

## **EVALUATING THE EFFECTIVENESS OF PINOLENE BASED POD SEALANT FOR REDUCING SHATTERING LOSSES IN SEVERAL CULTIVARS OF RAPE (*BRASSICA NAPUS* L.)**

L. ŠPOKAS and D. STEPONAVIČIUS

*Aleksandras Stulginskis University, LT-53361 Akademija, Kaunas Distr., Lithuania*

### **Abstract**

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The research was carried out in 2007–2009 at the Experimental Station of the Lithuanian University of Agriculture. The objective of the research – to find out the effect of climatic factors and pinolene based pod sealant on dynamics of seed moisture content and shattering losses in several cultivars of winter rape (*Brassica napus* L.). The pod sealant sprayed within two weeks prior to rape harvesting was found to have no effect on dynamics of seed moisture content within pods. With progression of pod maturation and reduction in moisture content up to 15–18% inside of them, the pod sealant did not substantially reduce shatter loss either. Meanwhile, controlled plots and plots treated with pod sealant showed no substantial difference in total shatter losses. Under weather conditions favourable for maturation of winter rape pods, after seed moisture content achieved 8–12%, pod sealant was found to substantially reduce shatter loss. In case of delayed rape harvesting, shatter loss increased substantially more rapidly in the cultivar non-treated with pod sealant when compared to the treated one. The action of pod sealant is also influenced by the properties characteristic to rape varieties. Moreover, abundant precipitation and strong winds (exceeding  $12 \text{ m s}^{-1}$ ) increase shattering losses by approximately  $15 \text{ kg ha}^{-1}$  per day. In Lithuania, harvesting of winter rape should be started at their seed moisture content below 15%. Under favourable weather conditions, rape harvesting should take no more than five days. Under production conditions, using grain combine harvesters to directly harvest matured spring rape, the effect of pod-sealant on shatter loss from harvesting was not substantial.

*Key words:* harvesting, rapeseed, shatter loss, siliquae, siliquae dehiscence, winter rape

### **Introduction**

The rapeseed (*Brassica napus* L.) is a raw material for technical and food-grade oils, bio-fuel and fuel production, and a rapeseed cake – a valuable feed with high crude protein content. In result of rape harvesting using combine harvesters, 3.7 t to 9.1 t of winter rape straw is spread or dropped in windrows in each hectare (Balodis et al., 2011). When the swaths of rape straw are picked up using balers they can be further used for production of bio-fuel.

Recently, the worldwide production of rapeseed stands at 60.3 million tons, whereas that in European Union countries – 19.1 million tons (Goldhofer and Schmidt, 2012). The area occupied by rape fields is expected to increase up to 5.7 mln. ha by 2015. In Lithuania, spring and winter rapeseed was grown on the area of 192 thousand hectares (Statistical year-

book of Lithuania, 2011). Spring rape is a predominant type (55.5%) as due to highly variable weather conditions in wintertime part of winter rape crop is inevitably lost. Moreover, siliquae (pods) dehiscence results in significant yield loss of rapeseed. Rape siliquae are derived from two carpels that form two locules separated by a thin, papery white replum. Dehiscence of siliquae due to external forces at or after maturity leads to siliquae shatter (Child et al., 2003). Research shows that force required for separation of siliquae carpels from each other varies from 1.33 N to 1.6 N (Davies and Bruce, 1997). Dehiscence is usually initiated at the proximal end of the siliquae (Hossain et al., 2012). The natural siliquae shattering is dependent on many different factors (Steve et al., 2011). Siliquae shatter can occur both prior to harvest due to adverse weather conditions and at harvest due to impact from combine harvesters (Pari et al., 2012).

