Article

Physical seed quality in 24 improved wheat varieties released in Mexico

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Abstract

Seed quality is an agronomic concept that considers physical, physiological, genetic and sanitary attributes, which allow an adequate establishment of the crop to achieve good optimal productivity. About 95% of the wheat grown by humanity is bread wheat, a product obtained by genetic improvement programs around the world. The objective of this study was to evaluate the physical quality characteristics of 24 wheat varieties from the collection of the National Institute of Forestry, Agricultural and Livestock Research. The seed of the varieties for the quality analysis was increased under field conditions over two cycles. The experimental design used was randomized complete blocks with four repetitions. In the evaluation, the varieties were grouped into eight decades according to the year of release and the data were analyzed in two ways, by varieties and years and by decades. Three variables were evaluated, and the results indicate that, for the weight of a thousand seeds, their value was increased by up to 30% in modern varieties; while for volumetric weight, it was 7%, for percentage of moisture, no difference was detected between the varieties generated in the different decades. The 24 varieties evaluated had an acceptable behavior under the standards that the seed industry demands. It is concluded that the genetic improvement of wheat in Mexico has positively and significantly influenced the weight of a thousand seeds.

Keywords: *Triticum aestivum* L., genetic improvement, physical seed quality, volumetric weight, weight of a thousand seeds.

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Introduction

Wheat (*Triticum aestivum* L.) is the most widely used cereal in human food due to its high energy value and higher protein content compared to corn (*Zea mays* L.) and rice (*Oryza sativa* L.). This cereal is harvested practically all over the world, although the northern hemisphere has more favorable conditions for its cultivation, such as altitude and low temperatures. The area of wheat sown globally, and its trade exceed other agricultural crops combined (FIRA, 2015). In Mexico, about three million tons were produced in 2020, concentrated in the states of Sonora, Baja California and Guanajuato, contributing together 72.7% of the national production (SIAP, 2022), the crop is considered the second most important cereal in the diet of Mexicans, who consume on average 57.4 kg per capita per year.

During 2019, around 10 000 ha were sown for seed production, of which approximately 66 800 t of certified category were obtained, which covers 53% of the national demand (Córdova-Téllez *et al*., 2019), which mostly corresponded to varieties generated by genetic improvement. The genetic improvement of wheat in Mexico is among the most dynamic and successful in the world, since from 1946 and through different strategies, it has been possible to incorporate the *Ppd1* and *Ppd2* genes to obtain varieties insensitive to photoperiod, the selection of the *Sr2* gene, which to date continues to give immunity against stem rust, the incorporation of the *Rht1* and *Rht2* genes which caused a reduction in plant height, the *1BL/1RS* translocation which led to favorable genes such as *Lr26*, *Sr31* and *Yr9*, which contributed to the resistance to rusts, the minor gene complexes *Lr31*, *Lr34* and *Lr36* which have generated varieties with durable resistance to leaf rust, the incorporation in the varieties of the *Yr18*, *Yr28* and *Yr29* genes which have improved the resistance to yellow rust and industrial quality has been improved through the best combinations of glutenins of high molecular weight, of low molecular weight and gliadins (Villaseñor, 2015).

Genetic advances in grain yield have also been important, increasing approximately from 4 to 7.3 t ha^{-1} from 1948 to 2014 (Paquini *et al*., 2016). The results of the genetic improvement of wheat in Mexico can be synthesized in the release of 234 varieties that have been the basis of national production, the main objectives are aimed at: genetic control of stem rust, reduction of plant size, increase in yield, genetic control of leaf and yellow rusts, improvement of industrial quality, tolerance to foliar diseases and tolerance to drought, mainly (Villaseñor, 2015). In the process of genetic improvement in Mexico, the physical quality of the seed has not been considered as an objective in research.

