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Stay-green effects on adaptability and stability in wheat

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The delayed leaf senescence (*stay-green*) has been frequently attributed to significant yield gains in different crops, especially under stress conditions. The goal of the study was to elucidate if the delayed leaf senescence of the wheat plant through the expression of the *stay-green* character brings effective contributions to adaptability and stability parameters for yield and weight of a thousand grains, aiming for genetic gains in the selection of more stable and productive genotypes. The experiment was conducted on the years 2003, 2004 and 2005 under field conditions. The experimental design was random blocks with three repetitions involving lines selected for high grain yield and distinct maturation groups (presence and absence of *stay-green*). The delayed leaf senescence in wheat had a strong contribution on the stability and increment in grain yield, especially in unfavorable years due to reduced precipitation. However, no changes were detected for the character weight of a thousand grains. Therefore, the introduction of the *stay-green* character into elite lines and cultivars represent a promising strategy for more stable and higher yielding wheat genotypes.

Key words: *Triticum aestivum* L., delayed senescence, grain yield, weight of thousand grains.

INTRODUCTION

Earth climate changes have set bigger challenges for plant breeders searching for superior genotypes (Araus et al., 2008). Beyond genetic gains for high yield and grain quality, maintaining yield stability by the reducing of losses by environmental stresses has received great attention (Oliveira et al., 2011). Among the strategies, the introduction of *stay-green* (delayed leaf senescence at late grain filling stage) character has shown promising results in several species. Strong evidences of the greater adaptability of *stay-green* genotypes under

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drought stress have been reported for *sorghum* (Kassahun et al., 2010), maize (Costa et al., 2008) and wheat (Izanloo et al., 2008). An evaluation of 936 wheat lines detected a significant association between tolerance to stresses by high temperatures and *stay-green*, indicating the delayed leaf senescence as a criterion for heat tolerance selection (Kumari et al., 2007). Plants with the character *stay-green* showed a lower reduction of the photosynthetic active area close to the physiological maturity (Ahlawat et al., 2008). Thus, delaying leaf senescence closer to physiological maturity stages may promote higher translocation and grain filling rates with direct reflex on yield components (Kumar et al., 2010).

Strong G x E interaction effects on grain yield has been reported for the wheat plant, making it difficult to select superior performance genotypes (Sanchez-Garcia et al., 2012). The analysis of adaptability and stability is essential for the partitioning of this interaction, allowing the identification of cultivars with predictable behavior and responsive to changes in environment (Franceschi et al., 2010). Among the various methods available for this determination, those based on regression of phenotypic values in relation to an environmental index have been the most widely used. Among those, is the model proposed by Eberhart and Russell (1966), commonly reported for cereals (Crestani et al., 2010). From regression models, the termed traditional method has also been used to estimate the stability with the advantage of application to a limited number of environments (Cruz et al., 2004). It is important to combine the adaptability and stability analysis via regression with other methods such as traditional, strengthening the inferences to be drawn against the predictability of genotypes (Silva and Duarte, 2006).

The contribution of genes that promote delayed leaf senescence of the plant may represent an effective mechanism that favors grain filling, adding benefits related to the higher yield stability. Thus, the aim of this study was to elucidate if the delayed leaf senescence in wheat by the expression of *stay-green* character brings forward effective contributions to the parameters of adaptability and stability in grain yield and thousand grain weight, longing for the possibility of genetic gain in selection of more stable and productive genotypes.

MATERIALS AND METHODS

The populations were formed by crossing the genetic constitutions of wheat TB438 (bearer of character "*stay-green*") and TB188 (synchronized maturation) comprising lines selected by the breeding program of Embrapa Clima Temperado (Pelotas/RS) obtained via recurrent selection with several promising lines that had the character *stay-green* and others revealing synchronized senescence. In 1998, crosses were made between these lines and the F_1 generation was obtained and used to obtain the two backcrosses and the F_2 population. These lines were advanced for many generations (F_n) in order to reach high grain yield and differences in maturity, that is, *stay-green* (SG) and synchronized (SZ). Moreover, the backcrosses, $RC1F_1$ (P1 // P1/P2) and $RC2F_1$ (P2 // P1/P2), respectively, were subjected to self-pollination and selected for the presence and absence of the *stay-green* character until highly homozygous.

