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Pod sealant and canola harvest methods for pod shattering mitigation

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Abstract

In this study, canola harvest methods that are sometimes associated with pod sealant were evaluated to mitigate pod shattering. The following six harvest methods were evaluated at four locations in the presence or absence of a pod sealant: a) untreated direct harvesting; b) swathing; c) diquat + direct harvesting (DH); d) glufosinate + DH; e) paraquat + DH and f) paraquat + diuron + DH. The analysis of variance showed significant interactions at the four locations between the presence and absence of the pod sealant and the harvest methods ($P \leq 0.01$). When harvesting was performed at the ideal time, the windrowing and direct harvest methods resulted in higher yields. In this case, the use of pre-harvested herbicides and pod sealant were not necessary to mitigate pod shattering. However, when harvesting was performed later, pre-harvest desiccation with diquat or paraquat resulted in the best yields. Thus, the use of pod sealant was the most effective method. The windrowing method should not be used at an inappropriate time because it can result in seed shattering when plants are drying in the field.

Keywords: swathing, pre-harvest herbicides, seed shattering, rapeseed, polymers.

Introduction

Canola is grown worldwide, mainly for manufacturing biodiesel and vegetable oil, and is the second-largest oil crop produced and third-largest vegetable oil produced globally (USDA Economic Research Service, 2012). Canola is a new alternative for cold season production in countries where canola cultivation is not habitual. This type of crop rotation system provides a proper fit with subsequent summer species, such as soybean and maize (Coimbra et al., 2004; Mohammadi et al., 2011). Crop rotation with wheat (*Triticum aestivum* L.) has economic benefits and can help break weed and pest cycles (Bushong et al., 2012; Zeleke et al., 2014). In addition, the demand for edible oil and biodiesel feedstock from vegetal crops is increasing (Smith et al., 2007). However, large losses due to seed shattering from natural dehiscence make it difficult to expand production. Seed loss in canola is highly variable and depends on the seed genotype. Several differences exist regarding the addition of canola genotypes to seedbanks and the use of different harvest methods (Haile et al., 2014b). The yield and quality of canola grains are directly related to appropriate harvest times and methods. In most cases, the best results are achieved when the windrowed method is used followed by combine pickup after plant drying. This method is the primary harvesting method used for canola in Canada (Vera et al., 2007) and Australia (Hertel, 2012) because it reduces seed ripening and seed shatter due to adverse weather conditions. In countries and regions that are starting to adopt canola cultivation, direct harvesting is used because it reduces production costs. However, irregular crop maturation reduces yields in this situation. Direct harvesting is successful when the crop matures equally (Irvine and Lafond, 2010). When using this method, herbicides such as diquat, glufosinate or paraquat are used for canola pre-harvest desiccation to allow the seeds to mature uniformly (Booth and Gunstone, 2004). Farmers use pod sealants, which are associated with pre-harvest herbicides, to coat the seed heads with a thin polymer film and hold it together to reduce the likelihood of shattering. The polymer used as a pod sealant varies depending on the company, and the most widely used polymers include carboxylated synthetic latex and the cyclohexane polymer. Little information is available regarding sealants, particularly under field conditions. However, field trials evaluated the performances of two pod sealants for five canola cultivars over two seasons and observed that neither pod sealant product decreased seed loss in canola (Haile et al., 2014b). In this study, we evaluated the following six harvest methods at four locations: untreated direct harvesting, swathing, and four pre-harvest desiccations followed by direct harvesting (diquat, glufosinate, paraquat and paraquat + diuron) with and without pod sealants. The treatments were performed at the ideal time at two locations and after the ideal time at the other two locations. We hypothesized that windrowing reduces pod shattering and the use of a pod sealants is not necessary for any harvest method when harvesting is performed at the ideal time. However, when harvesting was performed later, we hypothesized that pre-harvest desiccation and the use of a pod sealant reduces pod shattering. The objective of this study was to evaluate different harvest methods in the presence or absence of pod sealants to mitigate pod shattering.

Results and Discussion

Canola harvest methods performed at the ideal time

The analysis of variance showed significant interactions at the four locations between the presence and absence of the pod sealant and the different harvest methods (at a 1% proba-

Table 1. Canola yields (kg ha^{-1}) resulting from the interactions between the pod sealant and harvesting methods at Passo Fundo and Ernestina. The treatments were sprayed when 50% of the grain in the middle third of the main stem changed from green to brown and when the seed moisture content was approximately 35%.