Up to 5% of rapeseed yield is lost during rapeseed harvesting (Rademacher, 2012). Heavy rainfall with strong wind blows occurring prior to rapeseed harvest leads to seed losses of 2.5%, whereas delay of reaping increases yield loss further up to 9% (Špokas et al., 2004). Particularly adverse years may result in as high as 50% yield loss of rapeseed (MacLeod, 1981). During rapeseed harvesting, the siliquae is subjected to dynamic forces of reel teeth and cutting table active dividers of the combine harvester (Domeika et al., 2008). Their impact can be slightly reduced by adjusting the form of reel teeth, by covering the surface with elastic substance, by varying the speed of combine harvester and the reel rotation speed. The passive dividers located at the sides of the cutting table, tend to tear up some flattened stems with roots. Fitting the typical combine harvester with the rapeseed table containing active dividers, results in 0.66% reduced shatter loss (Pari et al., 2012). When the combine harvester has a belt conveyor behind the cutting table, the rapeseed harvest loss is reduced by 2.8% (Hobson and Bruce, 2002). Rapeseed harvest loss and grain damage are also associated with the structure of the threshing unit of a combine harvester. Grain damage depends on rapeseed flow fed into the combine harvester and technological parameters of the threshing unit (Feiffer et al., 2005). Researchers report that combine harvesters using tangential threshing units damage 0.15% of total grains, whereas those using axial threshing-separation rotor damage less of grains (Rademacher, 1998) as the rasp bars of the latter rub the pods instead of beating them. However, features characteristic to the structure of combine harvester have less influence on the pace and quality of rapeseed harvesting than weather conditions, crop condition, and biological properties of rapeseed varieties (Hossain et al., 2012). The total rapeseed shatter loss amounts for 5.1%, whereas in case of delayed harvesting it exceeds 10% (Ma et al., 2012). The natural shatter loss is further increased by heavy rain and strong wind. Finnish research shows that at the wind speed of  $8 \text{ m s}^{-1}$ , rapeseed shatter loss amounts for  $25 \text{ kg ha}^{-1}$  (Pahkala and Sankari, 2011). The influence of precipitation on the shatter loss depends on the genetic features of plants, environment and agronomic factors, and their interaction (Šidlauskas and Bernotas, 2003). For this reason, the same rapeseed variety shows different shatter losses year after year. In 1990, shatter loss of rapeseed *Cress* amounted for 7.3%, and in 1991 – 1% (Tys et al., 2003). The maximum shatter loss is observed at full maturity of rapeseed. In case of delayed rapeseed harvesting, shattering losses continue increasing every day (Zhu et al., 2012).

The herbicide *Roundup UltraMax* is used to speed up the maturity of rapeseed (Feiffer and Hesse, 2007), as each day of delayed rapeseed harvest brings additional 0.5% shatter loss. However, spraying rapeseed crops leads to loss of ap-

proximately 30% of total seeds present in pods (Feiffer and Wickenhagen, 2008). The research has been published about the influence of 2-chloroethylphosphonic acid (*ethephon*) on reduction of seed loss and rape productivity. *Ethephon* was applied to plants at the BBCH-62-64 stage (the outset of flowering) by aqueous plant spraying. *Ethephon* caused changes in the phytohormone system. According to data, the treatment of plants by *ethephon* evoked ethylene release from siliquae. Examination of the anatomical preparations revealed 10 days after application of *ethephon* the dehiscence zone slightly increased but that siliquae opening was the same as that shown in the control. Although *ethephon* had limited impact on dehiscence zone formation, it considerably decreased rapeseed loss in the full ripeness stage, especially in cv. *Landmark*: in 2008 by 37%, 2009 by 45% and in 2010 by 52% in comparison with the control (Darginavičienė et al., 2011).

To reduce rapeseed shatter loss the agricultural spray adjuvants are used as well as those physical means described, such as the „anti-shatter agents“ or pod sealants. Pod sealants are designed to reduce the risk of pod shatter as the seeds inside mature and are applied when approximately 30–40% of the pods have changed colour but are still generally pliable and not brittle (Holzapfel, 2010). The following are several preparations typically used as pod sealants: a group of pinolene products *Aventrol*, *Pe-dagral*, *Agrovital*, *Spondam*, and *Pod-Ceal* based on di-1-p-menthene (di-1p-menthene/ $\beta$ -pinene dimer + oligomers); latex polymer products *Iskay*, *Pod-Stik* and *Elastiq* their active ingredient is carboxylated styrene-butadiene copolymer; depolymerized low viscosity carboxymethyl cellulose (Bohus et al., 2011). The pod sealants of the first group as *Aventrol*, *Pod-Ceal* etc. are an organic terpene polymer, or pine resin, which regulates moisture transfer by allowing moisture to move out of the pod but not into it, thus reducing pod contraction and expansion due to wetting and drying cycles. The pod sealants of the second group as *Iskay*, *Pod-Stik* or *Elastiq* are a latex polymer that does not affect moisture transfer through the pod but provides physical reinforcement as the pods dry down and the seeds mature inside. If effective, pod sealants could lengthen the period that rape could safely be left standing, increasing harvest flexibility (Holzapfel, 2010).

