



Efficiency of Numerical Images Analysis in Selection of Durum Wheat [*Triticum turgidum* (L.) ssp. *durum* (Desf.) Husn.] Genotypes Growing under Semi-arid Conditions in Algeria

Benalia Frih¹, Abdelmalek Oulmi¹, Ali Guendouz²

10.18805/ag.DF-398

ABSTRACT

Background: This study was conducted during the 2020/2021 cropping season at Setif Agricultural Experimental Station, it aims to assess the efficiency of using numerical image analysis (NIA) in the selection of durum wheat genotypes in semi-arid areas.

Methods: The genetic materials used in this study consist of 11 advanced lines and 4 genotypes of which 3 are local landraces used as control to evaluate their performance, the genotypes tested were sown in a randomized block design (RDB) with three replications. Each plot consisted of 6 lines of 10 m long spaced of 0.2 m width makes 12 m² as plot area.

Result: Analysis of variance showed that all the parameters measured numerically (senescence and total reflectance) had a very high genotypic significance. The chlorophyll content at full heading showed a very highly significant genotypic effect. Thousand kernels weight, number of spikes per meter square, number of days to heading and plant height had a significant genotypic effect. The correlation study showed that all senescence parameters were significantly correlated. A significant and negative correlation was observed between chlorophyll contents; average of velocity and total reflectance. Grain yield was highly and significantly correlated with thousand kernels weight and number of spikes per meter square. Number of spikes per meter square was significantly and positively correlated with average of velocity and negatively correlated with sum of temperatures at mid-senescence. Number of days to heading was significantly and negatively correlated with senescence average and maximum of senescence average. A significant correlation was observed between plant height and sum of temperatures at mid-senescence.

Key words: Chlorophyll contents, Durum wheat, Grain yield, Reflectance, Semi-arid, Senescence.

INTRODUCTION

Durum wheat [*Triticum turgidum* L. ssp. *durum* (Desf.) Husn.] is the 10th most important crop worldwide with an annual production of over 40 million tons (Sall *et al.*, 2019). The largest producer is the European Union, with 9 million tonnes in 2018, followed by Canada, Turkey, United States, Algeria, Mexico, Kazakhstan, Syria and India (Tedone *et al.*, 2018). Durum wheat [*Triticum turgidum* (L.) ssp. *durum* (Desf.) Husn.] is one of the most cultivated cereals in the Mediterranean basin, where drought is a limiting factor for its production. (Royo *et al.*, 1998), it's mostly grown under rain-fed conditions, where drought and heat stress usually constrain yield potential during the grain filling period (Simane *et al.*, 1993).

Senescence is a universal phenomenon in living organisms and the word senescence has been used by scientists working on a variety of systems, such as yeast, fruit fly, worm, human being and plants. However, the meaning of the word senescence to scientists working on different organisms can be different and the difference can be subtle in some cases and very obvious in some other cases (Hafsi and Guendouz, 2012). Senescence is subject to strong environmental and genetic regulation and prior to visual yellowing and chlorosis up to 50% of leaf chlorophyll may be lost (Buchanan-Wollaston *et al.*, 2005; Borrill *et al.*, 2019). Photosynthesis is the primary source of dry matter production and grain yield in crop

¹Department of Biology and Plant Ecology, VRBN Laboratory, Farhat Abbas Sétif University 1, Algeria.

²National Institute of Agronomic Research of Algeria (INRAA), Sétif Unit, Algeria.

Corresponding Author: Benalia Frih, Department of Biology and Plant Ecology, VRBN Laboratory, Farhat Abbas Sétif University 1, Algeria. Email: benaliafrih@gmail.com

How to cite this article: Frih, B., Oulmi, A. and Guendouz, A. (2022). Efficiency of Numerical Images Analysis in Selection of Durum Wheat [*Triticum turgidum* (L.) ssp. *durum* (Desf.) Husn.] Genotypes Growing under Semi-arid Conditions in Algeria. *Agricultural Science Digest*. DOI: 10.18805/ag.DF-398.

