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TRENDS IN PRODUCTIVE ABILITIES OF MAIZE HYBRIDS FROM DIFFERENT FAO GROUPS

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Abstract

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Ten-year data (2001-2010) from official maize hybrids testing in IASAS and preliminary (ecological) trials of Maize Research Institute (MRI), carried out in different locations are compared. Besides the actions of many occasional factors – diversity of environments and great number of hybrids tested from 5 FAO groups (200-600) every year, common tendency of both groups of trials are observed. Grain yield (t/ha) has a relative maximum in semi-late hybrids (FAO 500-600). Closer to them are earlier groups – FAO 300-400 and 400-500. Correlations between grain yield and vegetation period like FAO groups are not significant and their regressions are not linear. Correlations of grain moisture at harvesting (%) and vegetation period are strongly positive and regressions are linear for both of trials. For the period of investigation, a progress of reduction of that trait was observed. Best combinations of relatively high grain yield and low grain moisture were pointed out for early hybrids (FAO 300-400) by performance index (Pi) values. Relatively good combinations of grain yield and stability were observed for FAO 500-600 hybrids, represented by their general adaptation index (x_i - b_i). IASAS trials, like final step of maize hybrids testing including Bulgarian and foreign varieties with the same checks out yielded MRI trials as average levels by FAO groups, but overcoming the correlation high yield – late maturity, better p_i values for earlier genotypes and their adaptation are very similar in both trials groups like general tendency. These results confirm the "post green revolution" trends in maize breeding discussed by Duvick and Gassman (1999).

Key words: maize hybrids trials, yield tendency, grain moisture

Introduction

Maize selection worldwide aims not only high grain yield as main economic index but its incidence in areas with shorter vegetation period (Carena, M., 2008). The genetic yield improvement of short season maize hybrids in Canada is mainly attributed to stress tolerance-increasing (Tollenaar and Wu, 1999). In the so-called "post green revolution" period at the end of 20th and the beginning of 21st century, the selection trends for that crop in the temperate zones and the US corn belt pointed out that the undesired high grain yield – long vegetation period correlation had been overcome to a great extent however another similar dependency – high grain yield – grain quality – was a problem not yet solved completely (Duvick and Gassmann, 1999). Not only in the USA, but also in different areas worldwide genetic contributions to maize yield expansion are in progress (Ivanovic and Kojic, 1990; Duvick, 1992; Eyherabide et al., 1994) The same authors stated that considerable progress was achieved in obtaining high-productive hybrids with fast grain moisture down that was a problem for the later vegetation groups.

The investigations in the recent past used to show the perspective for obtaining high-productive hybrids of FAO 400 and 500 group but it was considered that problem was difficult to be solved (Tomov et al., 1979). The objective of this investigation is to reveal the productive abilities, the adaptive potential and grain moisture at harvesting maize hybrids of different FAO groups tested in trials carried out at the Maize Research Institute (MRI) – Kneja and IASAS.

Material and Methods

The results of ecologic trials conducted at the Maize Research Institute – Kneja (ECO) and the official maize hybrids

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testing at IASAS for biological and economic qualities (KCO) with the objective to be recognized and entered in the official variety list of the country were used.

The results of both types of trials – ECO and KCO cover a ten-year period (2001-2010). Two traits were analyzed from all trials – grain yield (kg/ha) and grain moisture percent at harvesting.

All data were statistically processed – the mean values and the coefficient of variation ($CV_{\%}$) were calculated. Correlation and regression analysis was used for some comparisons. Two selection indices were utilized for the data analysis: performance index (p_i) according to E. Lee et al. (2001) and the general adaptation index (x_i-b_i) according to Vulchinkov (1990, 2007). The testing covered 4 FAO groups in ECO and 5 groups in KCO. Generally, established standards (checks) were used on both groups of trials.

Results and Discussion

The results of the trails carried out at MRI-Kneja and IASAS covered a 10-year period that supposed exceptionally great variety of environmental conditions. Each one of the years is unique with its agri-meteorological features. Each year different numbers of hybrids were tested in the different FAO groups. For ECO most of the hybrids were changed each year as a little part of them was repeated. For KCO testing of candidate-varieties first, second and third year were carried out simultaneously, i.e. there was a great dynamics in changing the tested hybrids. Only the standards were kept for a longer time in the trials however, for the entire period of the investigation they were also changed.