It is noteworthy that in these populations the selection also involved the simultaneous analysis for high grain yield and presence/absence of *stay-green* character. In 2002, 14 *stay-green* (SG30, SG39, SG47, SG53, SG65, SG71, SG74, RC1SG32, RC2SG34, RC2SG40, RC2SG46, RC2SG54, RC2SG62, RC2SG67), 16 synchronized (SZ31, SZ37 SZ49, SZ57, SZ69, RC1SZ43, RC1SZ45, RC1SZ55, RC1SZ58, RC1SZ68, RC1SZ72, RC1SZ76, RC2SZ35, RC2SZ42, RC2SZ56, RC2SZ61) were obtained and compared to parental lines TB438 and TB188.

The lines that were conducted in 2003, 2004 and 2005 in the experimental field located in Capão do Leão County, Rio Grande do Sul State, Brazil. And the soil is classified as Red Yellow Podzolic unit in Mapping Pelotas, which its U.S. equivalent is Typic Hapludalf (USDA, 2010). The County is situated at 31°52'00" S lat and 52°21'24" W long at an altitude of 13.24 m, with an average annual rainfall of 1280.2 mm.

A randomized complete block design with three replications was used, and each experimental unit consisted of five lines with three meters in length and spacing of 0.2 m, in a seeding rate of 300 viable seeds m^{-2}. The fertilization and liming were made based on recommendations for wheat to an expected crop yield around 2 t ha^{-1}. Other cultural practices such as weed control, diseases and pests were performed according to the indications for the crop.

This study evaluated the grain yield (GY, kg ha^{-1}) obtained by the yield value of each plot and scaled to a hectare, weight of a thousand grains (WTG, g), by the count of 250 grains in each plot with subsequent weighing and multiplied by four. Data were subjected to variance analysis (ANOVA) and comparison of means between wheat lines contrasting for the maturation in different growing seasons. After, it was determined by traditional phenotypic stability method based on environmental variation for each genotype, recommending that those who showed the smallest mean square values are considered stable (Cruz et al., 2004). Also, adaptability and stability parameters were obtained using the Eberhart and Russell (1966) method, based on linear regression using the mathematical model $Y_{ij} = \beta_{oi} + \beta_{1i}I_j + \delta_{ij} + \bar{\varepsilon}_{ij}$, where Y_{ij} is the average of genotype i at environment j; β_{oi}: overall average genotype i; β_{1i}: linear regression coefficient which measures the response of the genotype to variation of the environment; I_j: environmental index coded ($\sum_j Ij = 0$); δ_{ij}: deviations from regression; and $\bar{\varepsilon}_{ij}$: average experimental error. The genotype predictability was obtained with the determination coefficient (R^2). All analyzes were performed using the GENES software (Cruz, 2006).

RESULTS AND DISCUSSION

The genotype versus year (GxY) analysis indicated a significant source of variation for grain yield (GY) therefore a comparison of means was performed seeking to decompose the interaction effects (Table 1). The GY average for the lines TB438, SG65, SG74 and RC1SZ72 did not differ between years, suggesting a trend towards stability. However, despite the stability shown by the genotype RC1SZ72, it expressed a lower average grain yield than the lines carrying the *stay-green* character in different years, showing superiority of genotypes with

Table 1. Mean performance of wheat lines from different maturity groups in grain yield (GY, kg ha^{-1}) harvested in 2003, 2004 and 2005 in Capão do Leão County, RS, Brazil.

Character	Mean square				General	CV
	Genotype (G)	Year (Y)	GxY	Error	Mean	(%)
GY	**699850***	**16201278***	**307039***	**61214**	**2005**	**22.34**

