Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1679-9275
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v38i2.27901

Harvest time and agronomic performance of maize hybrids with contrasting growth cycles

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ABSTRACT. The delay of the maize harvest may cause qualitative and quantitative grain losses. This work evaluated the effects of the harvest time on the agronomic performance of maize hybrids with contrasting growth cycles. The experiment was set in Lages, Santa Catarina State, South Brazil, during the 2012/2013 and 2013/2014 growing seasons. A randomized block design, arranged in split plots was used. Five single-cross hybrids were tested in the main plots: P1630H and P32R22H (hyper-early), P2530 (super early) and P30F53YH and P30R50YH (early). Five harvest times were assessed in the split plots: 0 (grain physiological maturity), 10, 20, 30 and 40 days after physiological maturity. The sowing was performed on 12/5/2012 and 10/5/2013. The percentage of lodged and broken stems, grain mass, potential and real productivity were determined. The delay of the maize harvest increased the percentage of lodged and broken stems. The harvest time did not affect the weight of 1,000 grains. The harvests performed after physiological maturity decreased the real grain productivity, especially for the hyper-early hybrids P1630H and P32R22H. In the regions with high altitude and latitude, the productivity losses derived from late harvests are mainly due to the increase in the amount of broken and lodged stems.

Keywords: *Zea mays*, maturation, grain productivity, lodging.

Épocas de colheita e desempenho agronômico de híbridos de milho com ciclos de crescimento contrastantes

RESUMO. O atraso na colheita do milho pode ocasionar perdas quantitativas e qualitativas aos grãos. Este trabalho avaliou os efeitos da época de colheita sobre o desempenho agronômico de híbridos de milho com ciclos contrastantes. O experimento foi implantado em Lages, Planalto sul de Santa Catarina, Brasil, nas safras 2012/13 e 2013/2014. O delineamento experimental utilizado foi blocos casualizados dispostos em parcelas subdivididas. Na parcela principal foram testados cinco híbridos simples: P32R22H e P1630H (hiper-precoces), P2530 (super-precoce), P30F53YH e P30R50YH (precoces). Nas subparcelas foram testadas cinco épocas de colheita: 0 (maturação fisiológica dos grãos), 10, 20, 30 e 40 dias após a maturação fisiológica. A semeadura foi realizada em 5/12/2012 e 5/10/2013. Avaliaram-se a percentagem de plantas acamadas e quebradas, a massa de 1.000 grãos, produtividade potencial e real de grãos. O atraso na colheita aumentou o acamamento e quebra de plantas. A época de colheita não interferiu sobre massa de 1.000 grãos. A realização da colheita após a maturação fisiológica reduziu a produtividade real de grãos, principalmente dos híbridos de ciclo hiper-precoce P1630H e P32R22H. Em regiões de alta latitude e altitude, as perdas de produtividade ocasionadas por colheitas tardias se devem ao incremento na quantidade de colmos acamados e quebrados.

Palavras-chave: *Zea mays*, maturação, produtividade de grãos, acamamento.

Introduction

During the last 20 years, Brazilian soybean breeding programs have emphasized the development of early indeterminate cultivars that do not interrupt their vegetative growth after flowering. This allows farmers to sow them earlier than the genotypes that present a determinate growth habit (Stülp, Braccini, Albrecht, Ávila, & Scapim, 2009).

The anticipation of the sowing date and the earlier maturation of the cultivars have several advantages for soybean production, such as the reduction of stink bug attacks, the lower incidence of Asian rust, the decreased risk of low temperature and water restrictions during grain filling and a better sowing period for maize after the soybean harvest in the states that use this cropping system, such as Mato Grosso and Paraná States (Thomas & Costa, 2010).

However, in the south of Brazil, where soybean and maize are sown during the spring in a crop rotation system, the early ripening of the soybean cultivars, associated with sowing at the end of September/beginning of October, has accelerated the soybean harvest. This operation is currently concentrated in February, coinciding with the harvest of mature maize. Because soybeans are more profitable and more sensitive to harvest delay, growers prefer to harvest the legume first, leaving maize in the field for more than 30 days after its physiological maturity.