Submitted: 27-08-2021 **Accepted:** 02-12-2021 **Online:** 06-01-2022

plants, the improvements of leaf photosynthesis have occurred with the advance of breeding high-yielding cultivars (Jiang *et al.*, 2002).

The breeding of new cereal grain varieties requires methods that are rapid and preferably non-destructive, to assess the quality of grain in early generations. Near infrared (NIR) spectroscopy has great potential to meet these requirements for the durum wheat breeder (Sisons *et al.*, 2006). Our study aim to test the efficiency of the use of flag leaf senescence parameters, total reflectance and the chlorophyll contents as selection criteria for durum wheat genotypes growing under semi-arid conditions.

MATERIALS AND METHODS

The study site

This study was conducted during the 2020/2021 cropping season at Setif Agricultural Experimental Station (ITGC-AES, 36°12'N and 05°24'E and 1.081 m asl, Algeria).

Plant material

The genetic material used in this study consists of 11 advanced lines and 4 genotypes of which 3 are local landraces and used as control to evaluate the performance of the experimental material (Table 1).

Experimental device

The genotypes tested were sown at November 19 with sowing density adjusted to 300 grains m⁻² in a randomized block design (RBD) with three replications. Each plot consisted of 6 lines of 10 m long spaced of 0.2 m width which makes 12 m² as plot area.

Parameters measured

The following parameters were measured:

Physiologic traits

1. Senescence parameters : (Sa%; Vsa; Vmax; ΣT_{50s})

We have followed the evolution of leaf senescence during 13 dates of assessment from flowering until 100% of leaf senescence (S1-S13) by Numerical Image Analysis (NIA) according to Guendouz and Maamri (2011), Leaves were photographed on black surface, between 11:00 and 12:00 solar time with a color digital camera (Canon, Power Shot A460, AiAF, CHINA). Images were stored in a JPEG (Joint Photographic Expert Group) prior to downloading onto a PC computer and analyzed using IPP (Image Pro Plus, Version 4, Media Cybernetics, Silver Spring, MA, USA) software. The percentage of senescence (S) was calculated for each date of observation and for each genotype studied using Digimizer software (Fig 1) by calculating the percentage of

senescent zone from the total of leaf surface S(%) = (senescent area of flag leaf/flag leaf area)*100 (S1-S13). The 13 dates of assessment will be expressed subsequently in cumulative temperatures $\Sigma T^{\circ}C$ ($\Sigma 1-\Sigma 13$). In the base of these values the following parameters were calculated:

a. Average of senescence Sa (%): is the average of the following percentage of senescence in the following dates

$$Sa \% = (S1+S2+\dots+Sn)/n$$

n= number of dates

b. Average of velocity Vsa (%/°C):

• The velocity of senescence (Vs) was calculated every date of senescence values

$$Vs = (S_{n+1}-S_n) / (\Sigma TC_{n+1} - \Sigma TC_n)$$

ΣTC = Sum of temperatures in the date of senescence value

• Average of velocity Vsa is the average of the following velocity of the following dates

$$Vsa = (Vs1+Vs2+\dots+Vsn)/n$$

c. Maximum of the senescence velocity (Vmax): is the highest velocity unregistered.

d. Sum of temperatures at mid-senescence (ΣT_{50s}): estimated from the curve:

$S = f(\Sigma T^{\circ}C_s)$ (Fig 2) as the sum of temperatures corresponding to S=50%.

2. Total reflectance: R(t) (at full heading)

With the same images (using to calculate senescence), we calculate reflectance using Mesurim_pro_02 software (Guendouz and Maamri, 2011), this software can measure the reflectance at Red, Blue, Green band and total reflectance. We used the total reflectance for our work (Fig 3).

3. Chlorophyll contents CC (at full heading)

Chlorophyll contents (CC) of the flag leaf was measured using digital chlorophyll meter (CCM) with (cci) units, this device allows measuring the absorbance of light in the leaf.

Table 1: Varieties and their pedigrees.

