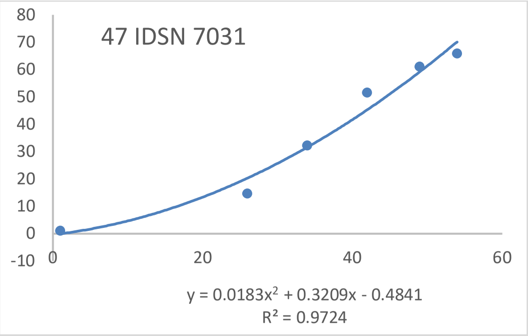
Table 3. The traits means and variance analyses values of 20 durum wheat lines and varieties

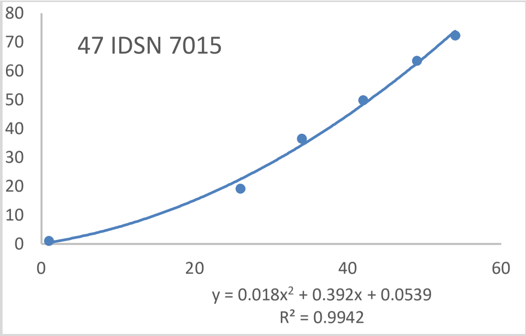
Genotypies	GY (kg/ha^{-1})						HT (day)						PH (cm)						SPAD (unit)						NDVI					
	2019		2020		Mean		2019		2020		Mean		2019		2020		Mean		2019		2020		Mean		2019		2020		Mean	
41 IDSN 7007	1790	nop	2549	ı-l	2169	h	101,7	cde	78,7	ghı	90,2	d-h	74,8	k-o	83,5	b-e	79,1	bcd	44,1	klm	48,3	f-k	46,2	gh	0,55	ı-l	0,75	b-f	0,65	de
46 IDSN 7153	1963	m-p	3482	c-f	2722	c-g	105,2	a	81,0	f	93,1	a	75,8	j-n	82,5	b-f	79,2	bcd	45,3	ı-m	48,4	f-k	46,9	fg	0,57	h-l	0,75	b-g	0,66	cde
46 IDSN 7190	1700	op	3096	fgh	2398	gh	103,2	a-d	78,3	hıj	90,8	b-g	72,5	mno	90,7	a	81,6	ab	48,6	f-j	51,4	a-f	50,0	a-e	0,57	h-l	0,71	efg	0,64	de
46IDSN 7201	2217	l-o	3764	bcd	2990	bcd	101,8	cde	76,0	k	88,9	h	80,2	d-j	86,1	ab	83,2	a	43,5	lm	48,5	f-j	46,0	gh	0,53	l	0,80	abc	0,67	a-e
47 IDSN 7015	1647	p	3816	bcd	2732	c-g	101,7	cde	79,3	f-ı	90,5	c-g	76,5	ı-m	79,1	e-l	77,8	cde	53,9	a-d	48,0	f-k	50,9	abc	0,60	hıj	0,69	g	0,64	de
47 IDSN 7027	2331	j-n	3668	b-e	2999	bc	103,0	a-d	80,7	fg	91,8	abc	74,3	l-o	78,7	e-l	76,5	c-f	47,6	f-l	48,2	f-k	47,9	c-g	0,62	h	0,74	c-g	0,68	a-d
47 IDSN 7031	2281	k-n	2609	ı-l	2445	fgh	103,7	abc	79,0	f-ı	91,3	b-f	72,5	mno	79,5	e-k	76,0	def	49,9	c-g	44,5	j-m	47,2	efg	0,59	h-k	0,72	d-g	0,66	cde
47 IDSN 7037	2440	j-m	4016	abc	3228	b	99,8	e	80,0	fgh	89,9	e-h	78,5	f-l	84,7	bcd	81,6	ab	48,1	f-k	55,0	a	51,6	ab	0,59	h-k	0,82	a	0,71	ab
47 IDSN 7050	1661	p	3350	d-g	2505	e-h	104,3	abc	79,0	f-ı	91,7	a-d	72,3	mno	78,2	f-l	75,3	ef	53,5	a-e	51,1	a-f	52,3	a	0,55	jkl	0,78	a-d	0,66	b-e
47 IDSN 7060	1976	m-p	3536	c-f	2756	c-g	103,3	a-d	81,0	f	92,2	ab	70,1	o	76,6	ı-m	73,4	f	45,5	h-m	54,0	abc	49,8	c-f	0,55	ı-l	0,71	fg	0,63	e