Harvest method	Passo Fundo				Ernestina			
	W/o Pod Sealant[1]		W/ Pod Sealant		W/o Pod Sealant		W/ Pod Sealant	
Diquat + DH[2]	1492	aC[3]	1355	aE	1694	aAB	1597	aCD
Glufosinate + DH	1915	bAB	2159	aA	1397	aC	1512	aD
Paraquat + DH	1868	aB	1603	bDE	1540	bBC	1810	aAB
Paraquat + diuron + DH	1601	aC	1683	aCD	1526	bBC	1878	aA
Windrowing	2147	aA	1874	bBC	1859	aA	1779	aABC
Direct harvesting (DH)	1928	aAB	2064	aAB	1663	aB	1637	aBCD
C.V %[4]	a=7.15		b=5.61		a=6.44		b=4.29	

1. W/o = without; W/ = With. 2. Pre-harvest desiccation with the indicated herbicide, which was followed by direct harvesting (DH). 3. The mean values in the columns are denoted by identical uppercase letters, and those in the same line are denoted by identical lowercase letters. At the same location, the mean values are not significantly different according to Tukey's pairwise comparison test with P ≤ 0.05. 4. Coefficient of variation; a = pod sealant (main plot); b = harvest method (split plot).

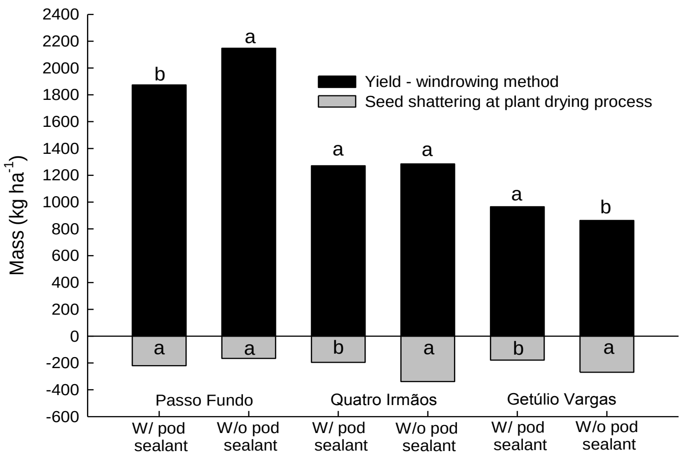

Fig 1. Canola yield (black column) in the windrowing harvest method and seed shattering during the plant-drying process (gray column) in kg ha^{-1} in the presence and absence of the pod sealant (w/ pod sealant and w/o pod sealant) at the Passo Fundo, Quatro Irmãos and Getúlio Vargas locations in 2014. For the same location and variables, the mean values of the columns, which are denoted by identical letters, are not significantly different according to Tukey's pairwise comparison test at P ≤ 0.05. At the Ernestina location, seed shattering during the plant-drying process was not determined.

Table 2. Environmental conditions of the herbicide and pod sealant applications in the four field experiments in the northern region of the state of Rio Grande do Sul, Brazil, 2014.

Location	Spraying date	Time	Temperature (°C)	R.H[1] (%)	Luminosity (x100 Lux)	Wind speedy (km h^{-1})
Passo Fundo	10/10/2014	15:15 to 16:20	29.8 to 31.0	39 to 48	315 to 350	2.0 to 2.8
Ernerstina	08/10/2014	16:00 to 17:00	29.3 to 33.2	49 to 59	300 to 660	0.0 to 0.5
Quatro Irmãos	04/10/2014	11:00 to 12:10	19.1 to 24.8	42 to 59	330 to 490	4.0 to 5.3
Getúlio Vargas	20/10/2014	16:10 to 17:10	28.7 to 29.5	31 to 40	450 to 470	2.0 to 2.5

1. Relative humidity.

Table 3. Canola yields (kg ha^{-1}) resulting from the interactions between the pod sealant and harvesting methods at the Quatro Irmãos and Getúlio Vargas locations. The treatments were sprayed when 65% of the grain in the middle third of the main stem changed from green to brown and when the seed moisture was approximately 28%.

