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CULTIVAR AND CROP MANAGEMENT EFFECTS ON TEST WEIGHT IN WINTER WHEAT (*Triticum aestivum*)

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ABSTRACT

Test weight or volumetric (hectolitre) weight is an important trait of wheat grain, being an important predictor of flour extraction rate and a determinant factor of the efficiency of wheat transport and storage. It is included in most standards for cereal grading and as such can influence the price received by farmers.

Test weight was measured in yield trials with winter wheat cultivars grown with several crop management practices at the National Agricultural Research and Development Institute Fundulea - Romania (44º27'45'' N latitude and 26º31'35" E longitude, 68 m above sea level) in three seasons.

Years were the main factor of test weight variation and this was associated with differences between years in maximum temperatures during the second half of grain filling period. Cultivars also had a very significant effect, while the influence of mangements and of interaction between cultivars and managements with years was not significant. On average most cultivars fulfilled the requirements for Grade 1 and 2, but the percentage of cases below the 75 kg hl^{-1} limit varied from 0 to 66.7%. Only two of the Romanian cultivars had half or more cases in Grade 3, while most Western European cultivars had more than 50% samples below 75% kg hl^{-1}. Variances of the test weight values suggest that cultivars are different in stability of test weight, with most of the Romanian cultivars being less affected by the weather conditions than most Western European varieties. Two of the shortest Romanian cultivars (Voinic and Izvor) had highest average test weight and lowest frequency of lower grades, which is a progress but at the same time suggesting large possibilities of improving this trait in semidwarf wheat.

Keywords: volumetric weight, maximum temperatures, grading, cultivars.

INTRODUCTION

Test weight refers to the average weight of a given volume in a cereal. In some countries (such as USA) it is measured in pounds per bushel, while in many others it is expressed as kilograms per hectoliter.

Test weight used to be an essential grain characteristic when trade was based on volume rather than on weight (Ionescu-Şişeşti, 1938), but it remains one of important traits included in the standards for cereal grading. Test weight is an important predictor of flour extraction rate for wheat. "Flour yield increases and flour ash decreases with increasing weight per bushel" (Finney et al., 1987). It is also important as a trait related to the efficiency of wheat transport and storage. When producers deliver grain that is significantly below the official standards, the prices are discounted, which makes test weight very important for farmers.

Kernel density and packing efficiency are described as the main components of test weight. Air spaces within the grain appear to be a major factor in determining kernel density, while grain shape and surface characteristics such as humping, dorsal or lateral depressions and wrinkling, cause variations in void space ratio; hence they directly affect random packing efficiency, shriveling of grain confounding varietal and environmental effects (Yamazaki and Briggle, 1969).

Genetic effects on test weight have often been described. Cox et al. (1988) noticed that genetic improvement in test weight during the period 1919-1987 resulted in an increase of 0.4 kg m^{-3} yr^{-1} in volume weight. Butler et al. (2005), studying the agronomic Performance of *Rht* alleles across a range of moisture levels found that lines with both tall alleles performed equal to or better than all other classes for test weight in all environments. Desirable values for most traits occurred

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across a relatively wide range of plant heights, with the best performing lines either shorter lines in the tall class or taller lines in the semidwarf classes.

On the other hand, many studies showed that environmental factors strongly influenced the test weight. For example, test weight reductions were linearly related to the number of precipitation events between harvests (Farrer et al., 2006).

Protic et al. (2007) observed a test weight reduction from the first to the third sowing date and the highest test weight at 60 and 90 kg N ha^{-1}, while the increase of N rates over these values led to an insignificant decrease of test weight, in all studied varieties.

Diseases have been shown to reduce test weight, and consequently fungicide application resulted in a 2.5 to 2.8% increase in test weight (Paul et al., 2010). *Septoria tritici* produced a significant reduction of test weight, while the percentage reduction due to the inoculation was similar in fertilized and nonfertilized conditions (Simon et al., 2002). Controling powdery mildew by chemical treatments led to a significant increase of test weight, by 1.01 kg hl^{-1} (Samobor et al., 2006).