*Aventrol* pod sealant based on pine resin is intended to be sprayed within two to three weeks prior to rapeseed harvest. Each hectare requires 300 l of water and 1 l of the pod sealant. In 2008, spring rapeseed *Terra* showed shatter loss of 22%, whereas those treated with *Aventrol* – only 7% (Darginavičienė et al., 2011). Shatter losses from control rapeseed and that treated with *Landmark* were only slightly different. In 2009 and 2010, the shatter losses from both varieties were by as much as twice lower when compared to

control cultivar. It was found that *Aventrol* shatter loss is influenced not only by the concentration of the sprayed solution, and time of harvesting, but also by weather conditions (Kosteckas et al., 2009). Under adverse weather conditions, the treated cultivar showed shatter loss of 37 kg ha<sup>-1</sup>, whereas non-treated – 421 kg ha<sup>-1</sup>. Under conditions favourable for rapeseed maturation, difference in yield amounted for only 31 kg ha<sup>-1</sup>. The rapeseed yield loss was also reduced by application of the spray solution *Agrovital* (Zimmer et al., 2006). The control cultivar showed shatter loss of 26%, whereas the sprayed one – 7%. The in-depth research (Holzapfel et al., 2010) found that application of pod sealants *Pod Ceal DC* and *Pod Stik* with different principles of action only slightly reduce yield loss, however data difference was not substantial. The tractor and sprayer wheels that shattered rapeseed from pods during field spraying with the preparation reduced yield gain. The results showed that pod sealants did not have a measurable effect on shattering losses (Holzapfel, 2010).

Investigating the effects of different preparations on rapeseed shattering losses and total harvest loss authors offer only generalized data. However, seed shattering from pods is associated with the course of rapeseed maturation and effects of external factors. For this reason, research must be undertaken to find out the dependence of rapeseed shatter loss on variation in seed moisture content, and to validate the time of outset of harvesting.

## Materials and Methods

**Shattering losses.** The dynamics of shatter loss of winter linear rapeseed varieties *Valesca* and *Sunday* as well as that of dwarf branchy rapeseed hybrids *PR45D01* and *PR45D03* was investigated in the period of 2007 to 2009 at the Experimental Station of the Lithuanian University of Agriculture. The soil used for the purpose of research was carbonaceous, deeper – gleyic leached soil (IDg-4), *Calc(ar)i-Epihypogleyic Luvisol (LVg-n-w-cc)*. For the purpose of finding rapeseed shatter loss, plots with 5 m and 10 m in width were used, where rapeseed was fertilized and managed in an analogous way as rapeseed in control plots.

Two weeks prior to full maturity, the rapeseed in one plot were treated (1.0 l ha<sup>-1</sup>) with pinolene based pod sealant *Aventrol* (di-1p-menthene/β-pinene dimmer + oligomers), whereas a 5×10 m plot was reserved non-treated for the purpose of control. Each of the plots under investigation was equipped with seven tin troughs of 0.055 m in width, 1 m long and 0.05 m height (Figure 1). To prevent seeds shattered out off pods from falling out of the troughs, their inner surface was covered with water resistant soft cloth. The holes were made in the bottom of the troughs to allow rainwater to escape.

Checking troughs before rapeseed harvest, the moment was captured of the first seed pod shattering. The seeds found each day at 2 p.m. in troughs were counted, weighted at the laboratory, and their moisture content was found trough desiccation method using a control measurement device *Pfeuffer He lite*. The weight of seeds was then recalculated for each trough by moisture content of 9%. The daily shatter loss was calculated. Summing up resulted in the total amount of seeds shattered in kg ha<sup>-1</sup> from the very beginning of the study.

