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GRAIN FILLING PARAMETERS IN HIGH-YIELDING NS WHEAT CULTIVARS

ABSTRACT: Grain yield of wheat is dependent on grain weight, which is the result of grain filling duration and rate. The study was undertaken to examine the relation between grain weight and rate and duration of grain filling in five high-yielding NS wheat cultivars. Stepwise multivariate analysis of nonlinear regression estimated grain filling parameters was used to examine cultivar differences in grain filling. On the basis of three-year average, the highest grain dry weight had cultivar Renesansa, and the lightest grains were measured for cultivar Evropa 90. Stepwise multivariate analysis indicated that all three nonlinear regression estimated parameters (grain weight, rate and duration of grain filling) were equally important in characterizing the grain filling curves of the cultivars studied, although sequence of their significance varied in different years, which is probably caused by different environmental conditions in three years of experiment.

KEY WORDS: grain filling, nonlinear regression, wheat

INTRODUCTION

Grain yield in wheat (*Triticum aestivum* L.) can be analyzed in terms of three yield components: number of spikes/m^2, number of grains/spike and grain weight. After anthesis, yield is largely dependent on final grain weight, which is the result of grain filling duration and rate (Whan et al., 1996).

The existence of genetic variation in wheat has been reported for both grain filling duration and rate (Darroch and Baker, 1995), and significant correlations have been found between grain weight and rate (Calderini and Reynolds, 2000), but also between grain weight and duration of grain filling (Evans et al., 1975). Gebeyehou et al. (1982) found significant correlations between both grain filling parameters (duration and rate) and yield.

Differences in relative importance of grain filling parameters for grain yield are probably caused by fact that environmental factors, especially temperature, also affect grain filling (Stone and Nicolas, 1994). A better understanding of the grain filling process may be helpful in breeding efforts to increase grain yield.

Linear regression (Van Sanford, 1985), quadratic (Nass and Reiser, 1975; Bruckner and Frohberg, 1987) and cubic equation (Gebeyehou et al., 1982) are statistical methods which have been used to describe grain filling in wheat. Univariate analysis of variance (ANOVA) can be used only to differentiate among grain growth curves and Darroch and Baker (1990) suggest stepwise multivariate analysis (Keuls and Garretsen, 1982) of nonlinear regression estimated parameters as more appropriate for analyzing growth curve parameters. Stepwise MANOVA can clarify the relative importance of the various parameters in a growth curve.

The objective of this study was to examine the relation between grain weight and rate and duration of grain filling in five high — yielding NS wheat cultivars.

MATERIAL AND METHODS

Five high-yielding NS wheat cultivars (Pobeda, Renesansa, Evropa 90, Sonata and Sofija) were chosen for this study in order to examine the possible differences in their grain filling pattern, and the relation between their grain filling parameters. It can point out the different ways for increasing yield in wheat.

The trial was conducted at the experimental field Rimski Šančevi, Institute of Field and Vegetable Crops, Novi Sad, in 2000, 2001 and 2002. The standard agrotechnic procedures were applied. Plot areas were 5 m^2, sown in four replications. Rimski Šančevi meteorological station data (temperature, precipitation) were used. Sampling started 14 days after anthesis and continued at 7-day intervals in first 3 weeks, and approximately 2-day intervals after, until maturity (13% moisture in grain). Random samples of 20 spikes per plot were harvested on each sampling date, selected in four replications. 10 grains from the middle of each of the 20 spikes were removed and oven dried at 80°C for 24 h. The grains were weighed before and after drying.

Dry matter accumulation over time and duration of grain filling were expressed as a function of accumulated growing degree days (gdd — °C) from anthesis. Growing degree days in particular sampling date is a sum of average daily temperatures from anthesis (Duguid and Brûlé-Babel, 1994). The grain weight and duration of dry matter accumulation data were fitted by nonlinear regression to a logistic curve: $y = W/(1+\exp(B-Cx))$ in order to calculate estimated grain filling parameters: final grain dry weight (W — mg), maximum rate (R — mg dry matter gdd^{-1}) and duration (T — gdd) of grain filling. Y is average grain weight (mg), x are gdd from anthesis, B is related to both duration and rate of grain filling and C is related to grain filling rate. The calculations are described in details in Darroch and Baker (1990). STATISTICA software package was used. Stepwise MANOVA described by

Keuls and Garretsen (1982) was used in order to determine which of the estimated parameters is the most important in characterizing the grain filling curves. The most significant parameter is one with the lowest Wilks' λ — value and the set can be extended to two or all three parameters. Only if the new parameter adds information not already contained in the set, its addition is considered to be important.

RESULTS AND DISCUSSION

The logistic curve provided a good fit to grain filling data in the study. In all 60 cases R^2 values exceeded 0.95, similar to results obtained by Duguid and Brûlé-Babel (1994).

Tab. 1 — Sum of temperatures (°C), average daily temperature (°C) and sum of precipitation (mm) in May and June in 2000, 2001. and 2002 (Rimski Šančevi meteorological station, Novi Sad)

Year	2000	2001	2002
Sum of temperatures	1214.5	1098.5	1245
Average daily temperature	20	18	20.4
Sum of precipitation	67	308	114

Univariate analysis of variance conducted on individual trials (years) showed significant differences among genotypes regarding all three (grain dry weight — W, rate — R and duration — T of grain filling) nonlinear regression estimated parameters in all three trials (Tab. 3). Stepwise multivariate analysis is used in order to determine the smallest set of estimated parameters that characterize the grain filling curves in each trial. Grain dry weight was the parameter with the smallest λ — value in 2000, therefore, of all three parameters, W was the most important in differentiating among grain filling curves. In 2001 the smallest λ — value is noted for parameter T, and for R in 2002 (Tab. 3).