Harvest method	Quatro Irmãos				Getúlio Vargas			
	W/o Pod Sealant[1]		W/ Pod Sealant		W/o Pod Sealant		W/ Pod Sealant	
Diquat + DH[2]	2101	aA[3]	2117	aB	1468	aA	1390	aA
Glufosinate + DH	2206	aA	1808	bC	1344	aB	1165	bC
Paraquat + DH	2061	aA	2093	aBC	1383	aAB	1285	bB
Paraquat + diuron + DH	2158	aA	2243	aAB	1328	aB	1318	aAB
Windrowing	1284	aB	1271	aD	863	bD	965	aD
Direct harvesting (DH)	1450	bB	2444	aA	1210	bC	1386	aAB
C.V %[4]	a = 7.49		b=6.21		a=5.33		b=6.20	

1. W/o = without; W/ = With..2. Pre-harvest desiccation with the indicated herbicide, followed by direct harvesting (DH). 3. The mean values in the columns are denoted by identical uppercase letters, and those in the same line are denoted by identical lowercase letters. At the same location, the mean values are not significantly different according to Tukey's pairwise comparison test at P ≤ 0.05. 4. Coefficient of variation; a = pod sealant (main plot); b = harvest method (split-plot).

Table 4. Harvest methods, active ingredients, trade names and rates that were used in the study in the northern region of the state of Rio Grande do Sul, Brazil, 2014.

Treatment	Harvest method[1]	Trade name	Rate (L ha^{-1})	Adjuvant (v/v)[2]
1	Diquat + DH[3]	Reglone®	2.0	0.1%
2	Glufosinate + DH[3]	Finale®	2.0	0.2%
3	Paraquat + DH[3]	Gramoxone®	2.0	0.1%
4	Paraquat + diuron + DH[3]	Gramocil®	2.0	0.1%
5	Windroing[4]	--	--	--
6	Direct harvest[4] (DH)	--	--	--

1. The harvest methods (split plot) were performed with and without the pod sealant (main plot). 2. Adjuvant ethoxylated alkyl ester of phosphoric acid (Lanzar®), applied as recommended on the label. 3. Pre-harvest desiccation with the indicated herbicide, followed by direct harvesting (DH). 4. Harvest process without the desiccants.

bability of experimental error). Harvesting of all treatments was performed at the ideal time at Passo Fundo and Ernestina and late at Quatro Irmãos and Getúlio Vargas. At Passo Fundo, the highest yields were shown in the windrowing, direct harvest, and glufosinate pre-harvest desiccation treatments when the pod sealant was not used, with yields of 2147, 1928 and 1915 kg ha^{-1}, respectively. However, lower yields were obtained in diquat and paraquat + diuron (Table 1). The behavior was similar when the polymer was used, and the highest yields were obtained in the glufosinate and direct harvest treatments. When comparing the harvest methods in the presence of the polymer, the productivity was greater when the canola was desiccated with glufosinate herbicide. Without the polymer, the highest yields were obtained when the paraquat and windrowing treatments were used (Table 1). At the Ernestina location, the highest yields were obtained in the windrowing and diquat treatments without pod sealant, which were 1859 and 1694 kg ha^{-1}, respectively. When using the polymer, the highest yields were obtained in the paraquat + diuron, paraquat and windrowing treatments, with yields of 1878, 1810 and 1779 kg ha^{-1}, respectively (Table 1). When comparing the cases with and without the polymer in each collection process, the presence of the polymer increased the productivity in the paraquat and paraquat + diuron treatments. These differences were not observed in the other treatments (Table 1). We hypothesize that the windrowing performance improves when the treatments are performed at the ideal time. This hypothesis was proven correct, although other methods, such as direct harvest, presented similar yields in some situations. Windrowing is the most common harvest method used in the main production regions around the world (Canola Council of Canada, 2012). However, directly harvesting canola with a combine is the most popular method used in some regions in the US and Europe (Boyle et al., 2010). A study conducted at three locations in Kansas and Oklahoma, US, indicated the optimum swathing time versus direct cutting and its effects on grain yield (Godsey and Stamm, 2010). Swathing resulted in a greater yield than direct cutting at the Stillwater location because strong winds result in seed shattering in the direct-cutting treatment. At Hutchinson, direct cutting resulted in a greater yield than swathing, likely because of the high temperatures following swathing. At the last location (Manhattan), no differences were observed between the two harvest methods. A field study of 16 directly harvested and 19 windrowed canola fields in western Canada during 2010-2012 indicated no differences in seed yield, seed loss or seedbank addition between the windrowing and direct-harvesting canola operations (Haile et al., 2014a).

