Article

Genetic variability and criteria for selecting yield and its components in rainfed wheats

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Abstract

Knowledge of the genetic variability and yield heritability and its components within the plant breeding allows to optimize the selection process. The objective of the research was to determine the genetic variability of yield and its components, as well as their correlations to identify selection criteria for increased grain productivity. 19 genotypes, planted in the spring-summer cycle, were used in 7 locations of rainfed in Mexico's High Valleys. The experimental design was Alpha lattice with two repetitions in each environment. The experimental unit was four grooves 3 m long with a separation of 30 cm. The variables evaluated were: days at maturity, plant height, grains per spigot, number of spikes of wheat and grains per square meter, as well as harvest index, weight of a thousand grains and grain yield. The highest coefficients of genetic variation 20.8 and 18.4 were for grain and grain yield per spigot, respectively. But the highest genetic variations and heritability are presented by the weight of a thousand grains and grains per spigot which facilitates the selection of these characters. The yield had significant correlations with number of grains per square meter, grains per spigot, number of spikes and harvest index with values of 0.92, 0.57, 0.54 and 0.54, respectively. So, they can be used as selection criteria to promote productivity. For this group of genotypes, it is necessary to increase the genetic variability for spigot per square meter and weight of a thousand grains. It is proposed to the genotypes Don Carlos M2015, 6, 11 and 8 as genetic sources to increase the weight of grain, number of grains per spike, greater number of spikes and grains per square meter to promote grain yield.

Keywords: coefficient of genetic variation, genetic variability, heritability, selection criteria, yield components.

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Introduction

The national average yield on wheat *(Triticum aestivum* L.) under rainfed conditions in Mexico was 2.5 t ha^{-1} with a planted area of 71 193 ha (SIAP, 2020) in 2019. However, it is estimated that its planted area can be increased by up to 300 000 ha in such a way that such production may be an option to reduce imports of this cereal which were around 4.2 million tons in 2016 (Canimolt, 2016). One condition for the crop to be more accepted among producers is to increase its profitability through the use of varieties with greater yield potential.

For this reason, one of the main objectives of the rainfed wheat improvement program of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) in Mexico is the release of varieties that match high yield potential (Villaseñor *et al*., 2018), tolerance to foliar diseases (Rodríguez-García *et al*., 2019) and that meet quality demanded by the industry (Hortelano *et al*., 2016).

In the case of genetic improvement for greater yield potential under irrigation conditions in Mexico some physiological selection criteria have been incorporated such as the weight of a thousand grains (Lopes *et al*., 2012), harvest index and aerial biomass (Lopes and Reynolds, 2011), in such a way that annual gains have been made in restricted low irrigation yield of 1.35% (Paquini *et al*., 2016), due to the intensive use of inputs, but a limit has been reached so it is necessary to look for new improvement strategies to maintain these advances.

In this context, in the case of the rainfed wheat program, it is necessary to incorporate different tools within these physiological variables as criteria that help the selection of genotypes of greater yield potential. As part of these strategies, the use of yield components is mentioned for the implementation of multi-selection schemes or indirect yield selection. This requires knowledge of the local genetic variability because the selection depends on it.

Genetic variability is expressed in dispersion measures such as range, phenotypic and genotypic variances, however, the coefficient of genetic variation is the best parameter for this purpose (Ehdaie and Waines, 1989). In this regard, Fellahi *et al*. (2013) reported values of phenotypic variance, genetic variance and coefficient of genetic variation for plant height of 98.33, 64.26 and 10.37, respectively; for weight of one thousand grains 15.05, 9.09 and 9.84; for grains per spigot 71.91, 40.48 and 5.17; for harvest index 10.05, 3.93 and 5.17, as well as for grain yield 29.39, 5.2 and 9.84.

Stress by a biotic agent can modify yield components, such as reducing the number of fertile spigots per unit area and the number of grains per spigot (Abayomi and Wright, 1999) and it is recognized that grain filling is negatively influenced by high temperatures and drought during maturation (Chmielewski and Kohn, 2000). Wheat yield is often analyzed in terms of yield components: spigots by area, grains per spigot or grain size, as well as their correlations. However, the compensations between them are the main obstacle to improving yield (Slafer *et al*., 2014).