Genotype	Pedigrees
G1	RASCON_37/GREEN_2/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/...
G2	MINIMUS_6/PLATA_16//IMMER/3/SOOTY_9/RASCON_37/9/...
G3	CMH77.774/CORM//SOOTY-9/RASCON-37/3/SOMAT-4
G4	CNDO/PRIMADUR//HAI-OU-17/3/SNITAN/4/SOMAT-3/
G5	RASCON_37/GREEN_2/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/...
G6	SILVER_14/MOEWEE//BISU_1/PATKA_3/3/PORRON_4/YUAN_1/9/...
G7	GUANAY /HU ALITA / 10/PLATA_10/6/MQUE/4/USDA573/...
G8	BCRIS/BICUM//LLARETA INIA/3/DUKEM_12/2*RASCON_21/5/R
G9	Simeto/3/Sora/2*Plata_12//SRN_3/Nigris_4/5/Toska_26/...
G10	Oss11/StjS5/5/Bicrcderaal/4/BEZAIZSHF//SD19539/Waha/3/St
G11	Stj3//Bcr/Lks4/3/Ter-3/4/Mgnl3/Aghrass2
G12	Jupare C 2001
G13	Boussellem
G14	Boutaleb
G15	Oued Bared

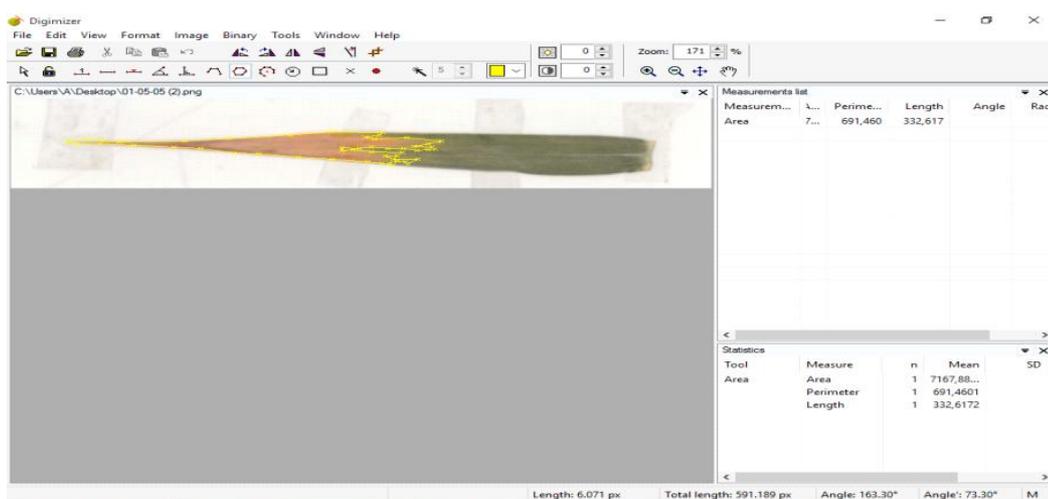


Fig 1: Estimation of senescence by Digimizer software.

Agronomic traits (at maturity)

Grain yield (GY)

The cereal yield performances of the different cultivars were measured at maturity in quintals per hectare (Qs. ha⁻¹) by measuring the grain yield in one linear meter and converting it into quintals per hectare. Thousand kernels weight (TKW) (g). Number of spikes per meter square (NSm⁻²). Number of days to heading (DH) (days) calculated from sown date 19/11/2020. Plant height (PH) cm.

5. Data analysis

All statistical analyses will be performed by Costat 6.400 (1998) software.