Pod sealants when the treatments were performed at the ideal time

Another hypothesis is that using pod sealants is not necessary for any harvest method when harvesting is conducted at the ideal time. The use of pod sealants is particularly effective when the crops are desiccated with paraquat, which can be explained based on the efficiency of paraquat and the time of harvest after desiccation. All treatments involving desiccation were harvested 7 days after application (DAA). The paraquat and paraquat + diuron treatments had higher desiccation rates than the diquat and glufosinate treatments. The environmental conditions surrounding the application of paraquat were appropriate for absorption in canola plants (Table 2). The desiccation level in the paraquat and paraquat + diuron treatments at 3 DAA was nearly 90%, and the desiccation level in the other herbicide treatments was approximately 60% (Fig. S1). When the treatments with paraquat were harvested at 3 or 4 DAA, no differences were observed between the cases with and without pod sealant, which indicates that the sealant can effectively resolve issues due to climate when harvesting is performed later. This hypothesis was tested at the Quatro Irmãos and Getúlio Vargas locations.

Later canola harvesting methods

At Quatro Irmãos in the treatments without pod sealant, pre-harvest desiccation resulted in higher grain yields than windrowing and direct harvesting (Table 3). However, when using the polymer, the best processes involved direct harvesting and desiccation with paraquat + diuron. When comparing the cases with and without the polymer within each harvest process, we observed two inverse situations. For the treatments with desiccation and glufosinate, the grain yields were 398 kg ha^{-1} lower than when the polymer was used. However, for direct harvesting, the use of the pod sealant increased the yield by 994 kg ha^{-1} (Table 3). At Getúlio Vargas in the treatment without polymer spraying, the highest yields were obtained from the diquat and paraquat treatments. In addition, the lowest yield of 863 kg ha^{-1} was obtained when using the windrowing process (Table 3). When using the polymer, the highest yields were 1390, 1386 and 1318 kg ha^{-1} in the diquat, direct harvest and paraquat + diuron treatments, respectively. Similar to the case without the polymer, the windrowing process had the lowest yield (Table 3). When comparing the cases with and without the polymer in each harvest process, the absence of the pod sealant increased the productivity of the glufosinate and paraquat treatments. The yields of the windrowing and direct-harvest methods decreased in the absence of the polymer (Table 3).

Pod sealants when the treatments were performed later

When the treatments are performed later, we hypothesize that pre-harvest desiccation improves the performance in the presence of pod sealant. In fact, higher yields were obtained when the crop was desiccated before direct harvest, except at Getúlio Vargas, where direct harvest with pod sealant resulted in the highest productivity. Pre-harvest desiccation may also reduce the incidence of pod shattering and seed loss, which makes it an alternative method to swathing while providing some weed control. The use of herbicides before harvest is recommended in late-maturing fields, which may not mature in time under normal conditions (Canola Council of Canada, 2012). Generally, the use of pod sealants results in good yields, particularly when using direct harvesting without desiccants or windrowing. However, although information is lacking regarding pod sealants, the use of pod sealants has increased because of the high losses that occur due to seed shattering. The polymer in the pod creates a thin film that prevents the movement of moisture into and out of the pod, which reduces shattering losses (Canola Council of Canada, 2012). In Australia, a study aimed at testing the efficacy of crop-sealing products on canola showed no significant differences in yields among different treatments (Gidding, 2011). Recent field studies that evaluated the performances of two pod sealants used on five canola cultivars across two seasons indicated that neither pod sealant product reduced seed loss in canola (Haile et al., 2014b).