In Romania, Ionescu-Şişeşti (1938) mentioned that hectoliter weight varied from 70 to 83 kg hl^{-1}, being dependent mostly on soil and weather (especially rains or heat during grain filling), but also on lodging or rust attacks. Romanian standards differentiate between three grades according to test weight of wheat: Grade 1 with test weight >78 kg hl^{-1}, Grade 2 between 75 and 78 kg hl^{-1}, and Grade 3 with test weight below 75 kg hl^{-1}.

The objectives of this study were to evaluate the contribution of several cultivars, some crop managements and years to test weight variation in yield trials performed in the continental climate of Southern Romania, and to estimate the frequency of achieving the required limits for grading according to hectolitre weight.

MATERIAL AND METHODS

Yield trials with winter wheat were grown at the National Agricultural Research and Development Institute Fundulea - Romania (44º27’45’’ N latitude and 26º31’35” E longitude, 68 m above sea level) in 2017/2018, 2018/2019 and 2019/2020 seasons. Soil on which the experiments were carried out was a cambic chernozem formed on loessoide deposits.

These included:

- 14 Romanian cultivars (varieties and lines) and a historical check (Bezostaya 1), grown with 4 management practices (usual recommended practices without and with fungicide foliar treatments; no supplementary N fertilization and late sowing - about 30 days later than the recommended date) (Experiment 1);
- 6 Western European cultivars and one Romanian check, grown with 3 management practices (usual recommended practices without and with fungicide foliar treatments and no supplementary N fertilization) (Experiment 2).

Weather conditions during the experiments are summarized in Table 1 and can be considered representative for the region in the last years. From the point of view of test weight, the temperatures during the grain filling are of interest.

Table 1. Weather conditions during the three seasons of research

Season	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Average temperature (ºC)											
2018	19	11.7	6.7	3.6	0.8	1.6	3.3	15.7	19.4	**22.6**	22.8
2019	19.1	13.4	5.2	-0.1	-1.2	3.8	9.3	11.2	17.2	**23.6**	23
2020	19.3	12.8	10.3	4	0.9	5.2	8.3	12.2	17	**21.7**	25.1
Rainfall (mm)											
2018	12.2	111.6	49.2	27.8	36	58.6	40.6	2.4	34	120.6	83
2019	28.6	10.8	23	43	53.8	21.4	21.6	51.4	124	74.6	87.4
2020	6.2	38	33.2	16.2	2	16.6	27.8	14	58	68.4	34.2

ANOVA was used to estimate significance of cultivars, crop managements and years effects on test weight.

RESULTS AND DISCUSSION

ANOVA showed that for both experiments Years were the main factor of test weight variation (Table 2). As shown in Tables 3 and 4, test weight averaged over all cultivars and management varied from 74.6 in 2019 to 80.5 kg hl^{-1} in 2020 in experiment 1, and from 72.8 in 2019 to 78.8 kg hl^{-1} in 2020 in experiment 2. A possible explanation of such large differences could be the evolution of daily maximum temperatures in the interval 11-24 June, because in 2020 was much cooler than in 2019 (Figure 1). This suggests that test weight was very much dependent on temperatures during the second part of grain filling period.