The delay of the maize harvest may promote quantitative and qualitative losses to the grain yield, caused by physiological and morphological factors. The grain yield and seed quality are potentially higher when the harvest is carried out right after physiological maturity (Araujo, Araujo, Sofiatti, & Silva, 2006; Marques, Dalpasquale, Vidigal Filho, Scapim, & Reche, 2011; Galvão, Conceição, Araújo, Karstein, & Finger, 2014). However, when maize grains are stored in the field and harvested with less than 20% moisture content, they may lose weight due to respiration (Kaaya, Warren, Kyamanywa, & Kyamuhangire, 2005; Lauren, Smith, & Di Menna, 2007). In addition, the removal of grain with low moisture from the field promotes mechanical damage at harvest. Such injuries may favour the occurrence of insects and diseases during grain storage (Santin, Reis, & Matsumura, 2004; Marqui, Menten, Moraes, & Cícero, 2006).

Morphologically, late harvest increases the susceptibility of maize stems to lodging and breakage. The intensity of the lodging and breakage depends on the hybrid's agronomic traits, the management practices used on the crop (fertilization, plant density and row spacing) and the meteorological conditions at the end of grain filling, especially the wind speed and rain fall distribution (Gomes, Brandão, Brito, Moraes, & Lopes, 2010).

Maize harvest delay may also compromise grain quality and productivity because it favours the incidence of fungi that cause ear and grain rot, such as *Stenocarpella maydis, S. macrospora, Fusarium verticillioides* e *F. graminearum* (Marques, Vidigal Filho, Dalpasquale, Scapim, Princinoto, & Machisnski Junior, 2009). These pathogens use starch from the endosperm as an energy source for their growth and decrease the quality of the grain, its nutritional value and its visual appearance (Pinto, Vargas, & Preis, 2007).

The problems caused by maize harvest delay can be mitigated by the choice of cultivar. Traits such as the hybrid's growth cycle, ear husk coverage, ear decumbence after grain physiological maturity, plant height and ear insertion height may affect the magnitude of morphological and physiological damage caused by late harvests (Gomes et al., 2010).

This work was carried out to evaluate the effects of harvest time on the agronomic performance of maize hybrids with contrasting growth cycles.

Material and methods

This study was conducted in the city of Lages, Santa Catarina State, in the highlands of southern Brazil, during the growing seasons of 2012/2013 and 2013/2014. The experimental site is located at 27º 52' latitude south, 50º 18' longitude west and 900 m above sea level. The climate of the region is classified by Köppen-Geiger, mentioned by Kottek (2006), as Cfb, presenting mild summers, cold winters and adequate rainfall during the whole year. The temperature and precipitation information were collected from a meteorological experimental station located 20 km from the experimental site.

The soil at the study site was an Oxisol (Hapludox), according to Embrapa (Empresa Brasileira de Pesquisa Agropecuária, 2006), having the following chemical characteristics: clay content - 560 g kg^{-1}; organic matter content - 60.0 g kg^{-1}; water pH - 5.2; SMP pH - 5.7; phosphorus – 4.4 mg dm^{-3}; potassium - 186 mg dm^{-3}; calcium – 5.79 cmolc dm^{-3}; magnesium – 2.47 cmolc dm^{-3}; aluminium – 0.2 cmolc dm^{-3}; CTC – 8.94 cmolc dm^{-3}.

A randomized block design arranged in split plots was used, with four replicates per treatment. Five single-cross hybrids with contrasting growth cycles were assessed in the main plots: two hyper-early hybrids (P32R22H and P1630H) that require 1282 and 1220 heat units (HU) to reach physiological maturity; one super-early hybrid (P2530) that requires 1390 HU to attain physiological maturity; and two early hybrids (P30R50YH and P30F53YH) that achieve physiological maturity with 1493 and 1556 HU. Five harvest times were evaluated in the split plots: 0 (grain physiological maturity), 10, 20, 30 and 40 days after physiological maturity. The first harvest time for each hybrid was carried out when there was a visible black layer in the grain insertion point on the cob (R6 stage of the growth scale proposed by Ritchie, Hanway, and Benson (1993). Each split plot comprised four rows, 0.7 apart and 7 m long. All measurements were taken from the two central rows, leaving borders of 0.5 m at the end of each row.

The experiment was set using a no-tillage system under a dead coverage of black oat (*Avena strigosa*).