It is considered a good quality seed when it presents varietal and physical purity, high physiological performance and free of pathogens, attributes that determine germination, vigor and longevity (Bishaw *et al*., 2007; Goggi *et al*., 2008; Courbineau, 2012; ISTA, 2015; García-Rodríguez *et al*., 2018). In Mexico, except for studies such as that of Gutiérrez *et al*. (2006), Fernández *et al*. (2015) and Noriega *et al*. (2019), little research has been done on seed quality in wheat. Fernández *et al*. (2015) determined that the production environment has an influence on the physical and physiological quality of the seed, in characters such as the percentage of germination, speed of emergence, length of the plumule, among others.

In the case of the physical quality of the seed, there are no reports on previous studies that use genetic improvement to study this characteristic. Therefore, the objective for the present study was to evaluate the percentage of moisture, volumetric weight and weight of thousand seeds, in twenty-four varieties of wheat released over eight decades and depending on the results, analyze the influence of genetic improvement and its impact on the physical quality of the seed.

Materials and methods

Genetic material

The genetic material was provided by the Wheat Program of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP, for its acronym in Spanish), Valle de México Experimental Field, which consisted of a batch of twenty-four varieties of bread wheat that were developed through eight decades of research (Table 1). These were increased during the Autumn-Winter (A-W) cycles, A-W/2018-19 and A-W/2019-20 in plots of four furrows of 3 m long and with a separation of 30 cm between furrows under irrigation conditions in the Bajío Experimental Field of INIFAP, the seed obtained was used to evaluate its physical quality.

Table 1. Wheat varieties from the national wheat collection of INIFAP studied and released at different times.

Num.	Variety	Genealogy*	Year of release	Decade
1	Candeal 48	na	1948	1
2	Chapingo 48	Newthatch/Marroqui588	1948	
3	Kentana 48	na	1948	
4	Chapingo 53	Kt48/Y48	1953	2
5	Mexe 53	Y48/Kt48	1953	
6	Bajío 53	Y50/Kt48	1953	
7	Siete Cerros T66	Pj62/Gb55	1966	3
8	Tobari F66	Tzzp/Sn64a	1966	
9	Ciano F67	Pi/Chr//Sn64	1967	
10	Ciano T79	By/Maya/4/Bb//HDd832.5.5/On/3/Cno67/Pj62	1979	4
11	Imuris T79	By/Maya/4/Bb//Hd832.5.5/0n/3/Cno67IPj62	1979	
12	Tesia F79	Pl/3/1nia66/Cno//Cal/4/Bjy	1979	
13	Seri M82	KvzIBuho//Ka1/Bb	1982	5
14	Ópata M85	Bjy/Jup	1985	
15	Bacanora T88	Jup/Bjy//Ures	1988	
16	Baviácora M92	BowlNac/Nee/3/Bjy/Coc	1992	6
17	Borlaug M95	Hahn∗2/PrI	1995	
18	INIFAP M97	Hahnl2∗Weaver	1997	

Num.	Variety	Genealogy*	Year of release	Decade
19	Tacupeto F2001	Babax∗2/9/KtlBage/IFnIU/3IBza/41Trrn/5/Aldanl6/S Rhlleri/7/Yr/S/Opata	2001	7
20	Kronstad F2004	Vee/Koel//Sirenl3/Ariv92	2004	
21	Roelfs F2007	Tacupeto F2001 x 2/Kukuna	2007	
22	Borlaug 100 F2014	Roelf07/4/Bow/Nkt//Cbrd/3/Cbrd/5/Fret2/Tukuru//Fret2	2014	8
23	Bacorehuis F2015	Rolf07∗2/5/Reh/Hare//2∗BCN/3/CROC_1/AE.Squarrosa(213)//PGO/4/Huites	2015	
24	Conatrigo F2015	Thelin/2∗Wbll1	2015	

*= Huerta *et al*. (2011); na= genealogy not available.

Variables evaluated

The percentage of moisture (PM) was determined on a wet basis by previously weighing empty aluminum boxes to which 3 g of seed were placed, the boxes with the seed were weighed again and the oven method was used at 130 °C for two hours, using a Thermo Scientific® OV702G laboratory oven, four repetitions were established per variety and once the drying was completed, the box with the seed was weighed and with the results the calculation was made using the following equation: $PM (\%)= \left[\frac{P2-P3}{P2-P1}\right]\times 100$. Where: P1= weight of the box and its lid (g); P2= weight of the box, lid and seed (g); P3= weight of the box, lid and seed after drying on the oven (g).