**Seed yield losses due to harvesting.** The effectiveness of pod sealant solution was investigated in the agricultural company *Nemunas* (Radviliškis district, Lithuania) while harvesting spring rapeseed *Jūra* grown on adjacent fields previously non-treated and treated with pod sealant using combine harvester with axial threshing-separation rotor, *Case IH 9120*. Seed moisture content was measured using a portable device. Threshed seeds were weighted at the warehouse. When harvesting the rapeseed with combine harvester, for the purpose of determining losses resulting from straw separation and chaff cleaning, the bowls with area of 0.0213 m<sup>2</sup> are normally used (Špokas and Steponavičius, 2010). As the combine harvester travelled, six bowls were placed under the harvester and beside it. The seeds that have entered into bowls were then weighted, and shatter loss was calculated in kg ha<sup>-1</sup> as follows:

$$G_2 = \frac{k a_1}{0,0213}, \quad (1)$$

where:  $a_1$  – the weight of seeds found in the bowl, g;

$k$  – the coefficient for taking into consideration of the width of the cutting table.

**The Biometric Parameters.** For the purpose of finding the biometric parameters of rapeseed in control plot and plot treated with pod sealant, the rapeseed was harvested in plots of 0.25 m<sup>2</sup> in five replicates. Numbers of rape stems were



**Fig. 1. Rapeseed plot with troughs arranged for collecting the pod-shattered seeds**

counted, pods were taken off each stem, counted and weighted at the laboratory. Following their threshing, seeds and siliquae carpels were weighted. Seed moisture content and weight of 1000 seeds was determined. Each stem of rape was weighted, and number of branches was counted. The distance to the first branch was measured. Weighting of the stubble with 250 mm in length resulted in its weight and moisture content values. The average weight of stems with 15% moisture content and of seeds with 9% moisture content was calculated and the average biological yield was estimated.

**Statistical analysis.** The experiments of rapeseed shattering were carried out in 7 replicates, whereas others – in 3 replicates. One-way analysis of variance (ANOVA) was performed with MS Excel to analyse data. Significant difference ( $p < 0.05$ ) between treated and non-treated rape was determined with Fisher's LSD range test.

## Results

**Weather conditions.** In July, 2007 weather conditions were not favourable for maturation of winter rapeseed (Table 1) as the average air temperature amounted for 17.1°C, and precipitation – 148.7 mm. The shatter loss of mature pods was further increased by wind, the average speed of which amounted for 3.5 m s<sup>-1</sup>, and maximum speed – 10.2 m s<sup>-1</sup>.

Weather conditions of July 2008 were favourable for maturation of rapeseed as the average air temperature amounted for 18.1°C, and precipitation over the third decade amounted for as little as 4.6 mm, the average wind speed was only 2.6 m s<sup>-1</sup> and the average maximum – 8.7 m s<sup>-1</sup>.

The maturity of winter rapeseed variety *Sunday* was delayed in 2009, although the average air temperature stood at 18.4°C, and precipitation reached 83.3 mm, the average wind speed was 2.7 m s<sup>-1</sup> and the average maximum – 8.8 m s<sup>-1</sup>. The onset of rapeseed harvest was delayed to the beginning of August. Weather conditions of the first decade were not so very favourable for maturation of rapeseed: the average air

temperature amounted for 18.4°C, precipitation was absent, the average wind speed was only 2.03 m s<sup>-1</sup>, and the average maximum – 7.5 m s<sup>-1</sup>. In the second decade of August, the average air temperature decreased to 16.6°C, and precipitation amounted for 26.2 mm, the average wind speed increased to 3.95 m s<sup>-1</sup> and on individual days amounted for as much as 5 m s<sup>-1</sup>. The maximum wind speed was 12.1 m s<sup>-1</sup>.

**The biometric parameters of winter rape.** Morphological characteristics of rapeseed depend on genetic properties of the variety, and cultivation conditions. Partial pod shattering occurs naturally before harvesting as rape pods reach their maturity at different time. Affected by rain, wind fully matured pods open, and shatter seeds on the top of soil. The major effect on harvesting comes from crop density, height of plants, distance to the first branch and general condition of crops.