The experimental area was planted with maize for three consecutive years before installing the trial. The soil fertilization was determined based on the goal of a grain yield of 18,000 kg ha^{-1}. Fertilization was performed at the sowing date by applying 30 kg ha^{-1} of N, 295 kg ha^{-1} of P_2O_5 and 170 kg ha^{-1} of K_2O. The fertilizers were superficially placed close to the sowing rows. Nitrogen was also side-dressed, applying 250 kg of N divided into three equal parts when the plants were at the V4, V8 and V12 growth stages, according to Ritchie et al. (1993). Urea was used as the N source.

The experiment was hand planted on 12/5/2012 and 10/5/2013. The plots were over-sown, dropping three seeds per hill and thinned to the desired density (80,000 pl ha^{-1}) when the plants had three expanded leaves.

The weeds were controlled with two herbicide applications. The first was conducted immediately after sowing and prior to plant emergence with a combination of atrasine (1,400 g a.i. per hectare) and metolachlor (2,100 g a.i. per hectare). The second application was performed after the emergence of the maize, when the plants were at V4, using tembotriona (100 g ha^{-1} de i.a.). Army worm (*Spodoptera frugiperda*) was controlled by spraying the insecticides lufenuron + lambdacyhalothrin (15 + 7.5 g de i.a. ha^{-1}) when the crop reached the V6 and V12 growth stages, according to Ritchie et al. (1993).

For each treatment, the percentage of lodged and broken stems was determined on the harvest day. In 2012/2013, harvest time 0 (grain physiological maturity) was carried out on 5/01/2013 and 5/10/2013 for the hyper-early and the other hybrids, respectively. In 2013/2014, harvest time 0 was performed on 3/06/2014, 3/16/2014 and 3/26/2014 for the hyper, super and early hybrids, respectively. The other harvests for each hybrid were performed at constant intervals of 10 days from harvest time 0.

At all harvest times, the ears were collected manually. Two harvest operations were carried out. In the first, the ears from the lodged and broken stems were harvested. Subsequently, the ears from erect plants were collected. The ears from both harvests were shelled and weighed separately. The kernel moisture was determined, and the grain yield per hectare was calculated and expressed at the standard moisture of 13%.

The grain yield was estimated in two ways. The first yield determination considered all harvested plants from each split plot, including those that were lodged and broken, simulating what would happen if the crop were manually harvested (potential yield). The second yield estimate subtracted from the potential yield a value equivalent to 50% of the weight of the grains harvested in the lodged and broken stems of each split plot, assuming that such kernels would not be removed from the field if the harvest were mechanically performed (real yield).

The data were statistically evaluated by a variance analysis, using the F test, at the significance level of 5%. The data from the lodged and broken stems were transformed before carrying out the variance analysis using the expression $(x + 1)^{1/2}$. When the F values were significant, the values were compared using Tukey's test. The effect of delaying harvest time was also assessed by polynomial regression analysis, testing the linear and quadratic models. Both evaluations were conducted at the significance level of 5%.

Results and discussion

The percentage of lodged and broken stems ranged from 0 to 33.4% in 2012/2013 and from 0 to 95.4% in 2013/2014 (Table 1). This variable was affected by the harvest time. In both growing seasons, the percentage of the lodged and broken plants increased in proportion to the delay in harvest time. The numeric values of the lodged and broken plants were greater in 2013/2014 than in 2012/2013. According to the regression analysis adjusted for the average values of the five hybrids, the percentage of lodged and broken stems presented a linear increase of 4.3 and 10.8% for each 10 days of delay in harvest time for the first and second growing seasons, respectively (Figure 1a).

Table 1. Percentage of lodged and broken stems of maize hybrids with contrasting growth cycles as affected by harvest time. Lages, South Brazil.