The volumetric weight (VOLW) was determined by pouring 50 g of seed into a 100 ml graduated cylinder, the volume occupied by the seed inside the cylinder was measured and the results were calculated using the following formula: $VOLW\ (kg\ hl^{-1})= \left(\frac{\text{Weigth of the seed (50 g)}}{\text{Volumen ocuppied (ml)}}\right)\times 100$.

The weight of a thousand seeds (WTS) was determined by counting and weighing eight repetitions of 100 seeds each, the average, variance, standard deviation and coefficient of variation were calculated. When the coefficient of variation obtained was less than 4, the weight of a thousand seeds was obtained by multiplying the arithmetic mean of the eight repetitions by 10 (ISTA, 2015).

Experimental design

The varieties were grouped by decades according to the year of release, three varieties formed one decade (Table 1). The evaluation was performed under an experimental design of randomized complete blocks. Analysis of variance and mean comparison tests were performed for varieties and years and for decades of the response variables (Tukey, 0.05). The statistical program SAS version 9.4 was used for the processing of information (SAS, 2019).

Results and discussion

The analysis of variance showed that for the variable weight of a thousand seeds (WTS), there were significant differences for the factor's varieties and years and for the interaction variety × year, with an overall mean of 40.06 g. For VOLW (Table 2), there were highly significant differences in the factor's varieties and years and for their interaction, with an overall mean of 80.35 kg hl^{-1}, while for PM, highly significant differences were obtained between varieties, years and their interaction, with a mean of 8.23%. The coefficient of variation for three variables was low, so the results are reliable.

Table 2. Mean squares and statistical significance for the physical quality variables evaluated in seed of 24 wheat varieties.

SV	df	WTS (g)	VOLW (kg hl^{-1})	PM (%)
Repetition	3	0.54 ns	0.13 ns	0.11 ns
Varieties	23	206.38**	15.24**	1.08**
Years	1	318.72**	557.7**	35.64**
Varieties × years	23	25.97**	6.48**	0.36**
Error	141	12.54	2.42	0.1
Total	191			
CV (%)		8.84	1.93	3.91
Mean		40.06	80.35	8.23

SV= source of variation; df= degrees of freedom; CV = coefficient of variation; WTS= weight of a thousand seeds; VOLW= volumetric weight, PM= percentage of moisture; **= highly significant; ns= not significant.

Table 3 shows the comparison of means for varieties, where it is observed that for the variable WTS, the Conatrigo F2015 variety had the highest value (48.41 g), followed by Borlaug 100 F2014 and Bacorehuis F2015 with 47.55 and 47 grams respectively; on the other hand, Candeal 48 and Bacanora T88 obtained the lowest weight with 29.75 and 34.05 g, respectively. Würschum *et al*. (2018) consider that exploring the genetic variation of WTS and its traits related to other components are an effective approach to increase wheat yield, the results coincide with what Valenzuela *et al*. (2018) indicate in reference to the aforementioned varieties as the highest yielding and with Paquini *et al*. (2016), who affirm that WTS is linearly and positively related to the time of release of the varieties, indicating that this character has contributed significantly to the increase in grain yield in the genetic improvement of wheat in Mexico.

In the variable VOLW, the Siete Cerros T66 variety showed the highest average value compared to the other varieties (82.68 kg hl^{-1}); Conatrigo F2015 and Borlaug M95 follow with averages of 82.01 and 82 kg hl^{-1} respectively; on the other hand, varieties such as Chapingo 53 and Candeal 48 had the lowest values, which coincides with what Gutiérrez *et al*. (2006) stated, who claim that the volumetric weight is not a parameter indicative of the weight of a thousand seeds, since varieties with high volumetric weights had medium and/or low weights of a thousand seeds, such as the Siete Cerros T66 variety (Table 3).