47 IDSN 7067	2269	k-n	4177	abc	3223	b	102,0	cde	77,7	ıjk	89,8	fgh	77,0	g-m	81,1	c-ı	79,1	bcd	50,6	b-g	46,4	g-l	48,5	c-g	0,59	h-l	0,74	c-g	0,67	a-e
47 IDSN 7075	2350	j-m	2859	gh	2605	d-g	102,0	cde	76,3	jk	89,2	gh	77,7	g-l	79,9	d-j	78,8	bcd	48,2	f-k	48,8	f-j	48,5	c-g	0,58	h-l	0,75	b-f	0,66	b-e
47 IDSN 7097	2260	k-n	3093	fgh	2676	c-g	102,0	cde	81,0	f	91,5	a-e	76,7	h-m	78,5	f-l	77,6	cde	48,0	f-k	51,6	a-f	49,8	d-f	0,58	h-l	0,79	abc	0,68	a-d
47 IDSN 7143	2219	l-o	2627	h-l	2423	fgh	102,0	cde	79,7	f-ı	90,8	b-f	78,0	f-l	81,1	c-ı	79,5	bc	48,8	f-j	51,2	a-f	50,0	a-e	0,57	h-l	0,72	d-g	0,65	de
48 IDSN 7048	1911	m-p	3656	b-e	2783	c-g	102,2	bcd	79,0	f-ı	90,6	b-g	78,3	f-l	81,0	c-ı	79,6	abc	49,3	e-ı	51,7	a-f	50,5	a-d	0,61	hı	0,81	ab	0,71	a
48 IDSN 7055	2417	j-m	3365	d-g	2891	b-e	101,7	cde	76,0	k	88,8	h	71,5	no	85,4	bc	78,5	b-e	54,6	ab	49,7	d-h	52,1	a	0,60	hıj	0,80	abc	0,70	abc
48 IDSN 7114	1710	op	3879	a-d	2795	c-f	103,5	a-d	80,7	fg	92,1	abc	72,5	mno	84,5	bcd	78,5	cde	47,6	f-l	47,7	f-l	47,6	d-g	0,56	ı-l	0,76	a-f	0,66	cde
FIRAT-93	2632	h-l	2769	h-k	2701	c-g	103,3	a-d	78,7	ghı	91,0	b-f	81,5	b-g	81,5	b-h	81,5	ab	42,0	m	45,3	ı-m	43,7	h	0,53	kl	0,76	a-f	0,65	de
SENA	2357	j-m	3535	c-f	2946	bcd	101,3	de	78,3	hıj	89,8	fgh	74,5	l-o	77,5	g-l	76,0	def	50,0	c-g	47,4	f-l	48,7	b-g	0,55	ı-l	0,75	b-f	0,65	de
SVEVO	3161	e-h	4389	a	3775	a	101,7	cde	79,3	f-ı	90,5	c-g	77,5	g-l	77,9	f-l	77,7	cde	49,5	e-ı	49,8	c-h	49,7	a-f	0,62	h	0,77	a-e	0,70	abc
Mean	2165	b	3412	a			102,5	a	79,0	b			75,6	b	81,4	a			48,43		49,34				0,58	b	0,76	a		
LSD (Y*G)			27,57	**					1,13	*					2,41	**					2,17	**					0,03	*		
LSD (G)			19,49	**					0,80	**					1,71	**					1,54	**					0,02	*		
LSD (Y)			9,53	**					0,69	**					0,44	**					ns						0,01	**		
CV(%)			12,11						1,52						3,76						5,44						5,79			