The objective of this research was to determine the genetic variability of yield and its components, as well as their correlations to identify criteria to increase the response to selection for grain yield in wheat (*Triticum aestivum* L.) for rainfed in the High Valleys of the Central Plateau of Mexico.

Materials and methods

19 wheat genotypes were used, Table 1. Five correspond to the commercial varieties: Romoga F96, Tlaxcala F2000, Triunfo F2004, Altiplano F2007 and Don Carlos M2015. Which have been recommended for planting in different environments of rainfed by INIFAP in different periods. On the other hand, the remaining 14 lines are the elite genotypes of the program, which have good yield potential, disease tolerance and the bakery quality demanded by the national industry. So, this group of genotypes are the most outstanding of INIFAP program in Mexico and commercial varieties are included as witnesses.

Table 1. Wheat genotypes included in the study of variability and genetic associations.

Number	Genotype
1	ROH//CENT WHITE/SNP/7/FAHAD_4/FARAS_1/5/274/320//BGL/3/MUSX/LYNX
2	ALHE/JUCHI
3	PFAU/SERI.1B//AMAD/3/WAXWING/4/BABAX/LR42//BABAX*2/3/KURUKU
4	Tlaxcala F2000
5	Romoga F96
6	GAVIA/ROM/GAL//BAR/MILAN/3/NANA
7	GAV/ROM/GALV//BARC
8	NAH/3/ALHE
9	WBLL1/KAMB1//REB/3/BAR//GAV/GAL/4/NAH
10	Don Carlos M2015
11	KA/NAC//TRCH/3/DANPHE #1
12	PRL/2*REB/3/BAR/GAV/OCOR/4/TRI
13	Gavia/ROM/GAL//BAR/MILAN/3/NANA
14	Gavia/ROM/GAL//BAR/MILAN/3/NANA
15	Altiplano F2007
16	ROH//CENT. White/SNP/7/FAHAD_4/FARAS_1/5/274/320//BGL/3/MUSX/LYNX
17	Monr/NANA
18	BAX*2/PRL//TLAX/3/NANA
19	Triunfo F2004

Genotypes were planted during the spring/summer cycle (PV) in seven environments of rainfed formed as follows: Soltepec, Tlaxcala; Juchitepec (2 dates), Tlalmanalco, Coatepec, Chapingo and Santa Lucía, State of Mexico. The towns of Santa Lucia de Prías and Chapingo are characterized by a temperate sub-humid climate C (Wo) (W) b(y)g. Chapingo is located at 19° 13' north latitude (LN) and 98° 51' longitude west (LO) at 2 250 meters above sea level (msnm) and St. Lucia is located at 19° 44' LN and 98° 87' LO at 2 260 msnm. Juchitepec and Coatepec are classified as humid temperate climate, Juchitepec is located at 2 571 msnm between 19° 06' LN and 98° 53' LO and Coatepec at 2 320 msnm.

The geographic coordinates of Soltepec, Tlaxcala are located at coordinates 19° 04' 00" and 19° 12' 42" LN and 97° 40' 36" and 97° 12' 36" LO. The height of the municipality ranges from 2 360 to 2 920 msnm. The municipality Tlalmanalco, Mexico State is located in the geographical coordinates 19° 80' 48" and 19° 15' 43" LN and 98° 37' 58" and 98° 51' 20" LO with an average altitude of 2 400 m (García, 1981).

The experimental design was Alpha lattice with two repetitions in each environment. The experimental unit was four grooves 3 m long with a separation of 30 cm. The planting density was 120 kg ha^{-1}, it was fertilized with the formula 40-20-00, applying all N and all P to the planting. Urea ($CO(NH_2)_2$) with 46% N and triple calcium superphosphate ($Ca(H_2PO_4)_2$) with 46% P_2O_5 was used as source of fertilization. Weed control was carried out with Esteron 47® and Topik 24EC®, respectively.