Days after physiological maturity	Hybrids					Average	CV (%)
	P1630H	P32R22H	P2530	P30F53YH	P30R50YH		
Lodged and broken stems							
Growing season 2012/2013							
0	0.0	0.0	0.0	2.1	3.6	1.1 b*	
10	4.5	5.7	0.4	2.5	8.2	4.3 b	
20	4.8	4.0	4.8	6.5	5.9	5.2 b	79.1
30	17.9	25.1	10.4	10.2	10.6	14.9 a	
40	17.3	33.4	14.5	10.4	12.4	17.6 a	
Averages	8.9NS	13.6	6.0	6.3	8.1		
CV (%)	96.2						
Growing season 2013/2014							
0	0.0	3.1	10.8	0.5	0.0	2.9 c*	
10	2.4	10.7	13.1	0.5	0.0	5.3 c	
20	4.5	19.9	19.8	6.7	5.3	11.2 bc	80.7
30	8.3	33.7	61.0	3.9	18.6	25.1 b	
40	58.4	95.4	50.4	15.8	17.0	47.4 a	
Averages	14.7 ab*	32.6 a	31 a	5,5 b	8,2 b		
CV (%)	81.7						

[NS]Differences among averages are not significant in the row ($p < 0.05$). *Averages followed by the same lower case letter in the row or in the column do not differ significantly by Tukey's test ($p < 0.05$).

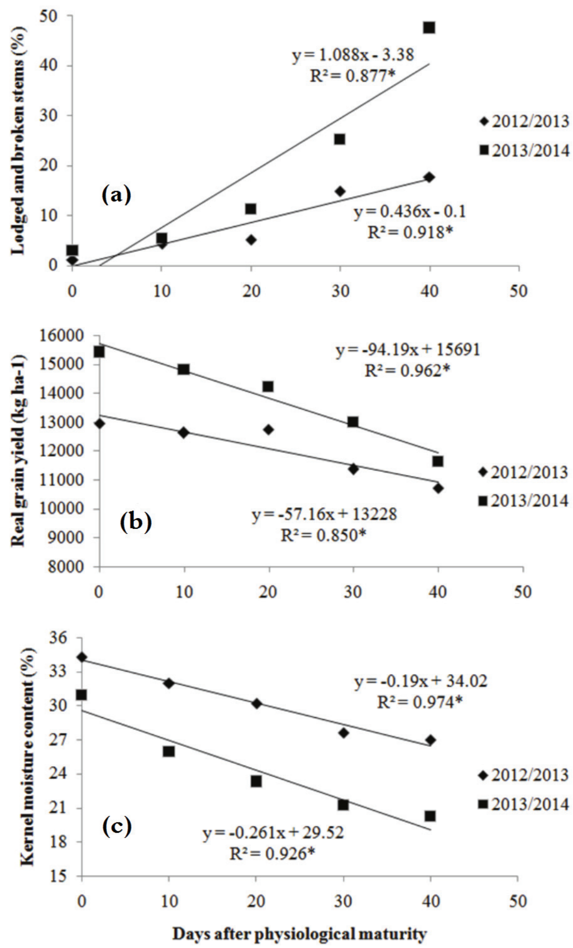

Figure 1. Percentage of lodged and broken stems (a), real grain yield (b) and kernel moisture content (c) of maize as affected by harvest time, in the average of five hybrids. Lages, South Brazil. *Determination coefficient significant at the 5% error probability level ($p < 0.05$).

In 2012/2013, there was no difference in the percentage of the lodged and broken stems among the hybrids. Conversely, in 2013/2014 the hyper- and super-early hybrids P32R22H, P1630H and P2530 had a higher percentage of lodged and broken stems than the early hybrids P30F53YH and P30R50YH. Even when the data transformation was performed prior to the variance analysis, the variation coefficients for this variable were high, ranging from 79.1 to 80.7 % (Table 1).

The delay of the maize harvest time is a risky management strategy because it favours stem lodging due to wind and rain (Gomes et al., 2010). This tendency was confirmed in the present work for both growing seasons. Maize allocates more than 50% of the plant biomass to the grains at physiological maturity (Sangoi, Silva, Argenta, & Rambo, 2010). Therefore, when the harvest is postponed, tissue senescence at the stem base and the constant presence of rainfall and temperatures below 17ºC that occur during April, May and June in the highlands of South Brazil (Table 2) increase the ear weight, favouring stem lodging and breaking. This behaviour is accentuated by the crop's early ripening because maize hybrids with shorter growth cycles remobilize greater amounts of the stem-stored carbohydrates to the kernels during grain filling (Blum, Sangoi, Amarante, Arioli, & Guimaraes, 2003). Other factors that may have favoured the increase in the lodged and broken stems when the harvest was delayed were the cropping system with maize for three consecutive years during the spring/summer season and the presence of black oat preceding maize during the Fall/Winter season. This combination of grass species stimulates the presence of fungi, such as *Fusarium graminearum* and *Stenocarpella macrospora*, which promote maize stem rot (Casa, Moreira, Bogo, & Sangoi, 2007; Casa, Reis, Kuhnen Junior, & Bolzan, 2009). Additionally, the tendency during the last 20 years to increase plant density increases maize susceptibility to lodging and breaking when the harvest is delayed (Sangoi et al., 2010).