Table 3. Comparison of means of the physical quality variables evaluated in seed of 24 wheat varieties.

Varieties	WTS (g)	VOLW (kg hl^{-1})	PM (%)
Conatrigo F2015	48.41 a	82.01 ab	8.28 bcdefg
Borlaug 100 F2014	47.55 ab	79.73 hij	8.01 fgh
Roelfs F2007	47.02 bc	80.21 fghi	8.28 bcdefg
Bacorehuis F2015	47 bc	78.8 jkl	8.03 fgh
Baviácora M92	46.39 cd	80.17 fghi	8.20 cdefgh
Tacupeto F2001	45.36 d	80.34 efgh	8.77 a
Siete Cerros T66	44.05 e	82.68 a	8.51 abcd
INIFAP M97	41.87 f	81.05 cdef	8.04 efgh
Chapingo 53	42.69 f	78.17 l	8.09 defgh
Borlaug M95	40.03 g	82 ab	7.93 ghi
Imuris T79	40.03 g	79.83 hi	7.51 ij
Seri M82	39.54 g	81 cdef	8.6 abc
Kentana 48	39.44 g	81.35 bcd	8.37 abcdefg
Bajío 53	39.1 g	80.85 cdefg	8.12 defgh
Mexe 53	37.45 h	78.82 jkl	8.62 abc
Ópata M85	37.38 h	80.54 defgh	8.72 ab
Kronstad F2004	37.27 h	81.18 bcde	8.49 abcde
Tobari F66	36.6 hi	79.95 ghi	8.29 bcdefg
Chapingo 48	35.65 ij	79.37 ijk	8.26 cdefg
Ciano T79	35.41 j	81.69 bc	7.79 hij
Ciano F67	34.81 jk	78.77 kl	7.97 fgh
Tesia F79	34.55 jk	81.52 bc	7.38 j
Bacanora T88	34.05 k	81.53 bc	8.39 abcdef
Candeal 48	29.75 l	76.94 m	8.81 a
Tukey (α=0.05)	1.1195	0.9408	0.4554

WTS= weight of a thousand seeds; VOLW= volumetric weight; PM = percentage of moisture. Values with the same letter by column are statistically equal (Tukey, α= 0.05).

For the variable PM, Candeal 48 and Tacupeto F2001 had the highest values, while Tesia F79 presented the lowest value; recently released varieties, such as Borlaug 100 and Bacorehuis F2015, showed low values, which indicates that the tendency of varieties to have moisture contents below the technical certification rules has been maintained. The percentage of moisture influences the physiological properties of wheat seed, causing it to be more susceptible to enzymatic activation (Faltermaier *et al*., 2014). Likewise, this parameter influences other properties of the seed such as bulk density, actual density, porosity, length, width, thickness and arithmetic and geometric average diameter of the grain (Sologubik *et al*., 2013).

Figure 1 shows the average behavior of the interaction variety × year for the variable WTS, it is observed that the same variety can have contrasting values, such is the case of Siete Cerros T66, Borlaug M95, Roelfs F2007, Borlaug 100 F2014, Bacorehuis F2015 and Conatrigo F2015, which increased their weight compared to the first production cycle; this variation between cycles is attributed to the effects of the interaction genotype × environment. These results are consistent with what was reported by Paquini *et al*. (2016), who mention that, for the same locality and production system (normal irrigation), there can be differences of up to 30% in yield under favorable conditions with respect to limited irrigation.