The variables evaluated in the experimental unit were: days to maturity (DM) which were determined when 80% of the aerial part of the plants showed straw color. The plant height was measured from the ground surface to the tip of the spigot in each experimental unit. (AP, cm). The number grains per spigot (GPE) that was determined by counting and averaging the number of grains per spigot in 10 complete spikes. The number of spikes per square meter (EPMC) was determined by counting the plants into four rows and dividing it among the harvest area.

Prior to harvest, a sampling of 50 stems was obtained to estimate the harvest index (IC) which was calculated by dividing the grain yield of the 50 stems and the total weight of the 50 stems. The harvest of the entire plot was done with a mini-combined Wintersteiger® when the grain moisture was less than 14% and the grain yield in kg ha^{-1} was measured (RENG). A random sample of 200 grains was taken from each plot to determine the weight of a thousand grains (PMG). The number of grains per square meter (GPMC) was obtained through the EPMC and GPE product.

The data was analyzed using SAS GLM (SAS Institute, 2002). A variance analysis was performed for environments and genotypes, Tukey tests ($p \leq 0.05$) were performed for comparison between genotype means and environment means. The coefficient of genetic variation was calculated by the quotient of the genetic standard deviation divided by the mean.

Coefficients greater than 20 are classified as high genetic variability, 10 to 20 intermediate genetic variability and less than 10 low variability. Inheritability was obtained by dividing genetic variance among phenotypic variance. In addition, simple correlations were obtained through the SAS CORR procedure.

Results and discussion

Table 2 presents the genetic variances, environmental variances and their interaction, as well as the grain yield and its components. Where it was observed that the grain per spigot variables, weight of a thousand grains and harvest index have greater genetic variance, while days at maturity, plant height, spigot per square meter, grains per square meter and grain yield was greater environmental variance.

This indicates that the grain variables per spigot, weight of one thousand grains and harvest index have a greater variation between genotypes indicating greater number of segregating *loci* and therefore greater number of different genotypes that can be selected (Molina, 1992; Espitia *et al*., 2004).

Table 2. Variance components for yield and their components of 19 wheat genotypes evaluated in seven environments of rainfed.

Variable	σ^2_{LOC}	$\sigma^2_{REP(SUBQ)}$	σ^2_{G}	σ^2_{LOC*G}	σ^2_{Error}
DAM	132.76	1.21	7.63	1.12	0.36
AP	58.78	2.53	28.97	1.86	32.32
EPMC	1721.4	426.22	528.31	873.75	2848.8
GPMC	2096316.3	152122.2	1190995.6	1561923.2	1909841.9
GPE	8.17	1.1	29.02	0.22	36.38
PMG	5.03	5	13.36	1.91	7.06
IC	$1x10^{-3}$	$3x10^{-4}$	$2x10^{-3}$	$1x10^{-3}$	$2x10^{-3}$
RENG	258411.3	86054.4	182274.3	164532.3	190295.7

DM= days to maturity; AP= plant height; GPE= number of grains per spigot; GPMC= number of grains per square meter; EPMC= number of spikes per square meter; IC= harvest index; PMG= weight of one thousand grains; RENG= grain yield; σ^2= variance; LOC= locality; REP= repetition; SUBQ= sub block; G= genotype.

The genetic parameters for yield and their evaluated components are given in Table 3. The highest coefficient of genetic variation was for grain yield, but with low heritability values which is partly explained by its genetic variation of less than 30%. The components of grain yield per spigot, number of grains per square meter, harvest index, weight of one thousand grains and number of spigots per square meter, had intermediate genetic variation coefficients.

For weight of one thousand grains and number of grains per spigot the values found of heritability match those indicated by Sadras and Slafer (2012); Philipp *et al*. (2018) who reported heritability of 0.6 and 0.59, respectively. These values were classified as high based on Stanfield (1971). This is explained because 62% of phenotypic variance corresponded to genetic variance indicating that these variables can be easily improved because their variation is mainly due to genetic effects.

Table 3. Genetic parameters for yield and its components in 19 wheat genotypes evaluated in seven environments of rainfed.