RESULTS AND DISCUSSION

Analysis of variance (ANOVA)

Agronomic traits

ANOVA (Table 2) showed that genotypic effect was significant ($p < 0.05$; 0.001) with Thousand Kernels Weight (TKW), number of spikes per meter square, days to heading and Plant Height (PH). Grain Yield average ranged from 2.87 Q.ha⁻¹ for G11 to 13.59 Q.ha⁻¹ for Boutaleb with genotypic mean of 6.34 Q.ha⁻¹. Thousand kernels weight arranged from 30.91 g for G8 to 46.69 g for G9 with 39.40 g as genotypic mean. Comparing to general mean, high values of TKW was observed with the local landraces Boutaleb (44.96 g). NSm² ranged from 178.33 s.m⁻² for G4 to 320 s.m⁻² for Boutaleb with a genotypic mean of 255.77s.m⁻². The number of days to heading ranged from 136 days for advanced lines G1, G2, G8, G10 and Jupare C 2001 to 147 for Boutaleb local landrace with 140.6 as genotypic mean. Plant height ranged from 56.11 cm for G4 to 67.38 cm for G10 with a mean of 62.76, local landrace Boutaleb registered a high plant height (66.16 cm).

Physiologic traits

For all genotypes studied, the senescence function with sums of temperatures after flowering was of sigmoid type.

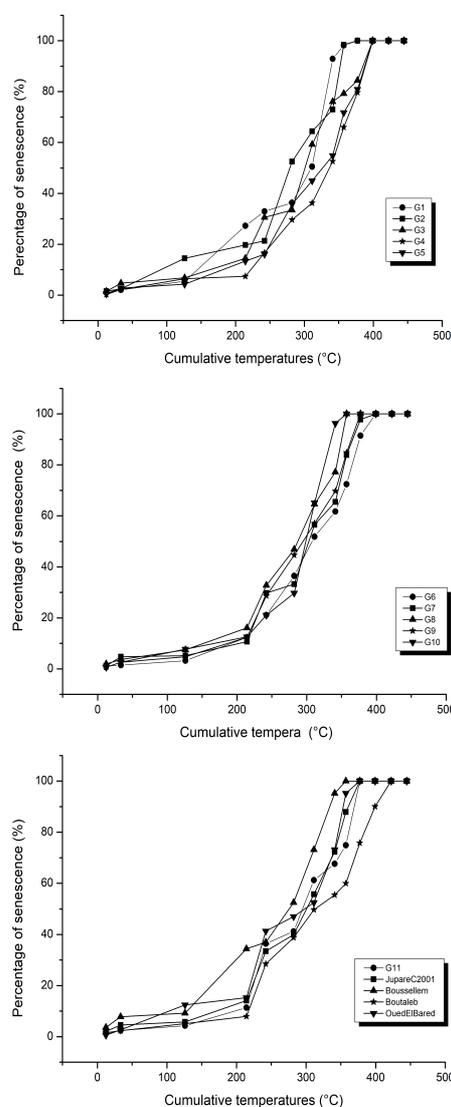


Fig 2: Senescence functions with sums of temperatures after flowering of the 15 genotypes studied.

$\Sigma T50_s$ the sums of temperatures corresponding to S= 50% (mid-senescence) differed markedly amongst genotypes, as shown in (Fig 2). ANOVA showed that genotype effect was highly significant ($P<0.001$) with all senescence parameters calculated Sa; Vsa; Vmax and $\Sigma T50_s$, total reflectance R (t) and chlorophyll contents at full heading (Table 3). Senescence average (Sa) ranged from 29.68% for advanced line G4 to 44.76 % for advanced line G2 with genotypic mean of 38.76%. Average of velocity (Vsa) arranged from 0.319%/°C for G3 to 0.429%/°C for Boussellem with a genotypic mean of 0.379%/°C .Vmax ranged from 0.792%/°C for Boutaleb to

1.593%/°C for G2 with genotypic mean of 1.139%/°C. $\Sigma T50_s$ arranged from 276.44°C for Boussellem to 337.13°C for G4 with genotypic mean of 302.25°C. The local landrace Boutaleb which was the best yielding genotype registered the low Sa% (32.49%), a low value of Vs% parameter (0.347%/°C), a low value of Vmax (0.792%/°C) and a high value of $\Sigma T50_s$ (311.91°C) comparing to genotypic means. The genotypes with lowest values of senescence average (Sa%) and highest values of sum of temperatures at mid-senescence were the most tolerant and adapted genotypes (Hafsi and Guendouz, 2020). At full heading, R

Table 2: Analysis of variance of agronomic traits.