The trials do not coincide in locations. For ECO testing were at a smaller number of sites, ranging from two to six as only one place was under irrigation conditions, excluding the year 2010. For KCO testing the locations varied from 4 to 7 sites as most often there were two irrigated locations (Tables 1 and 2). The number of tested hybrids was greater for ECO as in both groups of trials relatively the greatest number of tested hybrids belonged to the semi-early group FAO 400-500 and the semi-late one – FAO 500-600.

So far, it is evident that a great number of accidental factors had in impact for these trials – a different number of hybrids, different locations and different environmental conditions each year. It could be assumed as relatively fixed factor the vegetation group however, each FAO group has a defined range. For example, the semi-early hybrids are 400-499, the semi-late are 500-599, etc.

In spite of the impact and the probable interaction of so many accidental factors, stable trends were observed that

Table 1
Results from testing of maize hybrids in ECO trials of Maize Research Institute – Kneja (2001-2010) by FAO groups

Years	FAO 300-400			FAO 400-500			FAO 500-600			FAO 600 +			Average per year, kg/ha^{-1}
	Number of locations	Number of hybrids	Mean yield, kg/ha^{-1}	Number of locations	Number of hybrids	Mean yield, kg/ha^{-1}	Number of locations	Number of hybrids	Mean yield, kg/ha^{-1}	Number of locations	Number of hybrids	Mean yield, kg/ha^{-1}	
2001	2*+4	13	5233.0	2*+4	43	5367.0	2*+4	49	5346.5	2*+4	36	5081.2	5256.9
2002	1*+2	26	7033.5	1*+2	44	7571.6	1*+2	53	7373.2	1*+2	32	6773.1	7187.9
2003	1*+2	17	5063.8	1*+2	42	5573.8	1*+2	46	5822.5	1*+2	40	5415.3	5468.9
2004	1*+3	27	9309.1	1*+3	52	9713.8	1*+3	57	9940.4	1*+3	46	10323.5	9821.7
2005	1*+3	19	9615.5	1*+3	58	9737.6	1*+3	67	9853.6	1*+3	66	9780.6	9746.8
2006	1*+2	19	7927.2	1*+2	40	7712.3	1*+2	42	8298.1	1*+2	36	7707.5	7911.3
2007	1*+2	13	2237.5	1*+2	37	2410.8	1*+2	26	2262.2	1*+2	40	2266.3	2294.2
2008	1*+3	13	7176.4	1*+3	27	7945.4	1*+3	32	7549.0	1*+3	23	7400.0	7517.7
2009	1*+2	12	7811.5	1*+2	25	7308.6	1*+2	46	7549.5	1*+2	45	7702.3	7593.0
2010	2	14	8072.6	2	51	7858.2	2	53	7696.9	2	41	7824.6	7863.1
$\bar{x}$		*17.3*	*6948.0*		*41.9*	*7119.9*		*47.1*	*7169.2*		*40.5*	*7027.4*	*7066.1*
CV, %			*31.97*			*30.71*			*31.53*			*33.29*	
pi			*4.33*			*4.26*			*3.92*			*3.46*	
bi			*0.98*			*0.97*			*1.01*			*1.04*	
xi-bi			*5.96*			*6.15*			*6.16*			*5.99*	

* Irrigated and nonirrigated conditions

would be further discussed in both groups of trials based on the trait vegetation period duration or FAO group. Tables 1 and 2 show the results of hybrid testing for grain yield (kg. ha-1) from ECO and KCO groups, respectively. For both groups of the trials the highest grain yield was obtained in the semi-late group (FAO 500-600).

As far as it refers grain yield from ECO, this group was followed by the semi-early hybrids (FAO 400-500), then the late ones (600+ FAO) and at the end the early group (FAO 300-400).

Referring the grain yield, from KCO, then follows the late group (yield of 9362 kg.ha^{-1}) and the semi-early one (9351 kg.ha^{-1}), that have very close values, and they are followed by the early groups.

The correlation between grain yield and vegetation period (FAO group) for ECO is poor (r=0.378) and better expressed for KCO (r=0.823***) however in both cases the regression between these two traits is better described with non-linear equation (Figures 1a and 2a).