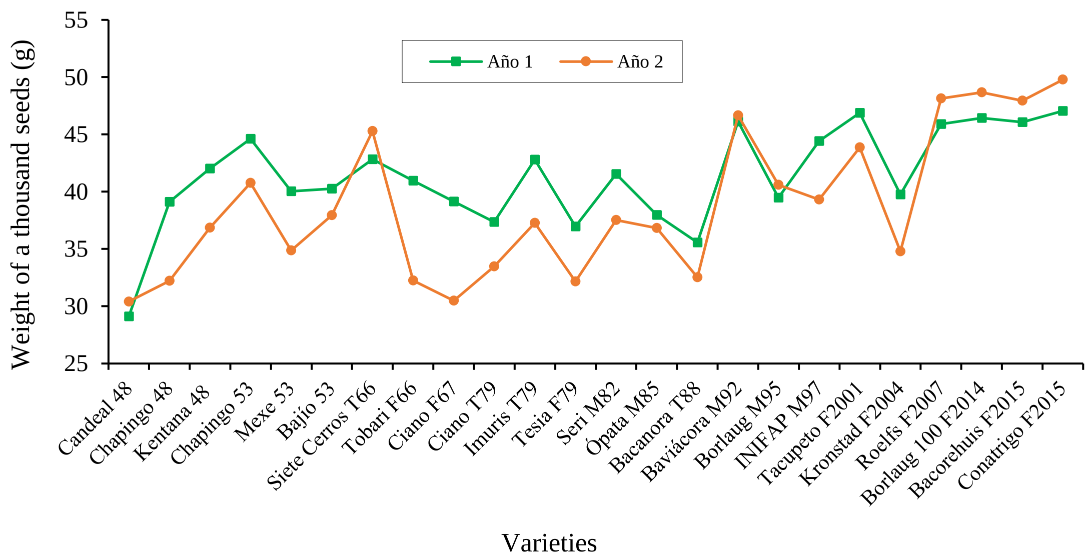

Figure 1. Average behavior of the interaction variety × year for the variable weight of a thousand seeds (WTS).

Figure 2 shows the average behavior of the interaction variety × year for the variable VOLW, the varieties in Year 2 obtained low values compared to the first year, although both production cycles were carried out in the same locality (Roque, Guanajuato), the environmental conditions (temperature and crop management) of each year indirectly influenced this quality parameter. Considering this reference, VOLW was affected by up to 7% on average, within the same variety, so the second production cycle would be considered as an environment with unfavorable conditions. These results support previous findings reported by Fernández *et al*. (2015); Guzmán *et al*. (2016) by finding a positive influence by the production environment favorable on the parameters of physical quality of the seed, as well as a differential response between varieties to the different environments (cycles) of production.

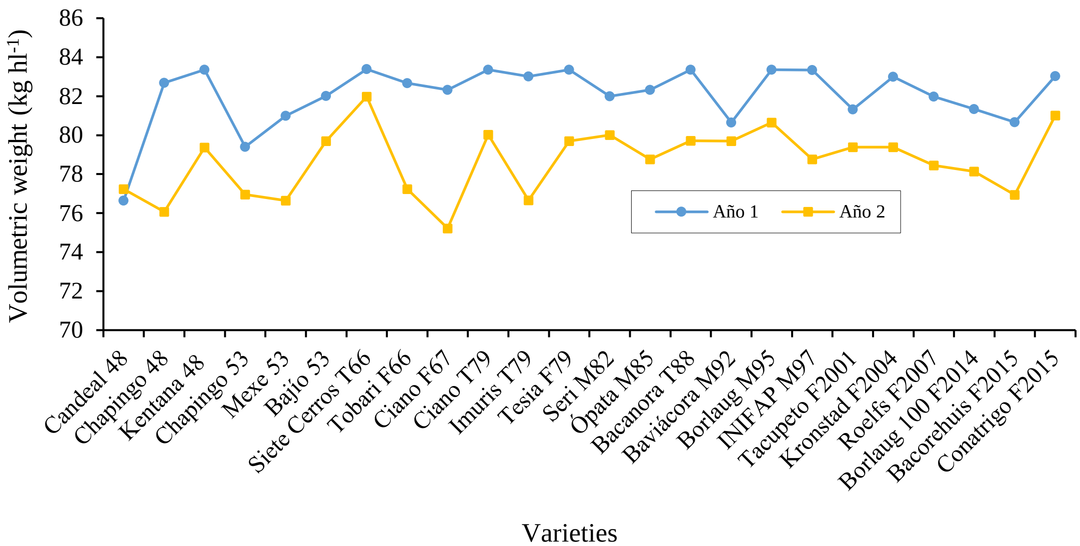

Figure 2. Average behavior of the interaction variety x year for the variable volumetric weight (VOLW).