Variable	σ^2_P	σ^2_G	h^2	CVG
Days to maturity	133.03	7.63	0.05	2.24
Plant height (cm)	69.46	28.97	0.41	6.1
Spigot per square meter	5870.17	528.31	0.09	10.37
Grains per square meter	5720203.6	1190995.6	0.2	17.15
Grains per spigot	45.43	29.01	0.63	18.42
Weight of one thousand grains (g)	19.02	13.36	0.7	11.54
Harvest index (%)	$4x10^{-3}$	$2x10^{-3}$	0.45	12.49
Grain yield (kg ha^{-1})	699293.7	182274.3	0.26	20.81

$\sigma^2_{P,}$ $\sigma^2_{G,}$ H^2; CVG; phenotypic variance; genetic variance; inheritability and coefficient of genetic variation, respectively.

The harvest index and plant height had intermediate values of heritability, while the lowest values were presented by grain yield, days at maturity and spigot per square meter. In the case of the harvest index its coefficient of genetic variation and heritability allow selection to increase its average from 0.33 to 0.58 since it was the maximum value found (Table 4). This is necessary since indices greater than 0.5 favor the yield potential according to Reynolds *et al*. (2012); Zhang *et al*. (2016) who also indicated the need to increase biomass as it is the source needed to continuously increase yield.

About number of grains per square meter and spigot per square meter amplitudes of 16 854 and 581.47 were obtained indicating that genetic improvement can be applied to take advantage of its variability (Table 4). According to the above, genetic variability for spigot per square meter, weight of one thousand grains and harvest index should be increased. It is possible to select the characteristics of number of grains per spigot and weight of one thousand grains due to their high genetic variability and heritability for the group of genotypes studied.

Table 4. Averages and ranges for yield and their components in 19 wheat genotypes evaluated in seven environments of rainfed.

Variable	Average	Minimum	Maximum	DS
Days to maturity	123.47	98	143	10.8
Plant height (cm)	88.24	55	131	10.71
Harvest index	0.33	0.09	0.58	0.07
Spigot per square meter	221.66	54.63	636.1	78.13
Grains per square meter	6 363	1 251	1 8105	2 558
Grains per spigot	29.25	10.87	81.36	8.47
Weight of one thousand grains (g)	31.69	16.13	45.89	5.54
Grain yield (kg ha^{-1})	2 052	240	5 458	911.65

DS= standard deviation.

Table 5 shows the averages per genotype for yield and its components. Experimental line 6 overcame all evaluated genotypes about yield and presented the second highest spigot value per square meter and the highest number of grains per square meter, which is consistent with Bustos *et al.* (2013) who indicated that the number of grains is one of the most important variables for increasing wheat yield.

Table 5. Mean per genotype for yield and its components in wheats evaluated in seven environments of rainfed.

Number genotype	DAM	AP	EPMC	GPE	GPMC	PMG	IC	RENG
6	121.7	89.07	261.97	31.33	8197.3	35.56	0.36	2924.9
Don Carlos M2015	128.91	109.71	165.9	42.34	7045.5	38.99	0.39	2637.1
11	125.8	92.57	230.84	32.34	7483.3	35.64	0.35	2623.3
16	122.4	82.93	178.66	38.62	7009.3	36.56	0.4	2588.4
8	129.7	87.29	278.6	26.51	7513.6	31.79	0.29	2403.1
1	126.2	91	217.96	32.6	6545.6	34.28	0.33	2277.9
18	123.3	88.43	212.47	31.37	6738.4	33.13	0.34	2249.5
17	121.36	89.5	192.75	34.02	6303.9	31.97	0.35	2231.9
Triunfo F2004	121.73	85.36	239.72	25.64	6231.6	33.11	0.31	2129.9
Romoga F96	122	86.64	244.09	33.49	8016.9	26.37	0.33	2107.6
Tlaxcala F2000	123.82	86	253.81	28.39	7126.7	29.24	0.33	2105.9
2	124.7	87.57	231.94	27.1	6283.2	30.91	0.32	1929.8
7	124	86.14	250.79	25.39	5855.7	32.90	0.32	1929.6
9	124.9	85.43	226.71	28.6	6545.6	27.23	0.32	1765.6
13	121.73	86.57	211.81	26.04	5400.4	31.74	0.32	1698.4
Altiplano F2007	121.73	87.07	173.96	26.76	4651.9	34.47	0.29	1574.1
14	119.18	85.64	220.52	25.28	5504.1	28.50	0.3	1553.4
3	123.9	82.93	227.89	26.44	5449	27.78	0.3	1508.9
12	119.6	86.71	174.86	17.52	3125.1	23.50	0.19	754.4
DSH	3.97	7.9	82.03	8.92	2156.1	4.35	0.06	659.51