Lines	GY mean values			
	2003	2004	2005	Mean
TB438^{gg}	A 2233[+] c	A 2042 c	A 2126 a	2134 a
SG30	A 2414 c	A 2241 b	B 1774 a	2143 a
SG39	A 2734 b	A 2760 a	B 1552 b	2349 a
SG47	A 2740 b	B 2210 b	B 2230 a	2394 a
SG53	A 3103 a	B 2443 b	B 2215 a	2587 a
SG65	A 2311 c	A 2523 b	A 2124 a	2319 a
SG71	A 3055 a	A 2763 a	B 1612 b	2477 a
SG74	A 2407 c	A 2379 b	A 2137 a	2308 a
RC1SG32	A 2609 b	A 2902 a	B 1322 c	2278 a
RC2SG34	A 2611 b	B 1562 d	B 1629 b	1934 b
RC2SG40	A 2524 b	A 2787 a	B 948 c	2086 a
RC2SG46	A 2922 a	B 1756 d	B 1507 b	2062 a
RC2SG54	A 2434 c	B 2074 c	B 1983 a	2164 a
RC2SG62	A 2941 a	B 2249 b	C 1711 b	2300 a
RC2SG67	A 2533 b	B 1923 c	B 1585 b	2014 b
TB188^{gz}	A 2523 b	B 1331 d	B 992 c	1615 b
SZ31	A 2426 c	B 1601 d	B 1535 b	1854 b
SZ37	A 2659 b	B 1578 d	B 1277 c	1838 b
SZ49	A 2160 c	B 1406 d	B 1389 b	1652 b
SZ57	A 2091 c	B 1488 d	B 1539 b	1706 b
SZ69	A 2500 b	C 1415 d	B 1879 a	1931 b
RC1SZ43	A 2281 c	A 2376 b	B 1262 c	1973 b
RC1SZ45	A 2140 c	B 1493 d	B 1548 b	1727 b
RC1S Z55	A 1907 c	A 1634 d	B 1166 c	1569 b
RC1SZ58	A 2137 c	A 2008 c	B 1437 b	1861 b
RC1SZ68	A 2331 c	A 2524 b	B 1978 a	2278 a
RC1SZ72	A 1802 c	A 1692 d	A 1661 b	1718 b
RC1SZ76	A 2225 c	B 1705 d	B 1315 c	1748 b
RC2SZ35	A 2431 c	B 1555 d	B 1448 b	1811 b
RC2SZ42	A 2141 c	B 1823 c	B 1509 b	1824 b
RC2SZ56	A 1992 c	B 1644 d	B 1318 c	1651 b
RC2SZ61	A 2092 c	A 2051 c	B 1414 b	1852 b
Overall Mean	A 2419	B 1998	C 1598	2005

[+] Means followed by the same letter in the row and column do not differ at 0.05 probability by the Scott & Knott test, * significant at 0.05 probability by the F test; ^{ns} not significant by F test; MS = mean square; CV = coefficient of variation; SG = *stay-green* trait; SZ = synchronized trait; ^{gg} and ^{gz} = *stay-green* parents and synchronized, respectively.

delayed senescence. Inconsistencies were found between high yield and stability in lines of *Triticum durum* L., confirming the need for the simultaneous assessment of these characters in order to release new superior genotypes (Pedro et al., 2011). Environments of greater instability are more amenable to G x E analysis, favoring the identification of responsive and stable genotypes (Crestani et al., 2010).

In the analysis of GY per year of cultivation (Table 1), a higher average yield was observed in 2003 (2419 kg ha^{-1}), proved to be a favorable year for the crop. Four lines with high GY, all carrying the *stay-green* character, were ranked together and statistically superior to others. In 2004, there was an average GY lower than in 2003, but

Table 2. Monthly precipitation for the years 2003, 2004 and 2005 and expected for the months of June to December, including the relationship between occurred rainfall and the regular for each month (RP), registered in the agrometeorological Pelotas station (EAP Capão do Leão, RS, Brazil).

Month	2003		2004		2005		Ratio
	mm	RP (%)	mm	RP (%)	mm	RP (%)	Mm
June	246.2	233	57.7	55	28.0	26	105.7
July	97.4	67	95.6	65	42.2	29	146.0
August	93.4	79	94.4	80	101.6	86	117.7
September	115.5	93	90.3	73	241.6	195	123.7
October	48.8	48	112.0	111	93.3	93	100.7
November	103.2	104	91.5	92	23.7	24	99.5
December	76.3	74	28.6	28	54.6	53	103.2

Source: EAP (2014).

within the expected average of 2 t ha^{-1}. Accordingly, some of the highest averaging genotypes were also from the delayed maturation type. In 2005, the low average rainfall between the months of November and December were decisive for the lower production values, including restrictive conditions during grain filling (Table 2).

This condition enabled a grain yield of 1598 kg ha^{-1} (Table 1). The reduced availability of water towards the end of the grain filling stage changes the plant relationships between source and drain, the concentration of reactive oxygen (Chen et al., 2010) and accelerates senescence and photoassimilate accumulation (Samarah et al., 2009), causing yield losses.