Figure 3 presents the average behavior of the interaction variety × year for the variable PM, the second production cycle with higher values in all varieties can be highlighted; however, for both cycles, the moisture contents are below the standards that the seed industry demands. Tesia F79 showed a value of 6.89% of moisture, which can be unfavorable, since very low values tend to affect other characteristics of the seed such as viability, germination and vigor of the seedling. Being part of the postharvest process, moisture levels of less than 12% should be required depending on the climate, this parameter is essential to monitor since it allows determining the duration of transport, storage and benefit of the seed (Christopolus and Ouzounidou, 2020).

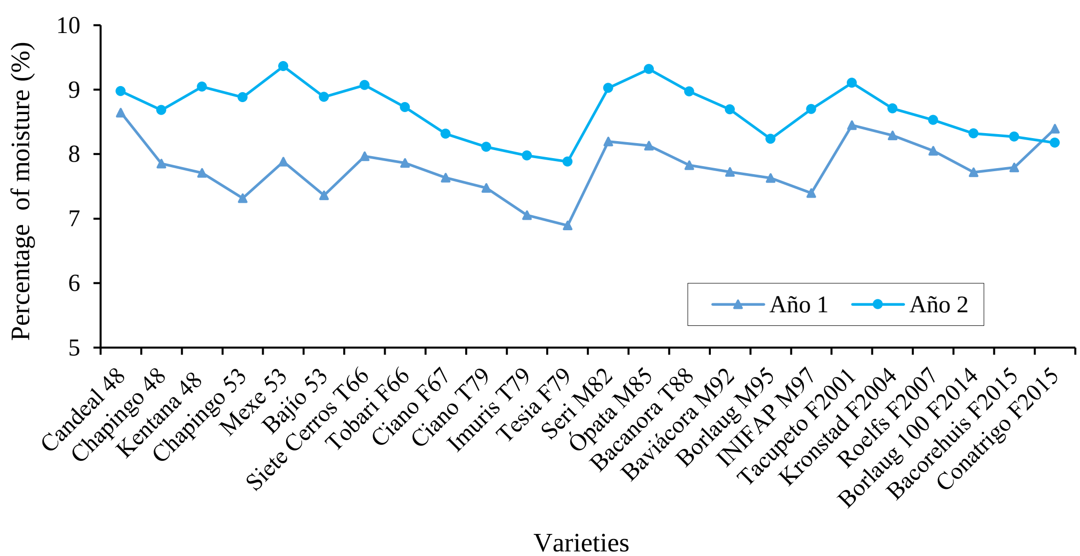

Figure 3. Average behavior of the interaction variety x year for the variable percentage of moisture (PM).

Table 4 shows the analysis of variance to compare the physical quality of the seed between the eight decades of genetic improvement, for WTS, highly significant differences were obtained for decades and years, while for their interaction, significant differences were only obtained in WTS, with an overall mean of 40.06 g. In the variable VOLW, there were highly significant differences for decades and years, but not for their interaction, reaching an average of 80.35 kg hl^{-1}. On the other hand, for PM, there are highly significant differences between decades, years and their interaction, with an overall mean of 8.23%.

Table 4. Mean squares and statistical significance for the physical quality variables of 24 wheat varieties considering decades.

SV	df	WTS (g)	VOLW (kg hl^{-1})	PM (%)
Repetition	3	0.54 ns	0.13 ns	0.11 ns
Decades	7	427.22**	13.48**	2.59**
Years	1	318.72**	557.7**	35.64**
Decades × year	7	33.47*	3.13 ns	0.85**
Error	173	12.54	2.42	0.1
Total	191			
CV (%)		8.84	1.93	3.91
Mean		40.06	80.35	8.23

SV= source of variation; df= degrees of freedom; WTS= weight of a thousand seeds; VOLW= volumetric weight; PM= percentage of moisture; **= highly significant (Tukey α= 0.001 probability); ns= not significant.