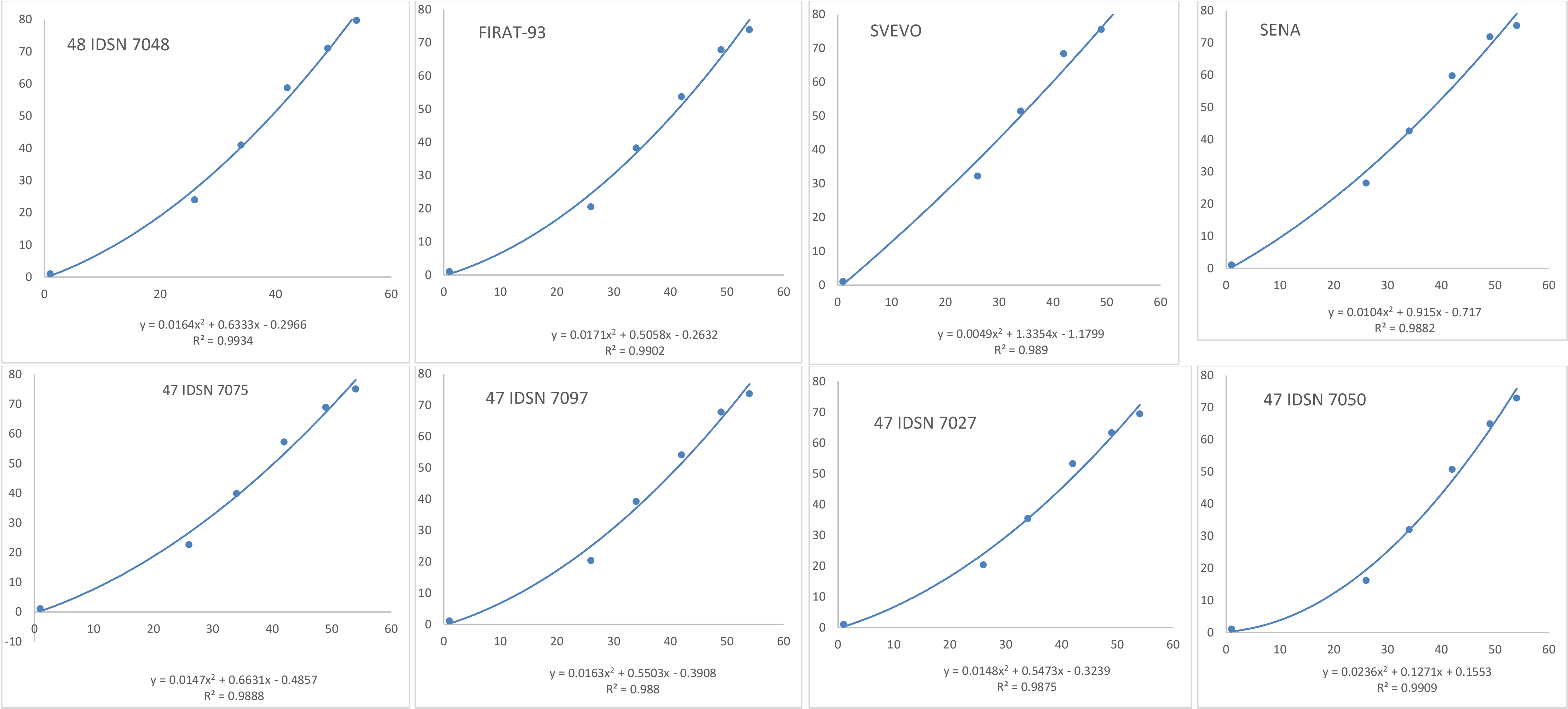
LSD: least significant differences, *, ** Significant at P < 0,05, P < 0,01 respectively. Grain yield (GY), Heading time (HT), Plant height (PH), Normalized differences vegetative index (NDVI) and Leaf chlorophyll content (SPAD).