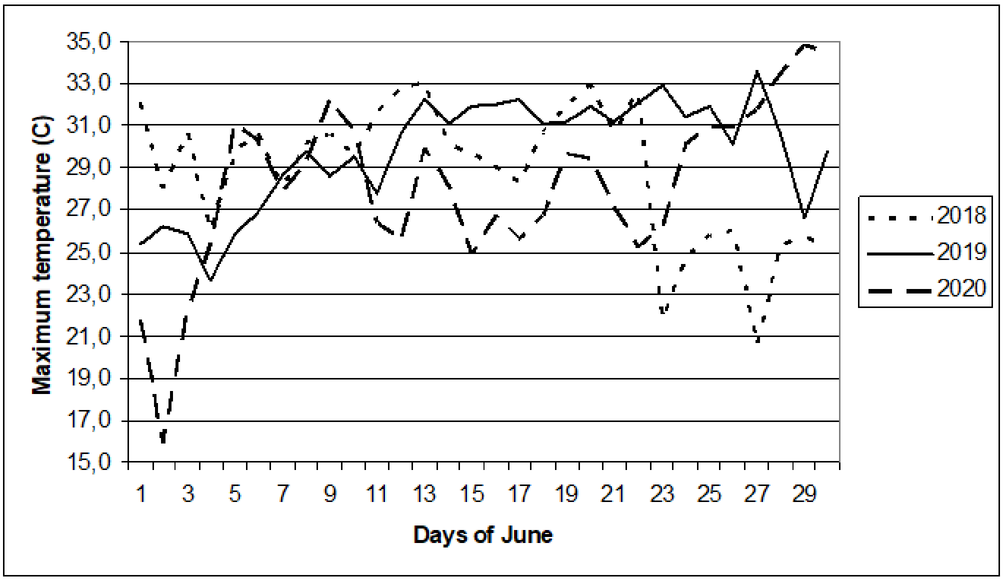

Figure 1. Maximum daily temperatures in June 2018, 2019 and 2020

Cultivars had a very significant effect, while managements influence on test weight was not significant. Interactions of cultivars and managements with years were also not significant.

Table 2. ANOVA for test weight in two winter wheat experiments

Experiment 1			
Source of variation	df	MS	F
Cultivar	14	38.89	3.487***
Managements	3	14.04	1.259ns
Years	2	513.65	205.105***
IA C*Y	28	2.12	0.848ns
IA C*M	42	1.05	0.095ns
Within	90	2.79	
Total	179		

Experiment 2			
Source of variation	df	MS	F
Cultivars	6	23.77	6.22***
Managements	2	17.44	4.56**
Years	2	222.04	58.11***
IA C*Y	12	1.75	0.46ns
IA C*M	12	0.95	0.25ns
Within	28	3.82	
Total	62		

*** = very significant at P<0.01%; ** = significant at 0.1>P>0.01%; ns = not significant.

A detailed analysis of test weight data (Table 3 and 4) showed a large variation of test weight, from 67.4 to 83.1 kg hl^{-1} in experiment 1 and from 66.2 to 81.8 kg hl^{-1} in experiment 2. Years caused a variation of 5.9 kg hl^{-1} (from 74.6 in 2019 to 80.5 kg hl^{-1} in 2020) in experiment 1 and of 6.0 kg hl^{-1} (from 72.8 in 2019 to 78.8 kg hl^{-1} in 2020) in experiment 2. The variation amplitude among cultivars was 5.7 kg hl^{-1} in experiment 1 and

5.1 kg hl^{-1} in experiment 2, while differences between managements for the same cultivar were never higher than 3 kg hl^{-1}. No cultivar recorded test weight below 75 kg hl^{-1} in 2020, while in 2019 in experiment 1 twenty nine of the 60 cultivar*management cases were below this limit, and 17 out of 21 cases had values below 75 in experiment 2.

Two cultivars (Izor and Voinic) had all values belonging to grades 1 and 2 in experiment 1.

Table 3. Test weight of several cultivars grown with 4 crop managements in 3 years (Experiment 1)