In more restrictive conditions (2005), nine genetic constitutions showed superior performance in GY, seven carrying the *stay-green* character, including one parent and two expressing synchronized maturation (Table 1). Some delayed maturation genotypes showed, in these conditions, GY values greater than 2 t ha^{-1}, strengthening the evidence that the *stay-green* character favors a greater ability to stress tolerance of reduced water availability in wheat, agreeing with other reports (Adu et al., 2011). A strong relationship in maize chlorophyll content and delayed leaf senescence with a higher yield stability under more restrictive water supply (Messmer et al., 2011). In the analysis involving three year average GY for each genotype (Table 1), near all the *stay-green* genotypes showed the better performance. On the other hand, in the synchronized group, only RC1SZ68 showed superior behavior. Wheat genotypes with delayed senescence indicate significant gains in GY, bringing great prospects for increasing production efficiency by modification of plant photosynthetic ability (Parry et al., 2011).

In the WTG analysis (Table 3), both simple effects such as interaction were statistically significant. Similar to GY, WTG also showed greater magnitude of the mean square for the year of cultivation, indicating the most significant source of variation in character changes (Table 3). Similar results were obtained by G x E analysis in oat (Crestani et al., 2010). A large number of lines showed unchanged average values in WTG over the years of assessment (Table 3), indicating stable behavior of delayed senescence *stay-green* genotypes. In 2003, a favorable year for wheat cultivation, there was a predominance of synchronized maturation genotypes and only three *stay-green* genotypes showing high WTG (Table 3). In this condition, a similar behavior was observed in the parents. In 2004, similar results were observed, with the highest WTG values predominantly displayed by lines of the synchronized maturation group. Of the seventeen lines of superior performance, six were *stay-green* and eleven synchronized.

Also, the synchronized displayed higher WTG expression when compared to the delayed senescence parent (Table 3). Thus, in favorable years (2003 and 2004) little contribution from the *stay-green* character to WTG was observed, prevailing a superiority of synchronized senescence genotypes. These results disagree with the literature regarding contributions of *stay-green* to grain filling (Ahlawat et al., 2008). In wheat, genetic stability for high WTG and the availability of photoassimilates next to anthesis may favor other components connected to yield (Silva et al., 2005). The low performance of *stay-green* lines for WTG may be results of negative relationship among weight average of grains and number of grains per ear, seen that in favorable environments the presence of *stay-green* character improve also the fertility of spikelets, specially of those presents in the base and apical of the ear, where the grains are smaller, reducing to WTG (Luche et al., 2013). Also, positive effects on the number of fertile flowers and spikelets and ear grains have been reported (Silva et al., 2005; Ahlawat et al., 2008). In 2005, the year with highest water stress conditions (Table 2), an opposite behavior was observed in lines with the different maturity groups (Table 3). The *stay-green* genotypes

Table 3. Mean performance of wheat lines from different maturity groups for weight of a thousand grains (WTG, g) harvested in 2003, 2004 and 2005 in Capão do Leão County, RS, Brazil.

Character	Mean square				General	CV
	Genotype (G)	Year (Y)	GxY	Error	Mean	(%)
WTG	**17.95***	**195.67***	**17.36***	**4.73**	**34.69**	**6.27**