Comparison of shattering losses for 2007 involved winter rapeseed variety *Valesca* and dwarf branchy hybrid *PR45D01* (Table 2). The crop density of both varieties was different in range of data error. The dwarf branchy hybrid *PR45D01* was by as much as 0.45±0.072 m lower than winter rape *Valesca*, and their first branches were closer to the soil surface, branches intertwined. The plant had a form of irregular cylinder. The yield of dwarf branchy hybrid was by 1.27 times higher than that of *Valesca* variety. Although rape hybrid *PR45D01* were lower and their first branches were closer to the soil, their harvesting using combine harvesters is more complicated, and in case the crop is flattened and some of branches are in contact with soil, substantial yield losses are practically inevitable.

The plot of *Valesca* rape treated with pod sealant was at the edge of the field, whereas a non-treated plot was surrounded by other plots used for experimental study of sowing rate effect on yield.

In 2008, the dynamics of shattering losses for two dwarf winter rape hybrids *PR45D01* and *PR45D03* was investigated. Biometric parameters of both rape hybrids were very similar. The cultivar of rape hybrid *PR45D01* showed slightly higher crop density.

**Table 1**  
**Weather conditions of July and August of 2007–2009 (Kaunas Meteorological Station)**

Date	Precipitation, in mm	Average wind speed, in m s <sup>-1</sup>	Air temperature, in °C	Relative air humidity, in %
July				
2007	148.7	3.5	17.1	80
2008	48.0	2.6	18.1	75
2009	83.3	2.6	18.4	78
August				
2007	78.6	3.0	18.5	89
2008	99.3	3.6	17.9	78
2009	87.5	2.8	16.9	74



In 2009, the pod shattering of rapeseed variety *Sunday* was investigated. Their areas were found to be the largest ones in many farms. The yield amounted for 5.6 t ha<sup>-1</sup>, weight of 1000 seeds – 4.86 g, plants showed good over wintering, resistance to flattening, however required more time to mature. In 2009, before harvesting, crop density amounted for 29±1.80 st. m<sup>2</sup>, whereas yield – 4.12±0.62 t ha<sup>-1</sup>. Their maturity was delayed to August.

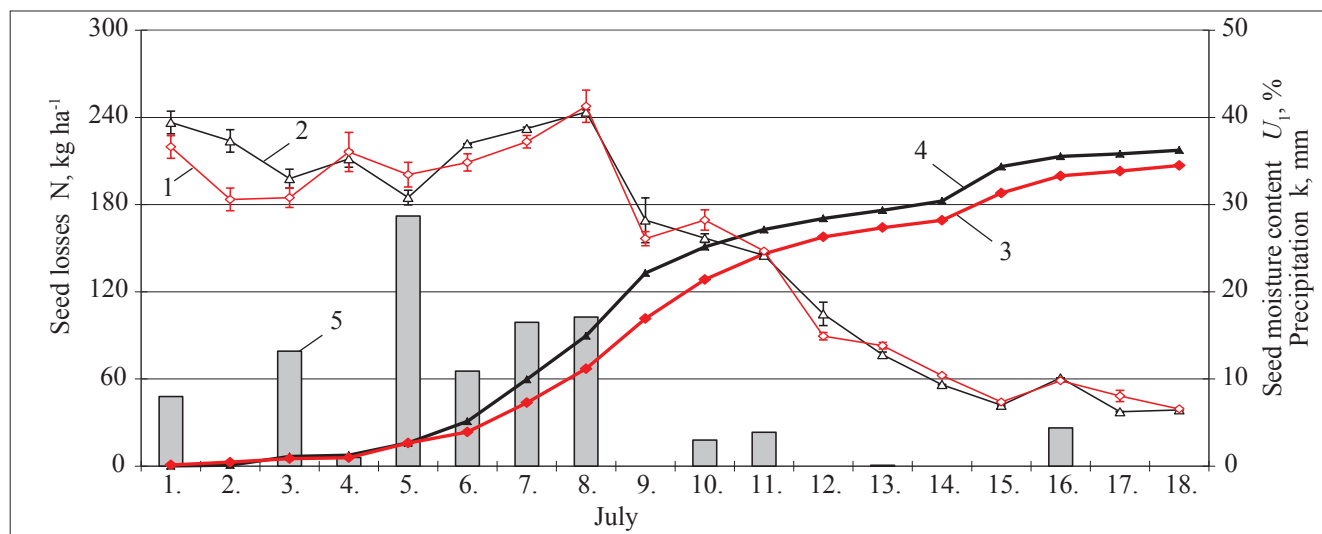
The crop density of spring rapeseed *Jūra* grown on production field of the agricultural company *Nemunas* amounted for 56±4.62 st. m<sup>2</sup>, the average height of plants – 0.91±0.02 m, and the distance to the first branch – 0.22±0.03 m.