Tables 3 and 4 display the average values for the other trait – grain moisture at harvesting for both trials. A very clear tendency is observed for both ECO and KCO that with increasing the FAO group the grain moisture content goes up too. The same result was obtained in previous studies of ours (Angelov and Vulchinkov, 2009).

For ECO the average rates are slightly higher – starting from 160 g.kg $^{-1}$ for FAO group 300-400 and reaching more than 200 g.kg $^{-1}$ for group 600. For KCO, grain moisture content starts from 152 g.kg $^{-1}$ in the earliest group reaching 190 g.kg $^{-1}$ in the late one. In both groups of trials, the correlation coefficients between grain moisture and vegetation period (FAO group) are very high and the dependency between them is described with linear equations (Figures 1b and 2b). The difference between the general average rates from both trials is 12.7 g.kg $^{-1}$ as the higher grain moisture is for ECO as already mentioned. Further similar tendencies are observed between both investigations. The variation, regardless the lower grain moisture content in the earlier groups, is higher compared to the later groups with higher grain moisture. CV% rates are lower for FAO group 500-600 and 600+ both for ECO and for KCO (Tables 3 and 4). That could be partially explained with the influence of the conditions upon that trait each year. The earlier hybrids (from FAO 200 to 500) have faster rate of grain drying in contrast to the later hybrids that show just the opposite tendency. If we subdivide, the investigated period 2001-2010 into two sub-periods – 2001-2005 and 2006-2010 we will further notice a similar tendency in both groups of trials. The first sub-period has higher average rates for that trait – 186.4 g.kg $^{-1}$ for ECO and 174.0 g.kg $^{-1}$ for KCO. During

Table 2
Results from testing of maize hybrids in KCO trials of IASAS (2001-2010) by FAO groups

Years	FAO 200-300			FAO 300-400			FAO 400-500			FAO 500-600			FAO 600 +			Average per year, kg/ha^{-1}
	Number of locations	Number of hybrids	Mean yield, kg/ha^{-1}	Number of locations	Number of hybrids	Mean yield, kg/ha^{-1}	Number of locations	Number of hybrids	Mean yield, kg/ha^{-1}	Number of locations	Number of hybrids	Mean yield, kg/ha^{-1}	Number of locations	Number of hybrids	Mean yield, kg/ha^{-1}	
2001	1*+5	15	6920.0	1*+5	27	7260.0	1*+5	51	6420.0	1*+5	44	7200.0	1*+5	19	7070.0	6974.0
2002	2*+4	13	8115.0	2*+4	19	8850.0	2*+3	38	10190.0	2*+3	31	10830.0	2*+3	22	10080.0	9613.0
2003	2*+4	10	7560.0	2*+4	24	8420.0	2*+4	37	8220.0	2*+4	30	8220.0	2*+4	29	8190.0	8122.0
2004	1*+5	12	10520.0	1*+5	25	10750.0	1*+5	50	11120.0	1*+5	31	11520.0	1*+5	30	10910.0	10964.0
2005	2*+4	7	10590.0	2*+4	25	10870.0	2*+4	48	11190.0	2*+4	33	11620.0	2*+4	27	11190.0	11092.0
2006	2*+5	12	9620.0	2*+5	31	10250.0	2*+5	42	10480.0	2*+5	32	10400.0	2*+5	14	10340.0	10218.0
2007	1*+3	12	4180.0	1*+3	30	4360.0	1*+3	40	4340.0	1*+3	40	4470.0	1*+3	9	4600.0	4390.0
2008	2*+5	16	8910.0	2*+5	32	9520.0	2*+5	35	9600.0	2*+5	41	9590.0	2*+5	7	9380.0	9400.0
2009	2*+5	6	10070.0	2*+5	23	10150.0	2*+5	27	10320.0	2*+5	27	10340.0	2*+5	13	10390.0	10254.0
2010	2*+5	3	11060.0	2*+5	24	11320.0	2*+5	20	11630.0	2*+5	22	11800.0	2*+5	14	11470.0	11456.0
$\overline{x}$		*10.6*	*8754.5*		*26.0*	*9175.0*		*38.8*	*9351.0*		*33.10*	*9599.0*		*18.4*	*9362.0*	*9248.3*
CV, %			*24.20*			*22.89*			*25.12*			*24.37*			*23.07*	
Pi			*5.76*			*5.99*			*5.88*			*5.68*			*4.93*	
bi			*0.95*			*0.95*			*1.06*			*1.06*			*0.98*	
xi-bi			*7.80*			*8.23*			*8.29*			*8.54*			*8.38*	