Table 2. Monthly average temperatures and pluvial precipitation during maize growing seasons in Lages, South Brazil.

Growing season 2012/2013[1]								
Month	Dec.	Jan.	Feb.	Mar.	Apr.	Mai.	Jun.	Average
Average temperature (°C)	21.4	18.9	19.5	17.4	15.3	12.9	12.0	16.7
Precipitation (mm)	203.5	195.4	214.7	179.2	62.3	86.3	199.3	162.9
Growing season 2013/2014								
Month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	
Average temperature (°C)	15.1	17.4	20.2	21.4	21.0	18.5	16.3	18.5
Precipitation (mm)	136.9	146.1	107.7	182.9	210.9	121.3	94.2	142.9

[1]Temperature and precipitation data were collected from a meteorological experimental station located 20 km from the experimental site.

The potential maize grain yield ranged from 11,320 to 13,686 kg ha^{-1} in 2012/2013 and from 13,165 to 17,047 kg ha^{-1} in 2013/2014 (Table 3). In the first growing season, there was a significant effect of the harvest time on the potential yield. There was a 9.8% (1,285 kg ha^{-1}) decrease on the average potential yield of the five hybrids when the harvest was delayed 40 days in relation to the physiological maturity. The harvest time did not significantly affect the potential yield in the second growing season. There were no differences among the hybrids regarding the potential yield in 2012/2013. On the other hand, the potential yield was lower for hybrid P32R22H than for hybrids P2530 and P30F53YH in 2013/2014, for the average of the five harvest times.

Table 3. Potential grain yield of maize hybrids with contrasting growth cycles as affected by harvest time. Lages, South Brazil.

Days after physiological maturity	Hybrids					Averages	CV (%)
	P1630H	P32R22H	P2530	P30F53YH	P30R50YH		
	Potential grain yield (kg ha^{-1})[1]						
	Growing season 2012/2013						
0	12,903	12,665	13,541	12,391	13,686	13,037 a*	
10	12,875	12,267	13,233	12,515	13,575	12,893 a	
20	12,377	11,818	13,777	13,451	13,369	12,958 a	7.3
30	11,875	11,629	11,964	12,684	13,176	12,266 ab	
40	11,577	11,320	11,746	12,104	12,012	11,752 b	
Averages	12,321 NS	11,940	12,852	12,629	13,164		
CV (%)			12.1				
	Growing season 2013/2014						
0	16,845	13,687	16,675	15,755	15,196	15,631 NS	
10	16,041	13,483	16,108	15,661	14,815	15,221	
20	16,534	14,359	15,050	14,346	14,886	15,035	6.7
30	14,918	13,598	15,642	15,432	14,354	14,788	
40	14,771	13,165	17,047	15,228	15,162	15,074	
Averages	15,821 ab	13,658 b	16,104 a	15,284 a	14,883 ab*		

[NS]Differences among averages are not significant in the row or in the column ($p < 0.05$)[1]. Calculated values considering manual harvest of all ears in the two central rows of each split-plot. *Averages followed by the same lower case letter in the row or in the column do not differ significantly by the Tukey's test ($p < 0.05$).

The maintenance of the maize kernels in the field for long periods after physiological maturity may increase their respiratory activity, favouring grain weight loss and decreasing crop productivity when the harvest is delayed (Pinto et al., 2007). The magnitude of the losses derived from kernel respiration depends on several factors, such as air temperature and relative humidity, the maize cultivar, and the size and shape of the kernel (Guiscem, Bicudo, Nakagawa, Zanotto, Sansigolo, & Zucarelli, 2002; Cella, Silva, & Azevedo, 2014).