**The effect of pod sealant on shattering losses of winter rape.** In July 2007, seed moisture content showed similar dynamics for winter rapeseed variety *Valesca* in control plot and the plot treated with pod sealant (Figure 2). The rapeseed cultivated on production field of the Experimental Station was harvested on July 13, when the seed moisture content amounted for approximately 15%. Under the influence of abundant rainfall (98.4 mm) and strong wind (3.65 m s<sup>-1</sup>) during the first decade of July, the top fully matured siliquae of rapeseed started pod shattering. During the first five days of July, pod shattering amounted for approximately 16 kg ha<sup>-1</sup> seeds in each of both, control plot

**Table 2**  
The biometric parameters of winter rape

Parameters	Units of measurement	2007		2008		2009
		<i>Valesca</i>	<i>PR45D01</i>	<i>PR45D01</i>	<i>PR45D03</i>	<i>Sunday</i>
Crop Density	st. m <sup>2</sup>	31±4.7	29±2.3	45.3±2.8	40±2.31	29±1.80
Height of plants	m	1.66±0.35	1.21±0.40	1.24±0.05	1.30±0.10	1.15±0.03
Distance from soil surface to the first branch of the plant	m	0.59±0.04	0.32±0.06	0.41±0.07	0.29±0.20	0.46±0.04
Number of branches of the plant	units	15±0.68	7±1.53	5.94±0.98	6.23±0.5	5.4±0.56
Length of siliquae	mm	76±0.57	70±0.49	61.73±0.79	64.8±0.3	66.28±1.78
Number of seeds within siliquae	units	22±0.28	23±0.19	22.4±0.68	26±0.31	27.6±1.15
Weight of seeds within siliquae (9%)*	g	0.103±0.001	0.12±0.005	0.103±0.005	0.115±0.002	0.15±0.007
Weight of 1000 seeds (9%)*	g	4.5±0.08	4.53±0.06	4.8±0.035	4.89±0.32	5.35±0.23
Biological yield (9%)*	t ha <sup>-1</sup>	2.2±0.32	3.47±0.8	5.25±0.44	5.13±3.2	4.12±0.62

\* Seed Moisture Content



**Fig. 2.** The dynamics of seed moisture content ( $U_1$ ) and total seed losses ( $N$ ) of winter rapeseed variety *Valesca* for July 2007: non-treated rapeseed: 1 – seed moisture content, in %; 3 – total seed losses, in kg ha<sup>-1</sup>; rapeseed treated with pod sealant: 2 – seed moisture content, in %; 4 – total seed losses, in kg ha<sup>-1</sup>; 5 – precipitation

and plot treated with pod sealant. Another five days passed, total shatter loss in control plot reached 128.47 kg ha<sup>-1</sup>, and in the plot treated with pod sealant – 150.94 kg ha<sup>-1</sup>. On July 8 alone, when the average maximum wind speed amounted for 17 m s<sup>-1</sup>, seed loss amounted for 23.38±8.82 kg ha<sup>-1</sup> and 29.95±13.10 kg ha<sup>-1</sup>, respectively. Under the rape seed moisture content of <15%, and maximum wind speed of 15 m s<sup>-1</sup> (on July 15), the difference in total shatter loss between the rapeseed treated and non treated with pod sealant was 18.18 kg ha<sup>-1</sup>. This difference has further decreased with the observation period ending (July 18). Over the entire period of observation, the control plot showed total shatter loss of 206.90 kg ha<sup>-1</sup>, whereas the plot treated with pod sealant – 217.48 kg ha<sup>-1</sup>. Dispersion analysis of research findings leads to conclusion that no substantial difference exists between the compared versions under the probability of 95%. The effect of pod sealant on rapeseed shatter loss was lower in comparison with the effect of wind and rain, as the treated plot was located at the edge of the field, and non-treated – surrounded by other plots.