Genotypes	Agronomic traits				
	GY (Qs.ha ⁻¹)	TKW (g)	NSm ⁻²	DH (days)	PH (cm)
G1	7.00 (bc)	41.98 (bc)	236.66 (bcde)	136 (d)	62.72 (cd)
G2	3.96 (bc)	35.62 (ef)	213.33 (de)	136 (d)	61.50 (d)
G3	7.05 (bc)	40.83 (bcd)	220.00 (cde)	142 (c)	61.88 (d)
G4	2.88 (c)	36.80 (de)	178.33 (e)	142 (c)	56.11 (e)
G5	4.70 (bc)	36.10 (e)	220.00 (cde)	142 (c)	61.27 (d)
G6	6.16 (bc)	31.88 (fg)	240.00 (bcde)	142 (c)	61.27 (d)
G7	6.89 (bc)	34.36 (efg)	253.33 (abcde)	142 (c)	57.66 (e)
G8	4.45 (bc)	30.91 (g)	268.33 (abcd)	136 (d)	61.16 (d)
G9	6.61 (bc)	46.69 (a)	310.00 (ab)	142 (c)	65.55 (abc)
G10	8.69 (ab)	41.98 (bc)	268.33 (abcd)	136 (d)	67.38 (a)
G11	2.95 (c)	44.47 (abc)	285.00 (abcd)	142 (c)	67.22 (a)
Jupare C 2001	7.89 (bc)	41.98 (bc)	255.00 (abcd)	136 (d)	63.61 (bcd)
Boussellem	4.75 (bc)	40.39 (cd)	291.66 (abc)	142 (c)	63.94 (bcd)
Boutaleb	13.59 (a)	44.96 (ab)	320.00 (a)	147 (a)	66.16 (ab)
Oued El Bared	7.59 (bc)	43.27 (abc)	276.66 (abcd)	146 (b)	63.88 (bcd)
Mean	6.34	39.40	255.77	140.6	62.76
Min	2.87	30.91	178.33	136	56.11
Max	13.59	46.69	320	147	67.38
Génotype effect	ns	***	*	***	***
LSD (5%)	5.672	4.162	76.53	1.526	3.167
CV %	53.45	6.30	17.89	6.4901e-8	3.017

ns: Non-significant; *: Significant ($P<0.05$); Very highly significant ($P<0.001$).

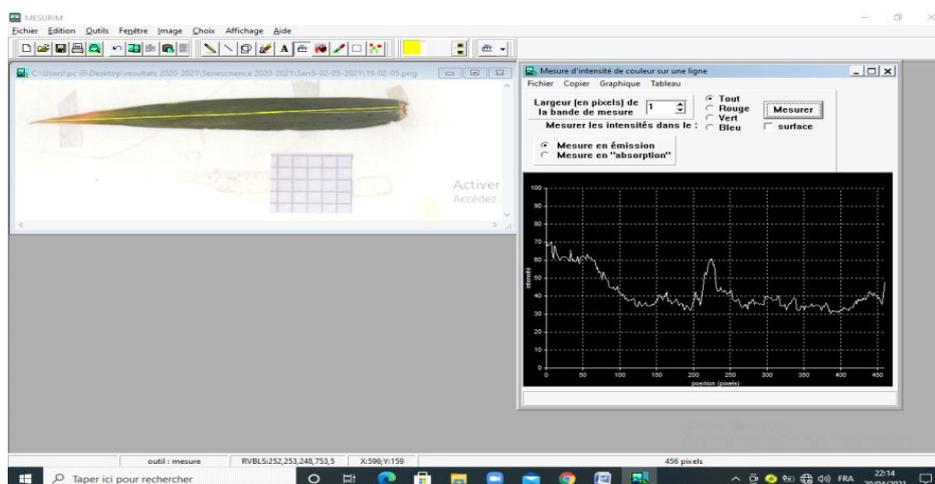


Fig 3: Reflectance calculating in total band using Mesurim_pro_02 software.