The losses in the potential yield detected in the present work were lower than those reported by Araujo, Araujo, Sofiatti, and Silva (2006) and Marques et al. (2009). There was no significant reduction in the mass of 1,000 grains when the harvest was delayed up to 40 days after physiological maturity (Table 4). Such behaviour is an indication that the kernel respiratory activity from physiological maturity to harvest was not high enough to degrade the endosperm storage compounds and to reduce kernel mass. An important factor that probably contributed to mitigate potential yield losses with harvest delay is the thermal regime that characterizes the region where the experimental site is located. The grain physiological maturity and harvest occurred from March to June (Table 2). The average air temperature at this time of the year in the highlands of South Brazil was low, ranging from 12 to 18ºC. The kernel respiratory activity is directly proportional to the temperature (Galvão et al., 2014). Therefore, the low temperatures recorded at the end of the maize-growing season probably reduce plant respiration, avoiding a significant decrease of kernel mass and mitigating losses in potential yield.

Table 4. Mass of 1,000 grains of maize hybrids with contrasting growth cycles as affected by harvest time. Lages, South Brazil.

Days after physiological maturity	Hybrids					Average	CV (%)
	P1630H	P32R22H	P2530	P30F53YH	P30R50YH		
	Mass of 1,000 grains (g)						
	Growing season 2012/2013						
0	304	340	382	315	338	331[NS]	
10	309	336	374	324	337	331	
20	301	337	358	313	342	327	4.5
30	321	345	369	316	335	331	
40	311	324	360	294	344	323	
Average	309 d*	336 bc	369 a	312 cd	339 b		
CV (%)			6.4				
	Growing season 2013/2014						
0	289	318	329	331	357	325[NS]	
10	287	313	342	313	348	321	
20	295	313	329	321	334	318	4.3
30	301	315	331	325	329	320	
40	303	314	356	329	355	331	
Average	295 d*	315 c	337 ab	324 bc	345 a		
CV (%)			3.8				

[NS]Differences among averages are not significant in the column ($p < 0.05$). *Averages followed by the same lower case letter in the row do not differ significantly by Tukey's test ($p < 0.05$).

The real productivity, considering a mechanical harvest and assuming that 50% of the grains produced by the lodged and broken plants would not be removed from the field, was affected by the harvest time in 2012/2013 and by the interaction between the harvest time and the hybrid type in 2013/2014 (Table 5). Considering the average of the five hybrids, the grain yield was 2,230 kg ha^{-1} lower when the crop was harvested 40 days after physiological maturity, representing a 17.2% yield loss, in comparison to the productivity registered for the first harvest time. In the second year, hybrids' grain yields reacted differently to the delay in harvest time. The hyper-early hybrids P1630H and P32R22H were more sensitive to late harvests than the early hybrids P30F53YH and P30R50YH. The average real productivity of the two hyper-early hybrids at the last harvest time was only 56% of the value registered when they were harvested at physiological maturity. However, at the last harvest date, the early hybrids showed a real yield equivalent to 90% of the productivity recorded at physiological maturity. The regression analysis adjusted to the average values of the real yield of the five hybrids showed a linear decrease of 57 and 94 kg ha^{-1} for each 10 days of delay in the harvest time after physiological maturity, during the first and second growing season, respectively (Figure 1b).

Kernel moisture content at harvest ranged from 23.5 to 35% in 2012/2013 and from 18 to 34% in 2013/2014 (Table 6). During both growing seasons, this variable was affected by the harvest time and hybrid cycle. The delay of the harvest reduced the kernel moisture content. Considering the average values of the five hybrids, the rates of decrease in the kernel moisture content for each 10 days of harvest delay were 1.9 and 2.6% in 2012/2013 and 2013/2014, respectively (Figure 1c). The lower rate of decrease in the kernel moisture content registered in the first growing season was due to the later sowing date of the trial (12/5/2012). Because maize was sowed in the beginning of December, the period between physiological maturity and harvest was concentrated in May and June, which coincided with the presence of low air temperatures, which slowed the drying of the kernel (Daltro, Albuquerque, França Neto, Guimarães, & Gazziero, 2010).

Table 5. Real grain yield of maize hybrids with contrasting growth cycles as affected by harvest time. Lages, South Brazil.