Table 5 shows the average behavior for each of the decades. For the variable WTS, the decade 8, made up of the three varieties of most recent release, shows the highest average with 47.6 g, which coincides with Sehgal *et al*. (2019), who states that WTS is a stable hereditary trait and an important selection target for the genetic improvement of wheat yield, which has been obtained during the process of genetic improvement in Mexican wheats.

Table 5. Comparison of means of the physical quality variables evaluated in 24 wheat varieties by decade.

Decade	WTS (g)	VOLW (kg hl^{-1})	PM (%)
8	47.66 a	80.18 ab	8.11 c
7	43.22 b	80.58 ab	8.52 ab
6	42.76 bc	81.07 a	8.06 c
2	39.75 cd	79.28 b	8.28 bc
3	38.49 d	80.47 ab	8.26 bc
5	36.99 de	81.02 a	8.57 a
4	36.66 de	81.02 a	7.56 d
1	34.95 e	79.22 b	8.48 ab

WTS= weight of a thousand seeds; VOLW= volumetric weight; PM= percentage of moisture. Values with the same letter by column are statistically equal (Tukey, α= 0.05).

For the variable VOLW, decades 4, 5 and 6 were statistically equal, obtaining 81.02, 81.02 and 81.07 g, respectively (Table 5), these values for the decades exceeded those reported by Castañeda *et al*. (2009). In Mexico, emphasis has been placed on increasing grain yield by improving its components *per se*; however, González *et al*. (2010) and Rodríguez *et al*. (2011) consider that there are other productive and agronomic management variables that can influence this (gluten strength, sowing date, fertilization, etc). On the other hand, for PM, decade 5 showed the highest value with an average of 8.57%, while decade 4 yielded the lowest average value with 7.56%.

In general, it was observed that the last three decades (6, 7 and 8) maintained high values for WTS, Tian *et al*. (2011) attribute a linear increase per decade of improvement in these parameters to the development of cultivars from the 1950s to the 2000s, WTS is mainly determined by genetic factors, which are influenced by effects of the interaction genotype × environment (Liu *et al*., 2020), VOLW presented a similar behavior in recent decades (7 and 8), which is attributed to the difference in grain size that exists between the varieties studied (Su *et al*., 2016).

They consider that characteristics such as length, width and thickness of grain act as components in its weight and size, these traits contribute indirectly to the yield and WTS, being considered as a predictor of the quality of wheat associated with the milling process (Osborne and Anderssen, 2003). PM is a parameter that, depending on the circumstances, allows the commercialization, storage and use of grain/seed, so to date it has not been considered as a selection criterion in wheat genetic improvement programs in Mexico.

Figure 4 shows an upward trend of WTS over the decades, so it can be said that the wheat varieties released in Mexico have been increasing the magnitude of this variable due to the passage of time, Ayoub *et al*. (2002); Qin *et al*. (2015); Liu *et al*. (2020) indicate that WTS increases significantly with the release and use of modern varieties, presenting a positive relationship with other yield components and they consider that these are traits controlled by multiple genes influenced by environmental conditions.

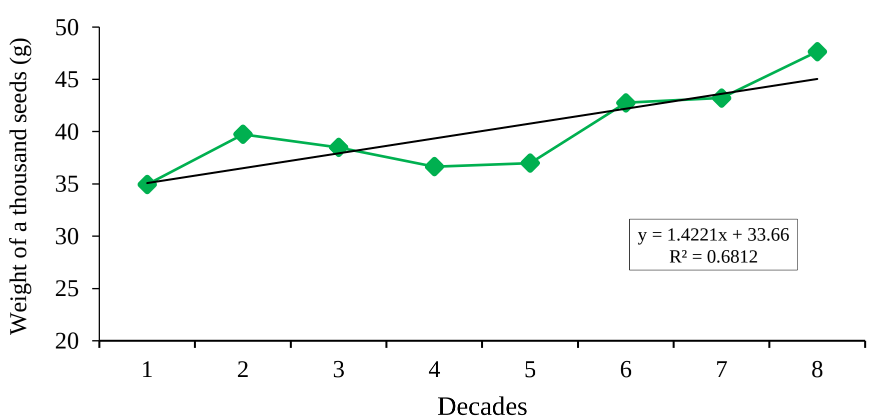

Figure 4. Average behavior of the weight of a thousand seeds (WTS) in 8 decades.