(t) was ranged from 32.74% for G7 to 40.77% for G3 with genotypic mean of 36.37%, Boutaleb registered a low value of R(t) (35.85%) comparing to mean. Chlorophyll content was ranged from 26.65 cci for Oued El Bared to 40.81 cci for G4 with genotypic mean of 33.05 cci. The diversity of the yield is a consequence of the variation of the duration rather than the variation of the rate of the photosynthetic activity; the delay of the senescence is a good parameter of selection of the cereals which must be followed (Hafsi et Guendouz, 2020).

Correlations among traits

Correlations among agronomic traits

The study of the correlations among agronomic traits (Table 4) showed that grain yield was high significantly ($P < 0.01$; 0.001) and positively correlated with thousand kernels weight and number of spikes per meter square ($r = 0.38^{**}$; 0.61^{***}). A high and significant ($P < 0.01$; 0.001) and positive correlation was observed between thousand kernels weight and number of spikes per meter square and plant height ($r = 0.39^{**}$; 0.61^{***}). Number of spikes per meter square was significantly ($P < 0.05$) and positively correlated with plant height ($r = 0.34^*$). Several works have proven the high correlation between grain yield and some agronomic traits (Guendouz *et al.*, 2012; Aissaoui and Fenni, 2021 and Mansouri *et al.*, 2018).

Correlations among physiologic traits

The study of the correlations among senescence parameters (Table 3) showed that senescence average (Sa) was highly and significantly ($p < 0.01$; 0.001) correlated with average of Velocity of senescence (Vsa) and maximum of Velocity (Vmax) ($r = 0.47^{**}$; 0.73^{***} respectively) and very highly and negatively correlated with sum of temperatures at 50% of senescence ($\Sigma T50s$) ($r = -0.74^{***}$). Velocity of senescence average (Vsa) was significantly ($p < 0.01$; 0.001) correlated with maximum of velocity ($r = 0.40^{**}$) and negatively correlated with sum of temperatures at mid-senescence and Total reflectance R (t) ($r = -0.63^{***}$; -0.39^{**}). Reflectance at total band R (t) was significantly ($P < 0.05$) and negatively correlated with chlorophyll contents ($r = -0.35^*$), the decrease of leaf reflectance increase the photosynthetic capacity of leaves by increasing radiations absorbed by chlorophyll pigments (Guendouz and Hafsi, 2016). Chlorophyll tends to decline more rapidly than carotenoids when plants are under stress or during leaf senescence (Gitelson and Merzlyak, 1994).

Correlation among physiologic and agronomic traits

Days to heading was high significantly ($p < 0.01$) and negatively correlated with senescence average and maximum of velocity ($r = -0.38^{**}$, $r = -0.41^{**}$) this results imply that precocity increases senescence rate, velocity average

Table 3: Analysis of variance of physiologic traits.