Lines	WTG mean values										
		2003			2004			2005		Mean	
TB438[gg]	B	34.30[+]	b	B	32.68	b	A	37.15	a	34.71	a
SG30	A	33.29	b	A	34.65	b	A	32.85	b	33.60	b
SG39	A	29.94	c	A	33.20	b	A	32.83	b	31.99	b
SG47	B	34.03	b	B	33.00	b	A	37.33	a	34.79	a
SG53	B	33.77	b	A	38.77	a	B	35.66	a	36.07	a
SG65	A	38.33	a	B	31.82	b	A	37.00	a	35.72	a
SG71	A	34.76	b	A	34.37	b	A	36.11	a	35.08	a
SG74	B	32.69	b	A	35.60	b	A	37.66	a	35.32	a
RC1SG32	A	33.20	b	A	35.74	b	A	31.36	b	33.44	b
RC2SG34	A	33.31	b	A	36.58	a	A	33.20	b	34.36	b
RC2SG40	A	32.28	b	A	34.69	b	A	33.31	b	33.43	b
RC2SG46	A	36.57	a	A	37.57	a	A	34.91	a	36.35	a
RC2SG54	B	32.33	b	A	36.73	a	B	33.55	b	34.20	b
RC2SG62	B	33.16	b	A	38.12	a	B	32.96	b	34.75	a
RC2SG67	A	39.64	a	A	39.00	a	B	32.01	b	36.88	a
TB188[gz]	B	32.41	b	A	36.96	a	A	36.71	a	35.03	a
SZ31	B	29.91	c	A	37.28	a	B	31.71	b	32.97	b
SZ37	B	33.02	b	A	37.28	a	B	32.80	b	34.37	b
SZ49	A	37.30	a	A	36.13	b	B	32.76	b	35.40	a
SZ57	B	32.68	b	A	37.82	a	B	31.11	b	33.87	b
SZ69	B	28.75	c	A	33.34	b	A	33.33	b	31.81	b
RC1SZ43	A	35.94	a	A	34.21	b	B	28.55	b	32.90	b
RC1SZ45	A	33.42	b	A	35.01	b	B	30.45	b	32.96	b
RC1S Z55	A	35.80	a	A	38.18	a	B	32.26	b	35.41	a
RC1SZ58	B	33.85	b	A	38.97	a	B	34.21	b	35.68	a
RC1SZ68	B	30.86	c	A	40.00	a	A	37.06	a	35.97	a
RC1SZ72	A	36.88	a	A	36.60	a	B	32.25	b	35.24	a
RC1SZ76	A	38.79	a	A	35.78	b	A	34.75	a	36.44	a
RC2SZ35	A	33.30	b	A	34.60	b	A	32.70	b	33.53	b
RC2SZ42	B	32.31	b	A	38.66	a	B	34.03	b	35.00	a
RC2SZ56	B	34.38	b	A	38.57	a	B	31.13	b	34.69	a
RC2SZ61	A	39.34	a	A	40.53	a	B	34.56	a	38.14	a
Mean	B	34.05		A	36.33		B	33.70		34.69	

[+] Means followed by the same letter in the row and column do not differ at 0.05 probability by the Scott & Knott test. * significant at 0.05 probability by the F test; [ns] not significant by F test; MS = square mean; CV = coefficient of variation; SG = *stay-green* trait; SS = synchronized trait; [gg] e [gz] = *stay-green* parents and synchronized, respectively.

showed higher values for WTG. These results coupled with genotype performances in the overall average between years (Table 3) appear to show the greatest effect of *stay-green* on WTG is more evident under conditions of environmental restrictions, enhancing the tolerance to abiotic stresses. Results were also observed in other species (Izanloo et al., 2008; Adu et al., 2011).

Seeking to strengthen the evidence and hypotheses, the results of adaptability and stability analyses through simple regression, proposed by Eberhart and Russell (1966) and stability of the traditional method were obtained (Table 4). The variable GY in the *stay-green* character genotypes showed higher values than on those with synchronized maturation. Moreover, WTG means were equivalent for both groups of maturation. This reinforces the hypotheses reported by other researchers,

Table 4. Mean values (β_0), adaptability parameters (β_1) and stability (S²d) and determination coefficient (R^2) by Eberhart & Russell and through the Traditional Method (NDE) on grain yield (GY, kg ha^{-1}) and weight of a thousand grains (WTG, g) on wheat lines of distinct groups of maturation.