Cultivar	Management	2018	2019	2020	Averaged over years
Izvor	1	**81.0**	77.0	**81.5**	79.8
	2	**79.5**	76.0	**82.4**	79.3
	3	77.0	77.1	**80.0**	78.0
	4	**81.7**	77.0	**80.7**	79.8
Voinic	1	**80.3**	76.8	**82.7**	79.9
	2	**78.0**	75.4	**81.6**	78.3
	3	77.1	**78.3**	**82.8**	79.4
	4	**79.5**	**78.6**	**79.5**	79.2
Bezostaya 1	1	**81.0**	77.7	**81.5**	80.1
	2	**78.8**	75.7	**81.8**	78.8
	3	77.3	**79.4**	**80.3**	79.0
	4	**78.9**	*74.8*	**80.5**	78.1
Otilia	1	**81.1**	*74.8*	**81.1**	79.0
	2	**79.4**	*74.6*	**82.0**	78.7
	3	77.1	77.3	**82.3**	78.9
	4	**79.9**	77.3	**80.6**	79.3
Pajura	1	**78.3**	76.8	**82.3**	79.1
	2	77.4	76.4	**83.1**	79.0
	3	76.7	77.4	**82.1**	78.7
	4	**78.9**	*73.8*	**81.7**	78.1
Ursita	1	**81.6**	76.0	**81.4**	79.7
	2	77.4	*72.7*	**82.5**	77.5
	3	**78.9**	**79.4**	**81.7**	80.0
	4	**78.9**	*74.0*	**79.8**	77.6
Adelina	1	**79.4**	76.0	**82.2**	79.2
	2	77.4	*72.7*	**83.1**	77.7
	3	76.0	**78.6**	**80.3**	78.3
	4	**79.4**	76.4	**82.3**	79.4
Glosa	1	**78.6**	*74.0*	**83.1**	78.6
	2	76.8	75.0	**81.8**	77.9
	3	76.3	77.4	**82.3**	78.7
	4	**80.5**	76.8	**79.7**	79.0
Pitar	1	**79.5**	76.1	**82.0**	79.2
	2	77.7	*74.4*	**79.4**	77.2
	3	*74.8*	77.3	**81.0**	77.7
	4	**79.5**	76.0	**79.0**	78.2
Lv 6111-18	1	77.4	75.4	**79.1**	77.3
	2	76.7	*70.9*	**81.2**	76.3
	3	76.4	*74.6*	**80.1**	77.0
	4	**78.0**	*72.3*	**80.5**	76.9
Lv 6113-18	1	76.8	*74.8*	**81.2**	77.6
	2	75.4	*72.6*	**80.0**	76.0
	3	75.8	75.8	**78.9**	76.8
	4	**78.2**	*73.1*	**78.9**	76.7
Miranda	1	75.4	75.3	**81.1**	77.3
	2	77.3	*72.3*	**79.2**	76.3
	3	75.3	*74.3*	**79.6**	76.4
	4	75.8	*72.3*	**78.7**	75.6

Cultivar	Management	2018	2019	2020	Averaged over years
Lv 5X	1	77.3	*72.3*	**79.8**	76.5
	2	*73.8*	*69.8*	**80.4**	74.7
	3	75.3	*71.6*	**78.3**	75.1
	4	77.1	*70.1*	**79.6**	75.6
Dacic	1	77.1	*73.8*	77.1	76.0
	2	*74.0*	*68.0*	**81.3**	74.4
	3	*74.8*	*72.7*	77.3	74.9
	4	75.1	*70.4*	76.4	74.0
A4-10	1	76.0	*70.7*	77.7	74.8
	2	*72.1*	*67.4*	76.9	72.1
	3	*72.1*	*73.8*	77.4	74.4
	4	*72.6*	*68.9*	76.5	72.7
Averaged over managements and years		77.4	74.6	80.5	77.5

Bold = Grade 1 (>78); normal = Grade 2 (<78, >75); *Italic = Grade 3 (<75)*.

Table 4. Test weight of several cultivars grown with 3 crop managements in 3 years (Experiment 2)

Cultivar	Management	2018	2019	2020	Averaged over years
Ursita	1	**78.6**	76.4	**81.7**	78.9
	2	*74.8*	75.3	**81.8**	77.3
	3	76.4	**80.3**	**80.3**	79.0
Alcantara	1	75.7	*73.6*	**80.0**	76.4
	2	*73.6*	*70.1*	**79.6**	74.4
	3	*73.3*	*73.4*	**78.2**	74.9
Solehio	1	75.1	*72.1*	**79.1**	75.4
	2	75	*69.4*	**79.0**	74.5
	3	*73.1*	75.0	**78.7**	75.6
Avenue	1	*74.4*	*74.3*	**79.9**	76.2
	2	*72*	*67.9*	**79.6**	73.2
	3	*71.4*	*74.3*	**78.3**	74.6
Apache	1	*73.6*	*74.6*	**80.4**	76.2
	2	*72.3*	*70.9*	**78.3**	73.8
	3	*72.7*	*73.8*	**78.2**	74.9
Rubisko	1	*71.1*	*71.4*	**78.5**	73.7
	2	*74.4*	*69.9*	75.9	73.4
	3	*73.3*	*74.0*	76.1	74.5
Exotic	1	*71.7*	*72.1*	**78.7**	74.2
	2	*72.4*	*66.2*	77.4	72.0
	3	*72.7*	*73.4*	75.3	73.8
Averaged over cultivars and managements		73.7	72.8	78.8	75.1

Bold = Grade 1 (>78); normal = Grade 2 (<78, >75); *Italic = Grade 3 (<75)*.