On the other hand, Figure 5 shows an increasing trend with respect to the variable VOLW; however, for the last two decades (from 2001 to 2015), low values were obtained. Fernández *et al*. (2015) consider the volumetric weight as an indicator of the quality obtained in the field in relation to agronomic management and environmental conditions that occur during the development of the crop and are expressed in the seed, in the present study the values of VOLW depended more on the genotypes than on the environmental effect, since, in the two cultivation cycles, the behavior of the decades was very similar.

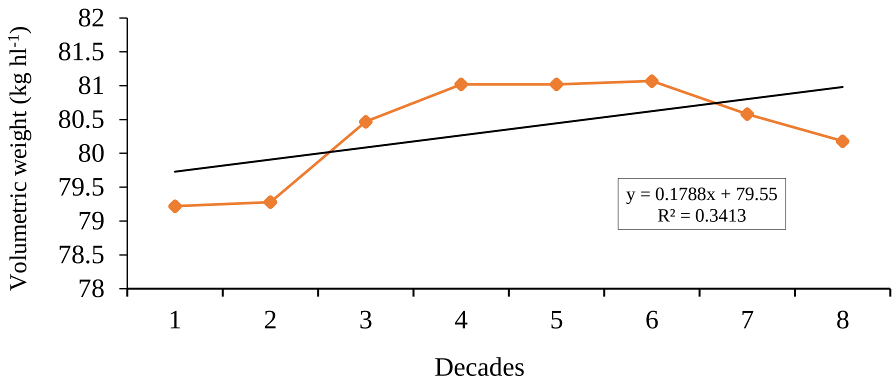

Figure 5. Average behavior of the volumetric weight (VOLW) in 8 decades.

Figure 6 shows that, over the decades, PM values have shown irregular behavior, with values below the requirements of the seed industry, in this variable no effect of genetic improvement was observed.

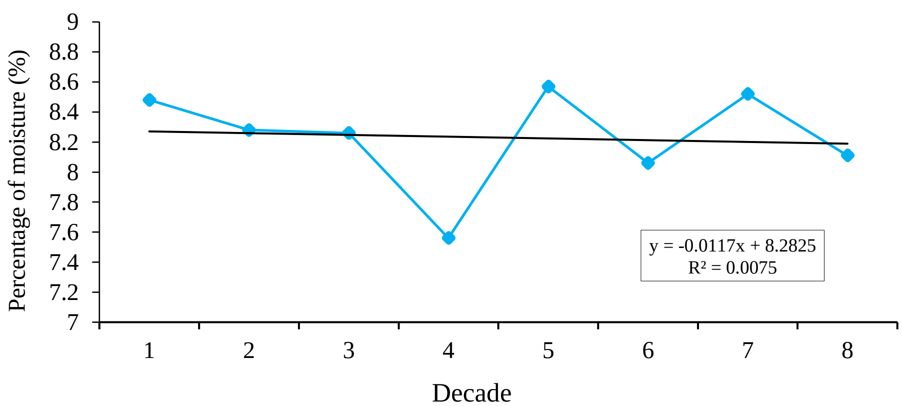

Figure 6. Average behavior of the percentage of moisture (PM) in 8 decades.

Conclusions

The genetic improvement of wheat in Mexico has positively and significantly influenced the weight of a thousand seeds, a variable of the physical quality of the seed that has been considered within the process of selecting experimental lines. The volumetric weight of the seed has also been increased by genetic improvement; however, it does not show a trend like the weight of a thousand seeds. Varieties generated in the last decade (Borlaug 100 F2014, Bacorehuis F2015 and Conatrigo F2015) had a greater weight of a thousand seeds, so their use as progenitors in genetic improvement is suggested to continue with the increase in grain yield.

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