Lines	GY					WTG				
	β_0	β_1	S²d	R^2	NDE	β_0	β_1	S²d	R^2	NDE
TB438^{gg}	2133 a	0.13*	-8077 ^{ns}	83	27500^{ns}	34.71 a	-1.35*	1.28 ^{ns}	72	15.36*
SG30	2143 a	0.78^{ns}	-4326 ^{ns}	93	329548*	33.59 b	0.65^{ns}	-1.56 ^{ns}	98	2.65^{ns}
SG39	2349 a	1.43^{ns}	245598*	72	1429714*	31.99 b	0.60 ^{ns}	3.30 ^{ns}	63	9.53^{ns}
SG47	2394 a	0.63 ^{ns}	27699 ^{ns}	73	270700*	34.79 a	-1.22*	2.60 ^{ns}	69	15.36*
SG53	2587 a	1.09 ^{ns}	7678 ^{ns}	93	639097*	36.07 a	1.55 ^{ns}	1.44 ^{ns}	76	19.11*
SG65	2319 a	0.22*	42822 ^{ns}	81	119565^{ns}	35.72 a	-2.29*	0.74 ^{ns}	90	35.43*
SG71	2477 a	1.75*	113058*	89	1746157*	35.08 a	-0.49*	-0.87 ^{ns}	78	2.51^{ns}
SG74	2308 a	0.33*	-12360 ^{ns}	82	65882^{ns}	35.32 a	-0.05 ^{ns}	10.90*	57	18.72*
RC1SG32	2277 a	1.55*	583926*	57	2118685*	33.44 b	1.47 ^{ns}	-0.69 ^{ns}	91	14.51*
RC2SG34	1934 b	1.21 ^{ns}	177892*	71	1033253*	34.36 b	1.34 ^{ns}	-1.51 ^{ns}	99	11.10^{ns}
RC2SG40	2086 a	1.90*	744560*	61	2968835*	33.43 b	0.71 ^{ns}	-0.74 ^{ns}	71	4.37^{ns}
RC2SG46	2062 a	1.73*	108952*	89	1711585*	36.35 a	0.81 ^{ns}	-0.62 ^{ns}	74	5.40^{ns}
RC2SG54	2164 a	0.55 ^{ns}	-9418 ^{ns}	90	170281^{ns}	34.2 b	1.47 ^{ns}	-0.05 ^{ns}	85	15.48*
RC2SG62	2300 a	1.50*	-17855 ^{ns}	99	1140015*	34.74 a	2.04 ^{ns}	-1.44 ^{ns}	99	25.59*
RC2SG67	2013 b	1.16 ^{ns}	-10153 ^{ns}	98	692953*	36.88 a	1.60 ^{ns}	23.73*	49	53.64*
TB188^{gz}	1615 b	1.87*	90511*	91	1939534*	35.03 a	0.93 ^{ns}	14.52*	48	29.47*
SZ31	1854 b	1.09 ^{ns}	69808*	82	739497*	32.97 b	2.52*	2.09 ^{ns}	88	44.23*
SZ37	1838 b	1.69*	72306*	91	1583982*	34.36 b	1.76 ^{ns}	-1.50 ^{ns}	99	19.11*
SZ49	1651 b	0.95 ^{ns}	65526*	78	582131*	35.4 a	0.64 ^{ns}	7.85*	55	16.62*
SZ57	1706 b	0.68 ^{ns}	47758*	69	335239*	33.87 b	2.45*	-1.33 ^{ns}	99	36.97*
SZ69	1931 b	0.77 ^{ns}	371299*	33	888512*	31.81 b	0.73 ^{ns}	10.31*	55	21.06*
RC1SZ43	1973 b	1.23 ^{ns}	233489*	67	1143172*	32.9 b	1.11 ^{ns}	23.35*	57	44.89*
RC1SZ45	1727 b	0.73 ^{ns}	58145*	70	385815*	32.96 b	1.36 ^{ns}	1.59 ^{ns}	71	16.10*
RC1S Z55	1569 b	0.90 ^{ns}	-12906 ^{ns}	97	421187*	35.41 a	1.82 ^{ns}	2.68 ^{ns}	76	26.61*
RC1SZ58	1860 b	0.85 ^{ns}	14670 ^{ns}	87	416894*	35.68 a	1.97 ^{ns}	-1.02 ^{ns}	97	24.46*
RC1SZ68	2277 a	0.42*	72614*	39	230094*	35.97 a	2.16 ^{ns}	23.04*	44	65.33*
RC1SZ72	1718 b	0.17*	-19464 ^{ns}	92	16528^{ns}	35.24 a	1.02 ^{ns}	7.71*	51	20.23*
RC1SZ76	1748 b	1.11 ^{ns}	-18486 ^{ns}	99	626210*	36.44 a	-0.22*	7.03*	42	13.20^{ns}
RC2SZ35	1811 b	1.20 ^{ns}	72120*	84	873797*	33.53 b	0.67 ^{ns}	-1.51 ^{ns}	96	2.83^{ns}
RC2SZ42	1824 b	0.77 ^{ns}	-20378 ^{ns}	99	299254*	35.00 a	2.13 ^{ns}	1.53 ^{ns}	85	32.42*
RC2SZ56	1651 b	0.82 ^{ns}	-20398 ^{ns}	99	340502*	34.69 a	2.47*	1.29 ^{ns}	90	41.73*
RC2SZ61	1852 b	0.82 ^{ns}	42052*	78	433369*	38.14 a	1.64 ^{ns}	7.38*	55	29.91*