* Irrigated and nonirrigated conditions

Table 3
Grain moisture at harvest (%) of maize hybrids, tested in ECO trials of Maize Research Institute – Kneja (2001-2010) by FAO groups

Years	FAO 300-400	FAO 400-500	FAO 500-600	FAO 600 +	Year means	Period means
2001	17.8	19.2	19.3	22.3	19.7	(2001-2005) 18.64
2002	18.1	19.2	20.0	20.0	19.3	
2003	13.4	14.2	16.2	16.4	15.0	
2004	18.3	19.4	19.6	21.8	19.8	
2005	18.0	19.0	19.7	21.1	19.4	
2006	15.4	16.5	18.1	20.7	17.7	(2006-2010) 17.04
2007	13.5	14.9	18.7	19.5	16.6	
2008	15.6	16.3	18.4	20.9	17.8	
2009	15.5	15.4	17.4	20.7	17.3	
2010	14.4	14.6	16.3	17.8	15.8	
Average by groups	16.00	16.9	18.4	20.1	17.8	
CV,%	12,01	12.12	7.46	7.98		

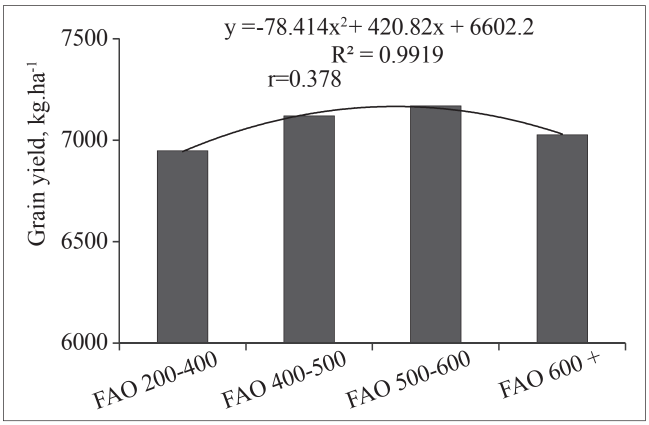

Fig. 1a. Ratio of grain yield to the vegetation period (FAO groups) of maize hybrids, tested in ECO (MRI-Kneja), by FAO groups

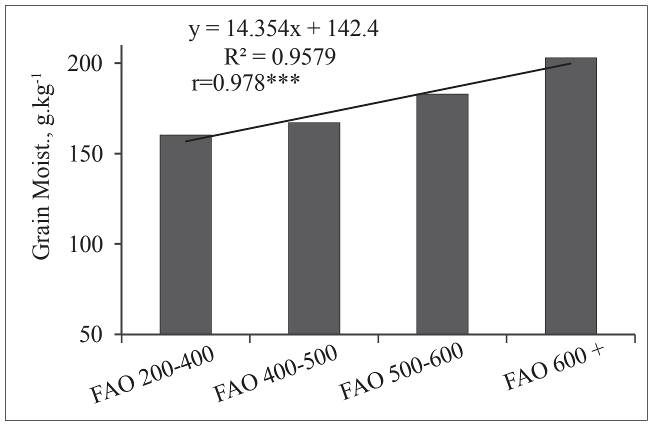

Fig. 1b. Ratio of grain moisture to the vegetation period (FAO groups) of maize hybrids, tested in ECO (MRI-Kneja), by FAO groups

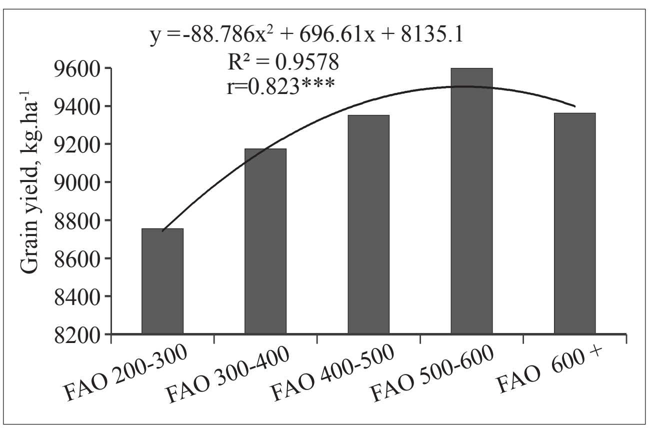

Fig. 2a. Ratio of grain yield to the vegetation period (FAO groups) of maize hybrids, tested in KCO (IASAS) by FAO groups