Pod sealant during the windrowing process

At the end of the windrowing process, the effects of the pod sealant on reducing seed shattering were measured (Fig. 1). In Passo Fundo, when the windrowing process was performed at the ideal time, the presence of the sealant showed no effect, and the losses during windrowing were 7-10%. However, the use of the sealant was important when windrowing management was performed late. At the Quatro Irmãos location, the amount thrashed during the drying process of the plants was 339 kg ha^{-1} without the polymer and 196 kg ha^{-1} with the polymer, which corresponded to 21 and 13% of the total, respectively. In Getúlio Vargas, the behavior was similar to that at the previous location, where the losses were 269 kg ha^{-1} without the polymer and decreased to 179 kg ha^{-1} with the polymer (Fig. 1). These results corroborate the hypothesis that using pod sealants can be effective for reducing seed shattering when harvest operations are performed outside of the ideal time. For barley, the total harvesting losses were 0.1-2.8% of the yield when using direct combining and 0.8–7.7% when using windrowing before combining when harvested at or before ideal ripeness (Clarke, 1989).

Materials and methods

Experimental description

The experiments were performed in 2014 at four farms in the northern region of the state of Rio Grande do Sul, Brazil (Table S1). According to the Köppen classification system, the regional climate is classified as Cfa. The soil is classified as a typical dystrophic Red Nitosol (Embrapa, 2006), and the hybrid Yola 571CL cultivar was used. The experiments were performed using an experimental randomized complete block design (RCBD), in which the treatments were arranged in a split-plot arrangement with three replications. The main plot was composed of 2 plots, one with pod sealant (Fixed® - Alamos Brasil Company) and one without pod sealant. The function of the pod sealant is to prevent the seedpods from opening during the maturation process. The subplots were arranged based on crop management processes (Table 4). The experimental units were 3 x 3 m, and only the plants in the center rows of the plots were evaluated. At Quatro Irmãos and Getúlio Vargas, the pre-harvest desiccants and pod sealant were applied when 65% of the grain in the middle third of the main stem changed from green to brown and when the seed moisture was approximately 28%. At Passo Fundo and Ernestina, the treatments were sprayed when 50% of the grain when the middle third of the main stem changed from green to brown and when the seed moisture was approximately 35%. The herbicides and pod sealant were applied using a CO_2-pressurized sprayer boom (CO_2-pressurized sprayer, Herbicat Co., Catanduva, SP, Brazil), which was equipped with four TeeJet 8001 XR flat-fan nozzles (TeeJet nozzles, TeeJet Technologies, Springfield, IL, USA) spaced at 50 cm. These nozzles were calibrated to deliver 200 L ha^{-1} at 200 kPa. The wind speed, temperature, relative humidity and light were monitored during spraying by using a portable digital thermo-hygro-anemometer (THAL model 300, Instrutherm, São Paulo, SP, Brazil) (Table 2).

Traits measured

Canola desiccation was assessed 3 and 7 days after treatment (DAT) based on a visual desiccation level of 0-100%, where 0 indicates no control and 100 indicates plant death. Canola was manually harvested from the three middle rows of each plot at 7 DAT, and the yield was corrected to a moisture content of 8.5%. In the windrowing treatment, the central rows were cut and dried in open air for seven days to simulate the actual field conditions. Seed shattering in the drying period was evaluated by collecting the seed losses at the end of the process. The collected mass in the plots was determined by using a semi-analytical digital scale (UX2200H model, Shimadzu, Kyoto, Japan) with an accuracy of 0.01 g.

Statistical analysis

The desiccation level and yield data were checked using the Shapiro-Wilk normality test. When necessary, the data were processed using the square root of x. Next, the data were subjected to an analysis of variance (ANOVA) test at each location according to the arrangement of the treatments in RCBD to examine the effects of the harvest methods and pod sealant combinations. The differences were considered significant if they achieved a 5% significance level, and the means were separated using Tukey’s test. All analyses were conducted using the ASSISTAT software (Universidade Federal de Campina Grande, Brazil, version 7.6) (Silva and Azevedo, 2002).

Conclusion

When the treatments were performed at the ideal time, the windrowing and direct-harvest methods showed good performance. Here, the use of pre-harvest herbicides and pod sealants was not necessary. However, when the treatments were performed later, pre-harvest desiccation with diquat or paraquat resulted in better performance. Thus, the use of a pod sealant was effective. Due to seed shattering during plant drying in the field, the windrowing method should be avoided when the process is performed at an inappropriate time.

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