$^{+}$ Means followed by the same letter in the row and column do not differ at 0.05 probability by the Scott & Knott test, * significant at 0.05 probability by the F test; ^{ns} not significant by F test; MS = Square Mean; DF = degrees of freedom; CV = coefficient of variation; SG = *stay-green* trait; SZ = synchronized trait; ^{gg} and ^{gz} = *stay-green* parent and synchronized, respectively.

indicating the superiority of *stay-green* genotypes in yield of grain goes beyond the greater capacity of grain filling, having an influence on other characters also linked to the formation of yield components (Silva et al., 2005; Ahlawat et al., 2008). The lines studied for GY indicated that the synchronized genotypes accounted for the majority of individuals with wide adaptability (β_1=0), showing greater responsiveness to environmental improvements. Moreover, the *stay-green* parent showed specific adaptability to the unfavorable environment, ranking on top in GY, unlike the parent synchronized, adjusted to favorable environments, but among the lowest in the character expression. However, TB438, SG65 and SG74 showed significantly lower adaptability values (β_1 <1.0), which, associated with phenotypic stability, discloses independently of method used, lines of great potential as sources for alleles for high GY and stability in unfavorable environments.

For WTG, the numbers of individuals with wide adaptability from different maturation groups were similar. The *stay-green* parent showed specific adaptability to harsh environments and was also included in the group expressing the best averages. On the other hand, the synchronized parent showed general adaptation, was also represented the group that expressed the highest values in character. Therefore, the similarity in WTG mean between the parents and the proportions of lines between maturity groups possibly indicate that the contribution of *stay-green* also affects other important characters in the increase of grain yield (Table 4). Stability parameters in the method of Eberhart and Russell (S^2d and R^2), the majority of exhibit delayed senescence genotypes were in stable expression of GY. It is noteworthy stability observed for who shows more permanent green plant next harvest parent, unlike what happened to the parent of synchronized pattern. In the analysis involving the traditional method (NDE) for the same character, there was a reduction in the number of phenotypic stability genotypes, showing that all tested lines, four belonged to the *stay-green* group and only a trend with the synchronized maturation. In a general analysis, involving the two observation methods, TB438, SG65, SG74 and RC2SG54 genotypes were those that showed the stability and effectiveness fully belong to *stay-green* ripening group. Even were included that expressed the best medium and limited adaptability to harsh environments group. We highlight the RC2SG54 lineage, because in addition to expressing high average with stability, was the one who showed ability to adapt front to GY expression in different years of assessment. Thus, maintenance of the photosynthetic active machinery for favoring higher chlorophyll concentration in tissues, provides maintenance of grain filling, providing greater stability in yield and grain yield, particularly under stress conditions (Izanloo et al., 2008).

Regarding WTG (Table 4), the adaptability parameter (β_1) from the Eberhart and Russell method was found to be similar between the two maturity groups, with the *stay-green* parent indicating adaptability to restricted environments and the synchronized with wide adaptation. It is highlighted by this method (S^2d and R^2), a slight tendency to stability in a larger number of lines representing the *stay-green* group. In the mean square stability analysis, six *stay-green* (SG30, SG39, SG71, RC2SG34, and RC2SG40 RC2SG46) and only one synchronized (RC1SZ72) line were stable. It is noteworthy that for WTG, the RC2SG46 genotype showed both high adaptability and stability by both methods.

The traditional method was more conservative than the Eberhart and Russell, detecting a lower number of stable genotypes. On the other hand, the study of correlations between methods for estimating stability and adaptability, indicated a high positive (0.83) correlation between the traditional method and proposed by Eberhart and Russell (1966) and Silva and Duarte (2006). However, the model in the Eberhart and Russell (1966) method takes into account a higher number of parameters for the analysis, defining an ideal genotype as one which displays high yield (β_0), regression coefficient equal to 1.0 (β_1= 1.0) and regression deviation equal to zero (S^2d =0), in other words, high average values for the character, wide adaptability and stability, respectively (Cruz et al., 2004).

Conclusions

Delayed senescence wheat plants have higher stability and grain yield, especially in unfavorable years marked by reduced precipitation. However, no detectable influence is found on weight of a thousand grains. The introduction of the *stay-green* character into superior cultivars and lines represents a promising strategy to obtain more stable and productive wheat genotypes.

Conflict of Interest

The authors have not declared any conflict of interest.

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