48 IDSN 7048
y = 0.0164x² + 0.6333x - 0.2966
R² = 0.9934
FIRAT-93
y = 0.0171x² + 0.5058x - 0.2632
R² = 0.9902
SVEVO
y = 0.0049x² + 1.3354x - 1.1799
R² = 0.989
SENA
y = 0.0104x² + 0.915x - 0.717
R² = 0.9882
47 IDSN 7075
y = 0.0147x² + 0.6631x - 0.4857
R² = 0.9888
47 IDSN 7097
y = 0.0163x² + 0.5503x - 0.3908
R² = 0.988
47 IDSN 7027
y = 0.0148x² + 0.5473x - 0.3239
R² = 0.9875
47 IDSN 7050
y = 0.0236x² + 0.1271x + 0.1553
R² = 0.9909
0
10
20
30
40
50
60
70
80
-10

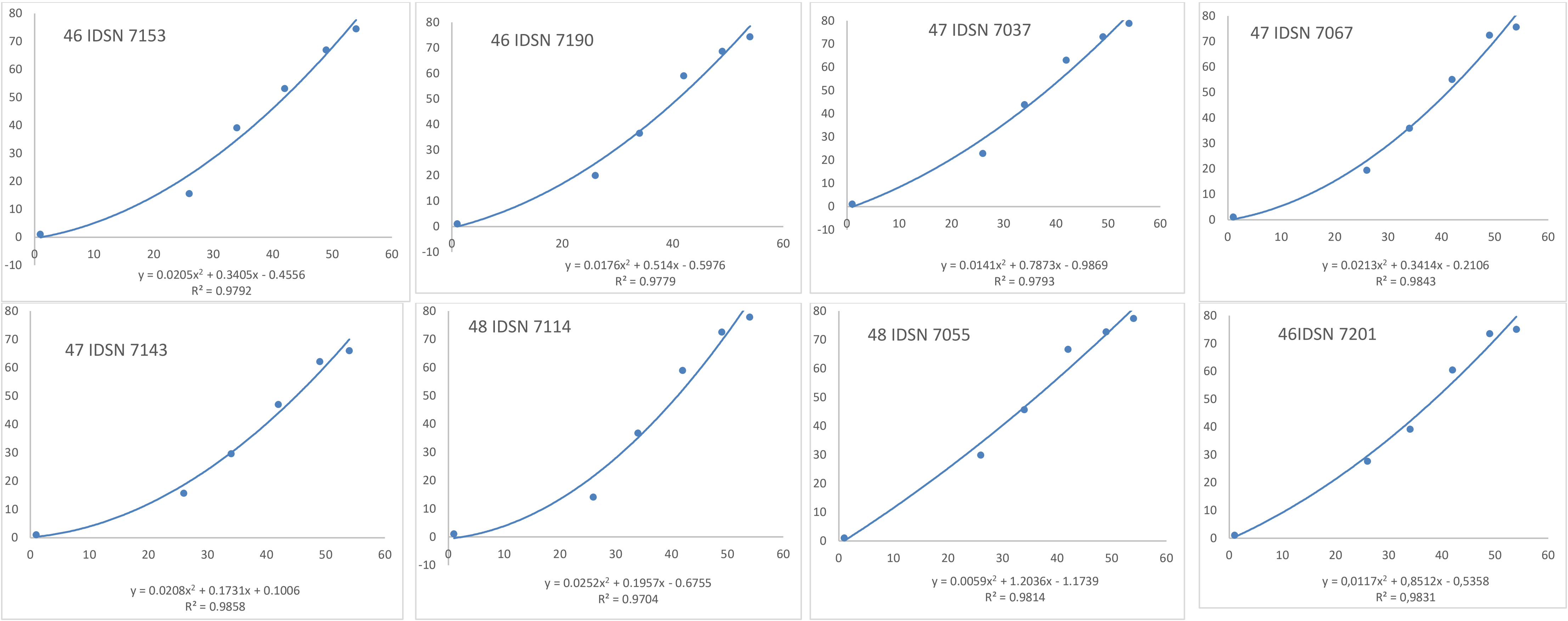


Figure 3. The regression curve and equations determined from different ground cover measurements belong to durum wheat genotypes. Vertical and horizantal values show ground cover rate (%) and measurement times (day), respectively.