DAM= days to maturity; AP= plant height, cm; GPE= number of grains per spigot; GPMC= number of grains per square meter; EPMC= number of spigots per square meter; IC= harvest index; PMG= weight of one thousand grains, g, RENG= grain yield; kg ha^{-1}; DSH= honest significant difference.

On the other hand, the witness variety Don Carlos M2015 that occupied the second place of grain yield showed the highest values of grains per spigot and weight of one thousand grains, which is consistent with Feng *et al*. (2018) who by path coefficients found that these variables had the greatest relationship to yield. Based on the above, it was observed that no genotype combined the highest weight values of one thousand grains and number of grains which is consistent with Foulkes *et al.* (2011) who found a negative linear relationship between these characters.

On the other hand, genotype 10 and the first five places with the highest grain productivity had a number of grains per square meter greater than 7,000 which corresponds to the highest values, compared to the rest of the genotypes evaluated. It is important to note that genotype 10 identified as the commercial variety Don Carlos M2015 presented values greater than 43 g of weight thousand grains that match as indicated by Buendia *et al*. (2019) who also showed that it had high values for grain width and length compared to other commercial varieties recommended for cultivation of rainfed in Mexico.

Said the above, Don Carlos M2015 can be a resource to generate high values of grain weight and grains per spigot. While experimental lines 6, 11 and 8 can generate progenies with the highest number of spigot and grains per square meter.

Grain yield presented the highest and most positive correlation with number of grains per square meter, as well as intermediate correlations with number of grains per spigot, spigot per square meter and harvest index (Table 6). The above, agrees with Bennett *et al.* (2012); Beche *et al.* (2014); García *et al.* (2014); Griffiths *et al*. (2015); Philipp *et al.* (2018) which reported high and positive correlations between the number of grains and yield. So, this variable is considered to be the most important to support yield improvement as indicated by Philipp *et al*. (2018).

Table 6. Pearson correlations between yield and its components for 19 wheat genotypes evaluated in seven environments of rainfed. PV 2014.

Variables	AP	IC	EPMC	GPMC	GPE	PMG	RENG
DAM	0.7^{**}	$-7x10^{-3}$ ns	-0.16^{*}	0.1 ns	0.25^{**}	0.1 ns	0.16^{*}
AP		0.15^{*}	$8x10^{-3}$ ns	0.34^{**}	0.45^{**}	0.27^{**}	0.4^{**}
IC			-0.1 ns	0.41^{**}	0.69^{**}	0.59^{**}	0.54^{**}
EPMC				0.64^{**}	-0.2^{**}	-0.05 ns	0.54^{**}
GPMC					0.56^{**}	0.12 ns	0.92^{**}
GPE						0.29^{**}	0.57^{**}
PMG							0.45^{**}

ns, *, **= not significant, significant and highly significant. DAM= days to maturity; AP= plant height; GPE= number of grains per spigot; GPMC= number of grains per square meter; EPMC= number of spigots per square meter; IC= harvest index; PMG= weight of one thousand grains; RENG= grain yield.

The above partially coincides with Beche *et al*. (2014) and Zhou *et al*. (2014) for the correlation between harvest index and grain yield, these authors reported correlations greater than 0.9 greater than those found in this study, indicating that this variable can be used indirectly as a selection criterion for grain yield. Also, positive correlations were found between the harvest index and grains per spigot and weight of one thousand grains.