Genotypes	Sénescence parameters				Total reflectance	Chlorophyll contents
	Sa (%)	Vsa (%/°C)	Vmax (%/°C)	$\Sigma T50_s$ (°C)	R(t) (%)	CC (cci)
G1	44.66 (b)	0.327 (m)	1.412 (b)	310.37 (c)	36.87 (c)	29.00 (de)
G2	44.76 (a)	0.382 (h)	1.593 (a)	278.97 (i)	38.73 (b)	30.18 (de)
G3	39.03 (g)	0.319 (n)	0.887 (i)	301.72 (ef)	40.77 (a)	30.21 (de)
G4	29.68 (l)	0.335 (l)	0.837 (j)	337.73 (a)	36.84 (c)	40.81 (a)
G5	32.52 (k)	0.348 (k)	1.059 (f)	327.69 (b)	36.45 (cd)	29.71 (de)
G6	35.32 (j)	0.370 (i)	0.954 (gh)	307.4 (d)	35.63 (def)	31.40 (cde)
G7	38.83 (h)	0.405 (f)	1.149 (e)	302.72 (e)	32.74 (g)	37.73 (ab)
G8	38.95 (g)	0.403 (g)	1.425 (b)	288.47 (h)	35.98 (cde)	32.15 (cde)
G9	40.53 (e)	0.415 (e)	0.941 (h)	295.14 (g)	36.17 (cde)	36.12 (abc)
G10	37.31 (i)	0.357 (j)	1.041 (f)	299.81 (f)	34.93 (f)	33.83 (bcd)
G11	40.06 (f)	0.420 (c)	1.254 (d)	295.14 (g)	35.71 (def)	35.90 (abc)
Jupare C 2001	41.59 (d)	0.417 (d)	0.975 (g)	299.81 (f)	35.61 (def)	38.16 (ab)
Boussellem	41.65 (d)	0.429 (a)	1.380 (c)	276.44 (j)	35.25 (ef)	34.16 (bcd)
Boutaleb	32.49 (k)	0.347 (k)	0.792 (k)	311.91 (c)	35.85 (def)	29.66 (de)
Oued El Bared	44.02 (c)	0.422 (b)	1.380 (c)	300.42 (f)	37.98 (b)	26.65 (e)
Mean	38.76	0.379	1.139	302.25	36.37	33.05
Min	29.68	0.319	0.792	276.44	32.74	26.65
Max	44.76	0.429	1.593	337.73	40.77	40.81
Genotype effect	***	***	***	***	***	***
LSD _(5%)	0.093	0.002	0.024	2.189	0.925	5.533
CV %	0.14	0.29	1.30	0.43	1.52	10.01

***: Very highly significant ($P < 0.001$).

Table 4: Correlations among physiologic and agronomic traits.

	Sa	Vsa	Vmax	"T50s	R(t)	CC	GY	TKW	NSm ²	DH	PH
Sa	1										
Vsa	0.47**	1									
Vmax	0.73***	0.40**	1								
"T50s	- 0.74***	- 0.63***	- 0.61***	1							
R(t)	0.19	-0.39**	0.07	-0.01	1						
CC	- 0.22	0.19	- 0.28	0.11	- 0.35 *	1					
GY	- 0.05	-0.13	- 0.28	0.05	- 0.04	- 0.02	1				
TKW	0.19	0.10	- 0.20	-0.07	0.14	- 0.08	0.38**	1			
NSm ²	0.14	0.35*	- 0.01	- 0.30*	- 0.27	0.07	0.61***	0.39**	1		
DH	- 0.38**	0.04	- 0.41**	0.29	0.02	- 0.12	0.18	0.28	0.20	1	
PH	0.24	0.21	0.02	- 0.34*	0.01	- 0.29	0.27	0.61***	0.35*	0.03	1

*Significant (P<0.05); **Highly significant (P<0.01); ***Very highly significant (P<0.001).

had a positive significance (P<0.05) correlation with number of spikes per meter square ($r = 0.35^*$), sum of temperatures a mid-senescence was significantly (P<0.05) and negatively correlated with number of spikes per meter square and plant height ($r = -0.30^*$; -0.34^*) (Table 4). These results are relatively adequate with those of Guendouz *et al.*, (2013) who suggested more or less similar correlations with some agronomic traits.

CONCLUSION

This study confirms the efficiency of the use of flag leaf senescence, total reflectance and chlorophyll contents at full heading as selection criteria for durum wheat in semi-arid areas using numerical image analysis (NIA). ANOVA showed that genotype effect was significant for thousand kernels weight, number of spikes per meter square, number of days to heading and plant height. Genotype effect were also significant for all senescence parameters, total reflectance and chlorophyll contents at full heading. The study of the correlations showed that grain yield was high significantly and positively correlated with thousand kernels weight and number of spikes per meter square, in addition all senescence parameters were significantly correlated. The negative correlation between chlorophyll contents and total reflectance at full heading suggest that the decrease of leaf reflectance increase the photosynthetic capacity of leaves by increasing radiations absorbed by chlorophyll pigments. The negative correlation between number of days to heading and senescence average and maximum of velocity implies that precocity increases senescence rate.

Conflict of interest

Authors declare that they have no conflict of interest.

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