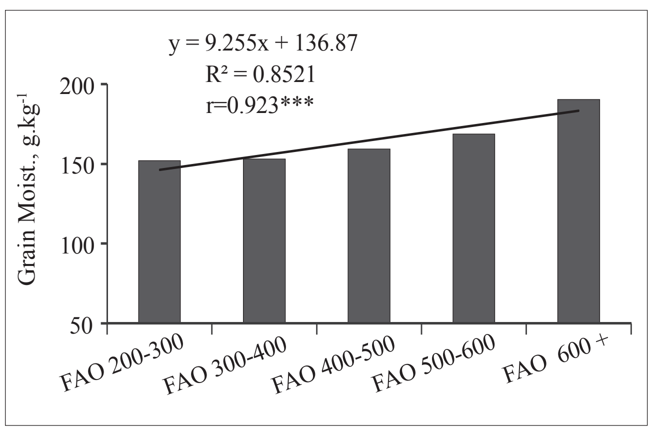

Fig. 2b. Ratio of grain moisture to the vegetation period (FAO groups) of maize hybrids, tested in KCO (IASAS), by FAO groups

the second sub-period grain moisture content reducing was observed for both categories of trials, 170.4 g.kg $^{-1}$ for ECO and 155.4 g.kg $^{-1}$ for KCO, respectively. That decrease is by 16.0 g.kg $^{-1}$ for the first group of trials and 18.6 g.kg $^{-1}$ for the second one. Notwithstanding the influence of the environmental conditions, each year the reduction of that significant trait could be considered as achieved selection progress for both cases. Their regression lines are almost parallel, pointed out on Figure 3. Referring the performance index (p_i) rates, it is the highest for the earliest group (300-400) and gradually drops down for the later groups. For KCO p_i rates are the highest for group 300-400 (5.99) with a tendency to drop down for the later groups.

The earliest group (200-300) has a value of p_i = 5.76, approximately between the groups FAO 500 and 600. For both groups of trials, the latest vegetation groups have the lowest rates, and the early group (FAO 300-400) has the highest ones. That fact could explain the orientation of the producers to the earlier vegetation groups combining relatively high yield with lower grain content, i.e. higher p_i rate.

The tendencies in both groups of trials are also similar for the other observed index (x_i-b_i) for general adaptation. The calculated regression coefficient b_i based on the average genotype – FAO group – in relation to the conditions of the investigated period and respectively calculated index as a difference from the average yield has the highest rates for FAO group 500-600 for both trials. According to the general adaptation index for ECO, it follows the semi-early group (400-500); then the late one and the early group with very small difference. For KCO it follows the late group and in descending order, the earlier groups. The rates for that index are the same as for the average grain yield in the FAO groups for both trials that support a previous study of ours on the correlation between these two parameters (Vulchinkov et al., 1998).

The semi-late hybrids of FAO 500-600 group having relatively higher grain yield in both groups of trials have also

Table 4
Grain moisture at harvest (%) of maize hybrids, tested in KCO trials of IASAS (2001-2010) by FAO groups

Years	FAO 200-300	FAO 300-400	FAO 400-500	FAO 500-600	FAO 600 +	Year means	Period means
2001	15.0	15.3	14.9	17.7	20.4	16.7	
2002	16.5	16.5	18.0	17.5	21.7	18.0	(2001-2005)
2003	12.9	12.1	14.6	15.7	18.7	14.8	17.40
2004	17.5	18.3	18.1	19.3	20.5	18.7	
2005	17.5	17.9	19.0	18.8	20.6	18.8	
2006	13.0	14.4	15.5	16.4	18.3	15.5	
2007	16.6	16.6	16.6	17.6	19.5	17.4	(2006-2010)
2008	14.1	13.2	14.3	15.5	16.8	14.8	
2009	14.1	14.2	13.5	14.3	16.7	14.6	15.54
2010	14.7	14.5	14.9	15.9	17.2	15.4	
Average by groups	15.2	15.3	15.9	16.9	19.0	16.5	
CV, %	11.41	13.10	11.73	9.30	9.30		