This indicates that both variables can be used to select for grain yield what is consistent with Aisawi *et al*. (2015). On the other hand, the number of grains per square meter was positively correlated with spigot per square meter so this component can also be used as a selection criterion for grain yield.

Conclusions

Genetic sources that increase the variability for spigot per square meter and weight of one thousand grains should be introduced into the INIFAP program, while they can be leveraged by selecting characteristics of the number of grains per spigot and weight of one thousand grains due to their high genetic variability and heritability specifically in this group of genotypes. To optimize yield potential discrimination, the number of grains per square meter can be used indirectly as a selection criterion.

It is recommending the INIFAP to use Don Carlos M2015 genotypes and experimental lines 6, 11 and 8 as genetic sources to increase grain weight, number of grains per spigot, number of spikes and grains per square meter, variables that favor grain yield.

Cited literature

Aisawi, K. A. B.; Reynolds, M. P.; Singh, R. P. and Foulkes, M. J. 2015. The physiological basis of the genetic progress in yield potential of CIMMYT spring wheat cultivars from 1966 to 2009. Crop Sci. 55(4):1749-1764.

Beche, E.; Benin G.; Da-Silva, C. L.; Munaro, L. B. and Marchese, J. A. 2014. Genetic gain in yield and changes associated with physiological traits in Brazilian wheat during the 20th century. European J. Agron. 61(1):49-59.

Bennett, D.; Izanloo, A.; Reynolds, M.; Kuchel, H.; Langridge, P. and Schnurbusch, T. 2012. Genetic dissection of grain yield and physical grain quality in bread wheat (*Triticum aestivum* L.) under water-limited environments. Theor. Appl. Genet. 125(2):255-271.

Buendía-Ayala, B. L.; Martínez-Cruz, E.; Villaseñor-Mir, H. E.; Hortelano-Santa, R. R.; Espitia-Rangel E. y Buendía-González, M. O. 2019. La incidencia de roya amarilla y la calidad industrial del grano y la masa en trigo harinero. Rev. Mex. Cien. Agríc. 10(1):143-154.

Bustos, D. V.; Hasan, A. K.; Reynolds, M. P. and Calderini, D. F. 2013. Combining high grain number and weight through a DH-population to improve grain yield potential of wheat in high-yielding environments. Field Crops Res. 145(4):106-115.

Canimolt. 2016. Cámara Nacional de la Industria Molinera de Trigo. Reporte estadístico 2015 con datos de 2016. http://canimolt.org/wp-content/uploads/2018/06/Canimolt2016-190717.pdf.

Espitia, R. E.; Villaseñor, M. H. E.; Peña, B. R. J.; Huerta, E. J. y Limón, O. A. 2004. Calidad industrial de trigos harineros mexicanos para temporal. II. Variabilidad genética y criterios de selección. Rev. Fito. Mex. 27(1):41-47.

Feng, F.; Han, Y.; Wang, S.; Yin, S.; Peng, Z.; Zhou, M.; Gao, W.; Xiaoxia, W.; Xiaoliang, Q. and Siddique, K. H. 2018. The effect of grain position on genetic improvement of grain number and thousand grain weight in winter wheat in North China. Frontiers Plant Sci. 9(2):1-9.

Foulkes, M. J.; Slafer, G. A.; Davies, W. J.; Berry, P. M.; Sylvester-Bradley, R.; Martre, P.; Calderini, D. F.; Griffiths, S. and Reynolds, M. P. 2011. Raising yield potential of wheat. (III) Optimizing partitioning to grain while maintaining lodging resistance. J. Exp. Bot. 62(2):469-486.

García, G. A.; Serrago, R. A.; González, F. G.; Slafer, G. A.; Reynolds, M. P. and Miralles, D. J. 2014. Wheat grain number: identification of favourable physiological traits in an elite doubled-haploid population. Field Crops Res. 168(10):126-134.

García, M. E. 1981. Modificaciones al sistema de clasificación climática de Köppen (para adaptarlo a las condiciones de la República Mexicana). 3ª (Ed). Universidad Nacional Autónoma de México (UNAM). México, D. F. 252 p.