The percentage of ground cover (Canopeo values) obtained between the 26th and 54th days after sowing is provided in Table 4, and the regression curves for the ground cover and growth behavior of durum wheat genotypes are visually represented in Figure 3 for five different periods. The number of days to reach the highest ground cover rate, the estimated average maximum growth rates, and specific instantaneous maximum growth rates were calculated from the y-equations obtained from the regression curves (Table 4). According to the latest Canopeo measurements, the SVEVO genotype displayed the highest ground cover rate at 83.2%, while the 47 IDSN7060 genotype had the lowest ground cover rate, measuring at 64.4%. According to the predictions in Table 4, it is observed that the 48IDSN7114 genotype reached maximum or 100% ground cover at the earliest, within 59,5 days. This situation indicates that, with the continuation of measurements, 48IDSN7114 is expected to reach the maximum ground cover earlier than Svevo. This indicates that, for more accurate results, Canopeo measurements should be extended until a ground cover rate of 90% or higher is attained. Indeed, the 48IDSN7114 genotype holds the top position by a significant margin in terms of maximum growth rate among all genotypes. The average growth rates of genotypes ranged from 1,56% to 1,83% per day. Genotypes with lower average growth rates, such as 41IDSN 7007, 41IDSN 7015, 41IDSN 7031, and 41IDSN 7060, exhibited growth curves with a flatter appearance (Figure 3).

The Leaf Area Index (LAI) varied between 1.87 and 3.07 (Table 4). According to the data from the second year, genotypes with high yields generally exhibited Leaf Area Index (LAI) values lower than the overall average. This suggests that, under heat stress conditions, having a lower Leaf Area Index (LAI) may be more advantageous for achieving higher yields. In two genotypes with grain yields above the overall average, having an LAI value exceeding 3 may be attributed to the translocation of soluble carbohydrates from the leaves to the grains under temperature stress conditions.

Table 4. Ground cover rate (Canopeo), growth rate estimates and LAI values of durum wheat genotypes

	Canopeo (%)										EMC	GR (%/day)			
Genotypes	**26th Day**		**34th day**		**42th day**		**49th day**		**54th day**		**day**	**Mean**	**Max**	**LAI**	
41 IDSN 7007	13,40	o	29,90	n	44,4	o	58,90	q	70,28	k	66,9	1,65	1,77	2,17	cde
46 IDSN 7153	15,53	l	39,05	g	53,1	j	66,90	l	74,40	fg	62,2	1,77	2,85	2,23	cde
46 IDSN 7190	19,90	h	36,50	ı	59,0	ef	68,60	j	74,30	g	61,5	1,78	2,69	2,37	cde
46IDSN 7201	27,60	c	39,10	g	60,4	d	73,50	b	75,00	ef	63,2	1,67	2,29	2,27	cde
47 IDSN 7015	19,13	ı	36,40	ı	49,7	m	63,40	n	72,20	j	64,4	1,65	2,63	1,87	ef
47 IDSN 7027	20,30	g	35,40	k	53,2	j	63,30	n	69,40	l	65,9	1,58	2,41	1,93	def
47 IDSN 7031	14,60	m	32,10	m	51,5	k	61,00	p	65,80	m	65,5	1,60	2,62	1,93	def
47 IDSN 7037	22,80	f	43,80	c	62,9	c	73,00	c	78,73	c	61,2	1,77	2,49	2,30	cde
47 IDSN 7050	16,14	k	31,93	m	50,7	l	64,90	m	72,90	ı	64,0	1,70	2,97	2,43	bcd
47 IDSN 7060	16,80	j	34,60	l	39,9	p	56,20	r	64,40	n	67,5	1,56	2,15	2,20	cde
47 IDSN 7067	19,40	ı	35,90	j	55,0	h	72,40	f	75,60	e	61,1	1,83	2,92	1,97	def
47 IDSN 7075	22,60	f	39,80	f	57,2	g	68,84	ı	75,01	ef	63,2	1,69	2,47	2,53	bc
47 IDSN 7097	20,33	g	39,20	g	54,1	i	67,73	k	73,60	h	63,4	1,69	2,56	3,07	a
47 IDSN 7143	15,63	l	29,60	n	47,0	n	62,10	o	65,97	m	65,3	1,63	2,78	1,90	ef
48 IDSN 7048	23,97	e	40,93	e	58,8	f	71,01	g	79,65	b	61,3	1,78	2,62	3,10	a
48 IDSN 7055	29,80	b	45,60	b	66,7	b	72,70	d	77,40	d	64,0	1,62	1,94	2,23	cde
48 IDSN 7114	14,08	n	36,70	ı	58,9	f	72,53	e	77,80	d	59,5	1,83	3,08	3,07	a
FIRAT-93	20,50	g	38,20	h	53,7	ij	67,80	k	73,90	gh	63,2	1,70	2,61	1,60	f
SENA	26,40	d	42,60	d	59,7	de	71,80	g	75,30	e	63,8	1,64	2,20	2,90	ab
SVEVO	32,20	a	51,40	a	68,4	a	75,50	a	83,20	a	61,8	1,68	1,93	2,10	c-f
Mean	20,60		37,9		55,2		67,6		73,7		63.5	1,69	2,50	2,30	
LSD (G)	0,98		0,59		0,81		0,09		0,52					13,60	
CV(%)	0,16	**	0,18	**	0,36	**	0,05	**	0,32	**				0,26	**