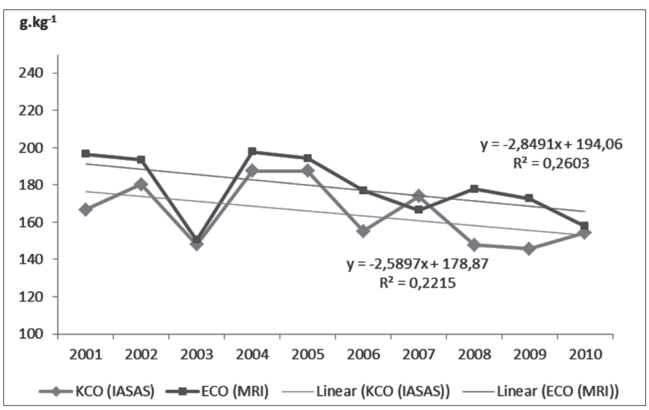

Fig. 3. Dynamics of grain moisture of both trials groups during the period of investigation

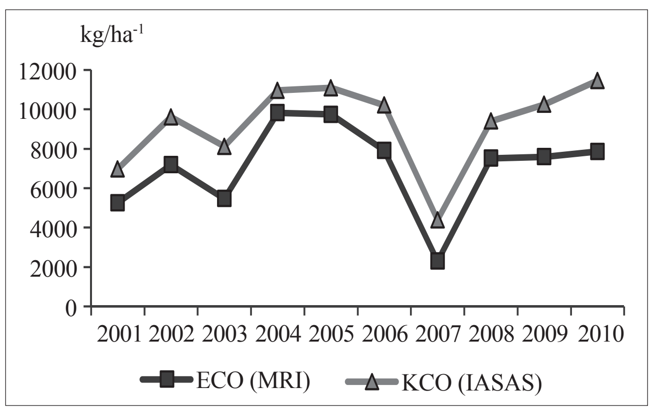

Fig. 4. Dynamics of grain yield for period investigated (2001-2010) from both trials groups

the best relative general adaptation, expressed through that index. Its using for other crops proves also their adaptation (Antonova et al., 2010).

The average rates for grain yield per years provide information for the most favorable conditions during the investigated period. For KCO it was 2010 and 2005 (with highest grain yield), for ECO – 2004 and 2005. As the most unfavorable year with expressed drought was 2007, evident from the lowest grain yield in both groups of trials. Dynamics of average grain yields are shown on Figure 4.

The grain yields from the trials of IASAS (KCO) were higher compared to ECO at MRI-Kneja however, we should state that the best-classified hybrids from ECO are further tested for KCO, i.e. these trials could be assumed as preliminary of the official testing at IASAS.

It is known that this testing includes not only Bulgarian but foreign hybrids representing the world selection level. For the investigated period (2001-2010) 1163 hybrids from FAO group 300 to 600+ were included in the official testing (summarized from Table 2) as 184 of them were from MRI-Kneja, or 15.8 %. For the same period 19 hybrids of the Institute were released that could be assumed as very good achievement of the Bulgarian selection (Ilchovska, 2011).

Overcoming the undesired by the breeders correlation between high yield and long vegetation period, the observed higher yields obtained for the earlier groups, the better adaptation of these hybrids, the better combination in the earlier groups of relatively high yield with low grain moisture at harvesting that were observed simultaneously in the trials at MRI-Kneja and IASAS as a general tendency coincides with the world trends in maize selection during "post green revolution" period well described by Duvick and Gassmann (1999).

Conclusions

The following general conclusions could be made based on the simultaneous investigation for the 10-year period in both groups of trials – ECO of MRI-Kneja and KCO at IASAS:

Grain yield-vegetation period correlation (FAO group) is not significant for all categories of trials and the dependency between these two traits is non-linear.

The vegetation period duration - grain moisture at harvesting correlation is positive, significant as it is described as linear regression.

Relatively the highest grain yield and general adaptation index is observed in the semi-late FAO group (500-600).

The best combination of high grain yield – low grain moisture at harvesting has the early FAO group (300-400) expressed by the performance index values.

The grain moisture variation is higher in the early groups regardless its lower rates as a tendency of reduction of this trait was observed in both groups of trials.

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