Griffiths, S.; Wingen, L.; Pietragalla, J.; García, G.; Hasan, A.; Miralles, D.; Calderini, D. F.; Ankleshwaria, J. B.; Waite, M. L.; Simmonds, J.; Snape, J. and Reynolds, M. 2015. Genetic dissection of grain size and grain number trade-offs in CIMMYT wheat germplasm. PloS One. 10(3):1-18.

Hortelano-Santa, R. R.; Espitia-Rangel, E.; Martínez-Cruz, E.; Villaseñor-Mir, H. E.; Huerta-Espino, J. y Mariscal-Amaro, L. A. 2016. Productividad y calidad industrial de trigos harineros en relación con enfermedades. Agrociencia. 50(8):1027-1039.

Lopes, M. S. and Reynolds, M. P. 2011. Drought adaptive traits and wide adaptation in elite lines derived from resynthesized hexaploid wheat. Crop Sci. 51(4):1617-1626.

Lopes, M. S.; Reynolds, M. P.; Jalal-Kamali, M. R.; Moussa, M.; Feltaous, Y.; Tahir, I. S. A.; Barma, N.; Vargas, M.; Mannes, Y. and Baum, M. 2012. The yield correlations of selectable physiological traits in a population of advanced spring wheat lines grown in warm and drought environments. Field Crops Res. 128(3):129-136.

Philipp, N.; Weichert, H.; Bohra, U.; Weschke, W.; Schulthess, A. W. and Weber, H. 2018. Grain number and grain yield distribution along the spike remain stable despite breeding for high yield in winter wheat. PloS One. 13(10):1-17.

Reynolds, M.; Foulkes, J.; Furbank, R.; Griffiths, S.; King, J.; Murchie, E.; Parry, M. and Slafer, G. 2012. Achieving yield gains in wheat. Plant Cell Envir. 35(10):1799-1823

Rodríguez-García, M. F.; Rojas-Martínez, R. I.; Huerta-Espino, J.; Villaseñor-Mir, H. E.; Zavaleta-Mejía, E.; Sandoval-Islas, J. S. y Crossa-Hiriart, J. F. 2019. Genética de la resistencia a roya amarilla causada por *Puccinia striiformis* f. sp. *tritici* W. en tres genotipos de trigo (*Triticum aestivum* L.). Rev. Fito. Mex. 42(1):31-38.

Sadras, V. O. and Slafer, G. A. 2012. Environmental modulation of yield components in cereals: heritabilities reveal a hierarchy of phenotypic plasticities. Field Crops Res. 127(2):215-224.

SAS Institute. 2002. SAS/STAT User's Guide, Software versión 9.0. Cary, N. C. USA. 4 424 p.

SIAP. 2020. Servicio de información Agroalimentaria y Pesquera. http://infosiap.siap.gob.mx: 8080/ agricola_siap_gobmx/AvanceNacionalSinPrograma.do.

Stanfield, W. D. 1971. Genética (teoría y 440 problemas resueltos). 2 (Ed). Serie Schaum, Graw-Hill, México, DF. 405 p.

Villaseñor, M. H. E.; Huerta Espino, J.; Hortelano-Santa, R. R.; Martínez-Cruz, E.; Espitia-Rangel, E.; Solís-Moya, E.; Osorio-Alcalá, L. y Rodríguez-García, M. F. 2018. Valles F2015: nueva variedad de trigo para siembras de temporal en México. Rev. Mex. Cien. Agríc. 9(6):1315-1320.

Zhang, Y.; Xu W.; Wang, H.; Dong, H.; Qi, X.; Zhao, M.; Fang, Y.; Gao, C. and Hu, L. 2016. Progress in genetic improvement of grain yield and related physiological traits of Chinese wheat in Henan Province. Field Crops Res. 199(12):117-128.

Zhou, B.; Sanz-Sáez, Á.; Elazab, A.; Shen, T.; Sánchez-Bragado, R.; Bort, J.; Serret, M. D. and Araus, J. L. 2014. Physiological traits contributed to the recent increase in yield potential of winter wheat from Henan Province, China. J. Integrative Plant Bio. 56(5):492-504.