A synthesis of test weight data averaged over crop managements showed that, while on average most cultivars fulfilled the requirements for Grade 1 and 2, the percentage of cases below the 75 kg hl^{-1} limit varied from 0 to 66.7% (Table 5 and 6). Only two of the Romanian cultivars had half or more cases in Grade 3 (Table 5), while most Western European cultivars tested in experiment 2 had more than 50% samples below 75% kg hl^{-1} (Table 6).

Table 5. Test weight averaged over managements and years, and frequency of grades in experiment 1

Cultivar	Average Test weight	Variance	% cases belonging to:		
			Grade 1 (>78 kg hl^{-1})	Grade 2 (>75, <78 kg hl^{-1})	*Grade 3* (<75 kg hl^{-1})
Izvor	79.2	5.22	**58.3**	41.7	*0*
Voinic	79.2	5.41	**75.0**	25.0	*0*
Bezostaya 1	79.0	5.05	**66.7**	25.0	*8.3*
Otilia	78.9	7.18	**58.3**	25.0	*16.7*
Pajura	78.7	8.48	**50.0**	41.7	*8.3*
Ursita	78.7	9.83	**66.7**	16.7	*16.6*
Adelina	78.6	9.57	**58.3**	33.4	*8.3*
Glosa	78.5	8.75	**50.0**	41.7	*8.3*
Pitar	78.1	5.79	**50.0**	33.3	*16.7*
Lv 6111-18	76.9	10.33	**41.7**	33.3	*25.0*
Lv 6113-18	76.8	7.2	**41.7**	33.3	*25.0*
Miranda	76.4	8.0	**33.3**	41.7	*25.0*
Lv 5X	75.4	14.8	**33.3**	25.0	*41.7*
Dacic	74.8	12.06	**8.3**	41.7	*50.0*
A4-10	73.5	11.87	**0**	41.7	*58.3*

Table 6. Test weight averaged over managements and years, and frequency of grades in experiment 2

Cultivar	Average Test weight	Variance	% of cases belonging to:		
			Grade 1 (>78 kg hl^{-1})	Grade 2 (>75, <78 kg hl^{-1})	*Grade 3* (<75 kg hl^{-1})
Ursita	78.4	7.53	**55.6**	33.3	*11.1*
Alcantara	75.3	11.22	**33.3**	11.1	*55.6*
Solehio	75.2	11.27	**33.4**	33.3	*33.3*
Apache	75.0	10.40	**33.3**	0	*66.7*
Avenue	74.6	16.08	**33.3**	0	*66.7*
Rubisko	73.8	7.58	**11.1**	22.2	*66.7*
Exotic	73.3	13.20	**22.2**	11.1	*66.7*

It is interesting to note that the variances of the test weight values, caused mainly by differences between years, suggest that cultivars are different in stability of test weight, with most of the Romanian cultivars being less affected by the weather conditions than most Western European varieties.

Weather conditions caused large variation of test weight, but the interaction between cultivars and years was small and not significant. Most of the cultivars originated from Fundulea had higher test weight and frequency of high grades according to this trait. This suggests that selection for good grain filling in years with less favorable conditions apparently contributed to higher and more stable test weight.

Taller wheats were described as having on average higher test weight (Butler et al., 2005). The only two tall cultivars included in experiment 1 had contrasting behavior: Bezostaya 1 placed on third position with an average test weight of 79.0 kg hl^{-1} and most cases belonging to first grade, while the line A4-10 had an average test weight of 73.5 kg hl^{-1} and most cases in third grade. Lower test weight in A4-10 was probably due to lodging, which occurred in this line, which is recommended for regions with less fertile soils.

Semidwarf cultivars also showed very diverse behavior. Highest average test weight and lowest frequency of lower grades were recorded in two of the shortest Romanian cultivars (Voinic and Izvor), suggesting large possibilities to improve this trait in semidwarf wheat.

CONCLUSIONS

The large variation of test weight found in our study was mainly the result of weather conditions of the testing years and of cultivar diversity. Cultivars selected in breeding centers with frequent drought and high temperatures had higher test weight and frequency of high grades according to this trait. Selection for good grain filling in years with less favorable conditions apparently contributed to higher and more stable test weight.

Besides its role in influencing milling properties and transport–storage efficiency, test weight can provide essential information on cultivar adaptability to local environmental conditions.

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