Estimated max cover day: EMC day, Growth rate: GR

When examining the biplot graph (Figure 4-A) showing the relationship between genotypes and traits, it is observed that the total variation is determined to be 67.47%. Out of this variation, 39.55% is represented by the first principal component (PC1), and 27.88% is represented by the second principal component (PC2). In terms of the PH parameter, genotype 48 IDSN 7201; for the GY and NDVI parameters, genotypes 48 IDSN 7055 and Svevo; for the SPAD parameter, genotypes 48 IDSN 7055, 47 IDSN 7050, 47 IDSN 7037, 47 IDSN 7060, and Svevo; and for the HT parameter, genotypes 46 IDSN

7153 and 47 IDSN 7060 exhibited specific relationships." In Figure 4. A, it can be observed that the examined traits separate four different mega-groups. Accordingly, genotypes within the same mega-group can be interpreted as having high values for the respective traits. For example, genotypes 48 IDSN 7048 and 48 IDSN 7055, which are located in the GY and NDVI mega-groups, have emerged as the most optimal for these parameters. In the biplot graph (Figure 4-B) showing the correlation relationship between traits and genotypes, the GY parameter is highly positively correlated with NDVI and negatively correlated with HT and PH. The PH parameter has a negative correlation with HT. Under heat stress, a strong correlation was observed between the narrow-angle GY and NDVI features, as seen in Figure 4-B. SPAD, although not as strong as NDVI, has been found to be positively related to yield, similar to the findings of Mohammadi et al. (2019).