Tab. 2 — Nonlinear regression estimated grain dry weight (W — mg), rate (R — mg dry matter $°C^{-1}$), duration (T — gdd) of grain filling and anthesis date (AD — number of days from 01. 01. to anthesis) in five high-yielding NS wheat cultivars, three-year trial

Cultivar	2000				2001				2002			
	W	R	T	AD	W	R	T	AD	W	R	T	AD
Pobeda	48.8	0.145	655	128	39.9	0.145	559	135	53.2	0.103	712	132
Renesansa	56.1	0.127	737	125	45.8	0.119	650	134	53.2	0.119	700	130
Evropa 90	50.5	0.130	684	128	39.8	0.116	618	135	47.4	0.099	711	130
Sonata	48.9	0.143	652	128	42.8	0.140	581	135	50.0	0.116	647	132
Sofija	50.1	0.125	711	127	44.0	0.106	706	136	50.3	0.113	680	132
Average	50.9	0.134	688	127	42.5	0.125	623	135	50.8	0.110	690	131

Variation in sequence of significance is probably the result of different environmental conditions in three years of experiment (Tab. 1). In all cases the

sets are extended to all three parameters (Tab. 4), which implies the significant impact of both grain filling duration and rate on grain weight.

Tab. 3 — Tests of significance of cultivar effects in MANOVA of final grain dry weight (W), maximum grain filling rate (R) and grain filling duration (T), measured in three trials (years)

Conditional set	df	2000		2001		2002	
		λ	F	λ	F	λ	F
W, R, T	12, 34	0.0121	12.46**	0.0027	24.28**	0.0006	43.31**
W, R	8, 28	0.0508	12.03**	0.0217	20.25**	0.0164	23.81**
W, T	8, 28	0.0655	10.18**	0.0221	20.05**	0.0099	31.75**
R, T	8, 28	0.0859	8.44**	0.0108	30.11**	0.0170	23.38**
W	4, 15	0.1495	21.34**	0.3250	7.79**	0.2156	13.64**
R	4, 15	0.3307	7.59**	0.0712	48.88**	0.1193	27.67**
T	4, 15	0.2222	13.13**	0.0515	69.00**	0.2602	10.66**

** — significant at the 0.01 level of probability
df — degrees of freedom
λ — Wilks λ criterion

Cultivar Renesansa had the highest grain dry weight in all trials, as a result of long grain filling with medium rate. On three-year average, the lowest grain filling rate and medium long grain filling of cultivar Evropa 90 resulted in the lightest grains of all five cultivars studied (Tab. 2). Thus, in our environments, the condition for heavy grains is not only long grain filling duration, but also the adequate balance between grain filling duration and rate. It is important to remark that cultivar Renesansa reached anthesis on three-year average two days earlier than other four cultivars (Tab. 2). Grain filling of Renesansa occurred in conditions different enough to provide gradual dry matter accumulation and to avoid terminal dry and temperature stress, in contrast to other cultivars studied.

Tab. 4. — Determination of the smallest set of variables required to completely characterize the grain filling curves in five high-yielding NS wheat cultivars

Year	Conditional set	λ	df	F	Final set
2000	W	0.1495	4, 15	21.34**	
	R/W	0.3398	4, 14	2.51^{ns}	
	T/W	0.4381	4, 14	1.79^{ns}	
	RT/W	0.0809	8, 26	8.21**	W, R, T
2001	T	0.0515	4, 15	69.00**	
	R/T	0.0108	4, 14	30.27**	
	W/TR	0.2500	4, 13	9.77**	T, R, W
2002	R	0.1193	4, 15	27.67**	
	W/R	0.1375	4, 14	5.94**	
	T/RW	0.0366	4, 13	86.04**	R, W, T

ns ** — nonsignificant, significant at the 0.01 level of probability
W — nonlinear regression estimated final grain dry weight
R — maximum rate of grain filling, T — grain filling duration
df — degrees of freedom
λ — Wilks' λ criterion

Variation among wheat genotypes regarding grain filling duration and rate indicates the possibility for breeding manipulation in purpose of increasing yields, however, other factors, such as anthesis date, number of grains per spike, number of spikes per m^2 and leaf area duration should also be considered.

CONCLUSION

The results of stepwise multivariate analysis of nonlinear regression estimated wheat grain filling parameters showed significant impact of both grain filling duration and rate on grain dry weight. The highest grain dry weight is noted for cultivar Renesansa, which was characterized by long grain filling with medium rate. Renesansa also reached anthesis two days earlier comparing to other cultivars studied.

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ПАРАМЕТРИ НАЛИВАЊА ЗРНА ВИСОКОПРИНОСНИХ НС СОРТИ ПШЕНИЦЕ

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Резиме

Принос пшенице зависи од масе зрна, која је резултат дужине и интензитета наливања зрна. Циљ рада је био испитивање веза између масе зрна и интензитета и дужине наливања зрна код пет високоприносних НС сорти пшенице. Stepwise мултиваријациона анализа нелинеарном регресијом процењених параметара наливања зрна је употребљена да се испитају разлике међу сортама у погледу наливања зрна. У трогодишњем просеку је највећу масу зрна имала сорта Ренесанса док су најлакша зрна измерена код сорте Европа 90. Stepwise мултиваријациона анализа је показала да су сва три нелинеарном регресијом процењена параметра (маса зрна, интензитет и дужина наливања зрна) једнако значајна за карактеризацију кривих наливања зрна проучаваних сорти, мада је редослед значајности варирао у различитим годинама. Овоме су вероватно узрок различити услови средине којима су проучаване сорте биле изложене током три године експеримента.