Days after physiological maturity	Hybrids					Average	CV (%)
	P1630H	P32R22H	P2530	P30F53YH	P30R50YH		
Real grain yield (kg ha^{-1})[1]							
Growing season 2012/2013							
0	12903	12665	13541	12260	13432	12960 a*	
10	12578	11948	13205	12355	13026	12622 a	
20	12709	11595	13438	13008	12974	12745 a	8.1
30	10816	10150	11376	12028	12459	11366 b	
40	10560	9464	10894	11465	11265	10730 b	
Average	11913NS	11164	12491	12223	12631		
CV (%)			13.5				
Growing season 2013/2014							
0	A16845 a*	A13484 a	A15818 a	A15715 a	A15196 a	15412	
10	A15856 a	A12796 a	A14988 a	A15623 a	A14815 a	14816	
20	A16139 a	A13007 a	A13523 a	A13872 a	A14487 a	14206	11.3
30	A14305 ab	B11419 ab	AB12807ab	A15136 a	A13054 a	12985	
40	B10505 b	B 6887 b	AB11013 b	A14019 a	A13872 a	11618	
Average	14730	11519	13630	14873	14285		
CV (%)			16.8				

[1]Calculated values considering that 50% of grains produced by lodged and broken plants would not be removed from the field if harvest was performed mechanically. [NS]Differences among averages are not significant in the row ($p < 0.05$). *Averages preceded by the same upper case letter in the row and followed by the same lower case letter in the column do not differ significantly by Tukey's test ($p < 0,05$).

Table 6. Kernel moisture content of maize hybrids with contrasting growth cycles as affected by harvest time. Lages, South Brazil.

Days after physiological maturity	Hybrids					Average	CV (%)
	P1630H	P32R22H	P2530	P30F53YH	P30R50YH		
Kernel moisture content (%)							
Growing season of 2012/2013							
0	34.0	33.0	34.6	35.0	34.3	34.3 a*	
10	27.8	25.5	32.8	35.3	34.0	32.0 b	
20	30.1	28.9	29.2	30.2	30.8	30.2 c	3.7
30	25.8	26.0	26.2	29.1	28.1	27.6 d	
40	24.6	23.5	26.4	29.1	28.4	27.0 d	
Average	28.5 cd*	27.4 d	28.8 bc	31.7 a	31.1 ab		
CV (%)			4.3				
Growing season 2013/2014							
0	34.0	30.5	30.9	34.0	29.7	30.9 a*	
10	27.5	24.8	25.6	27.5	26.3	25.9 b	
20	23.4	21.6	21.9	23.4	24.9	23.3 c	3.2
30	19.6	18.9	21.2	19.6	23.2	21.2 d	
40	18.7	18.0	19.8	18.7	22.4	20.2 e	
Average	24.6 ab*	22.7 c	24.0 bc	24.6 ab	25.3 a		
CV (%)			4.1				

[NS]Differences among averages are not significant in the column ($p < 0.05$). *Averages followed by the same lower case letter in the row or in the column are not significantly different by Tukey's test ($p < 0,05$).

Collectively, the results of this work show that when the harvest is carried out after physiological maturity, maize grain yield might be reduced. The decrease in crop productivity is caused by the direct effects derived from kernel respiration or by the indirect factors related to the increase in stem lodging and breaking. In regions with high altitude and latitude, such as the highlands of South Brazil, the direct effects of harvest delay on the kernel mass were not significant due to the low air temperatures recorded from March to June, a period that included the end of grain filling, physiological maturity and the harvest. Conversely, the indirect effects of postponing harvest were relevant, mainly for the hyper-early hybrids. These cultivars usually produce a smaller leaf area and a greater carbohydrate mobilization from the stem to the kernels during grain filling (Blum et al., 2003; Brito, Silveira, Brandão, Gomes, & Lopes, 2011). Such traits enhanced their susceptibility to stem lodging and breaking when the harvest was delayed, especially because maize was grown continuously for several years in the same area without rotation with other crops and was preceded by a plant species of the same family (black oat).

Because there is an increasing tendency of growers to use hyper- and very-early maize hybrids in Brazil, which are usually sown at high plant densities, special care must be taken to avoid a delay in harvest time to prevent stem lodging and yield losses.

Conclusion

The delay in harvest time after physiological maturity increases the percentage of lodged and broken plants, reducing real grain yield, especially for hyper- and super-early hybrids.

The delay in harvest time does not affect grain mass in regions with high altitude and latitude.

Acknowledgements

The authors thank the financial aid of Fapesc (Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina).

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Received on May 21, 2015.
Accepted on September 8, 2015.