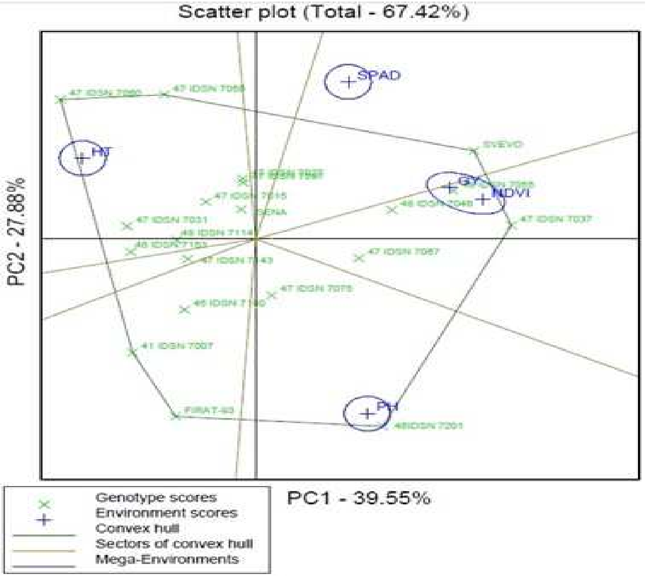


Figure 4. A- Biplot graph showing the genotype x trait relationship

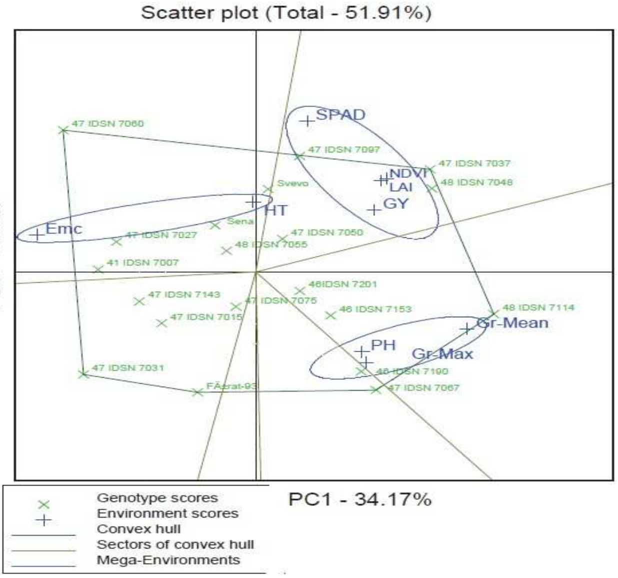


Figure 5. Relationships between the predicted EMC, GR Max, and Gr Mean values obtained through Canopeo application during the 2020 growing season and the examined traits and genotypes

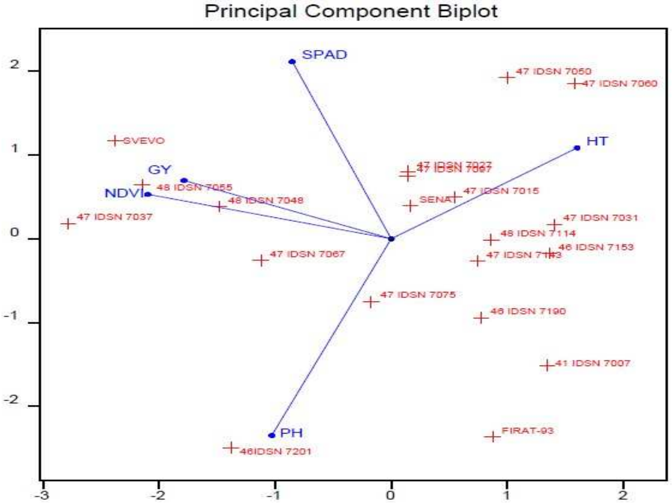


Figure 4 B- Principal component analysis showing the genotype x trait relationship

The biplot graph in Figure 5, which shows the relationship between the number of days when plants covered the soil at the highest rate (EMC), average and maximum soil cover rates (Gr-Mean and Gr-Max) calculated from the regression curve, and plant agronomic traits, reveals a total variation of 51.91%. Out of this variation, PC1 accounts for 34.17% and PC2 accounts for 17.73%. The examined traits form three different mega-groups, and the traits and genotypes are grouped into six sectors. These mega-groups are clustered as follows: EMC-HT, SPAD-NDVI-LAI-GY, and PH-GrMax-GrMean. The SENA and 47 IDSN 7027 genotypes within the EMC-HT group, the 47 IDSN 7097, 47 IDSN 7037, and 48 IDSN 7048 genotypes within the SPAD-NDVI-LAI-GY group, and the 48 IDSN 7114, 48 IDSN 7190, and 47 IDSN 7067 genotypes within the PH-GR-Max-GR-Mean group are associated with high values for the respective traits. According to Figure 5, physiological traits have been found to be related to grain yield, and in many genotypes, selections can be made for grain yield using these traits. The association of EMC with earliness indicates that early soil surface closure is related to rapid growth.

Conclusions: The identification of some traits, such as heading time, plant height, chlorophyll content, NDVI, and canopy cover, allowed for evaluating how different durum wheat genotypes respond to temperature stress. SVEVO and 47 IDSN 7037 genotypes exhibited potential in relation to grain yield and some traits such as SPAD and NDVI.Despite the decrease in yield potential due to heat stress in durum wheat genotypes, the identification of extreme genotypes in terms of the studied traits indicates the potential for developing heat-resistant genotypes. This research finding can provide valuable insights for breeding programs aiming to develop heat-tolerant durum wheat varieties.

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