The plots of dwarf branched winter rapeseed hybrid *PR45D01*, non-treated and treated with pod sealant, were located among other non-treated plots. They were subjected to the identical effect of meteorological conditions. Their maturation was slower when compared to rapeseed variety *Valesca*. The more intensive pod shattering of rapeseed hybrid *PR45D01* was observed on July 11, 2007 (Figure 3), whereas of rapeseed variety *Valesca* – on July 6 (Figure 2). The difference in variation of seed moisture content of both rapeseed varieties was in range of data error. Over the period of five first days of July, the non-treated rapeseed showed the total shatter loss of 8.27 kg ha<sup>-1</sup>, and treated with pod sealant – 4.37 kg ha<sup>-1</sup>, which increased to 39.68 kg ha<sup>-1</sup> and 23.01 kg ha<sup>-1</sup>, respectively, until July 11 (Figure 3). Further, the difference of losses was substantial, and was only increasing as preparation prevents seeds from being shattered. On July 12, taken alone, the control plot showed shatter loss of 73.80±20.04 kg ha<sup>-1</sup>, and plot treated with pod sealant – 31.15±10.76 kg ha<sup>-1</sup>. During the rapeseed harvesting (on July 13), the difference of averages of trials amounted for as much as 62.56 kg ha<sup>-1</sup>. With the delayed rapeseed harvest (July 18), it has increased to 98.99 kg ha<sup>-1</sup>.

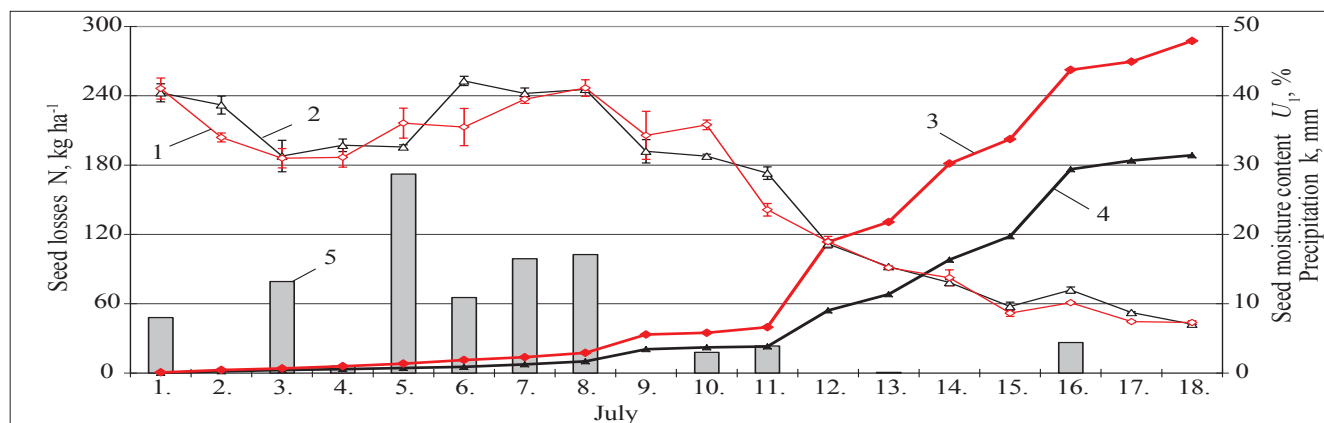
In 2008, the weather conditions for maturation of dwarf winter rapeseed hybrids *PR45D01* (Figure 4) and *PR45D03* (Figure 5) were significantly more favourable when compared to 2007. The plots with both rapeseed varieties were located side-by-side. The variation of their seed moisture content of control and treated with pod sealant rapeseed was in range of data error. The seeds of rapeseed variety *PR45D03* treated with pod sealant, in the middle of July, showed slightly higher seed

moisture content in comparison with the control (Figure 5). The effect of precipitation on seeds with higher seed moisture content was less significant.

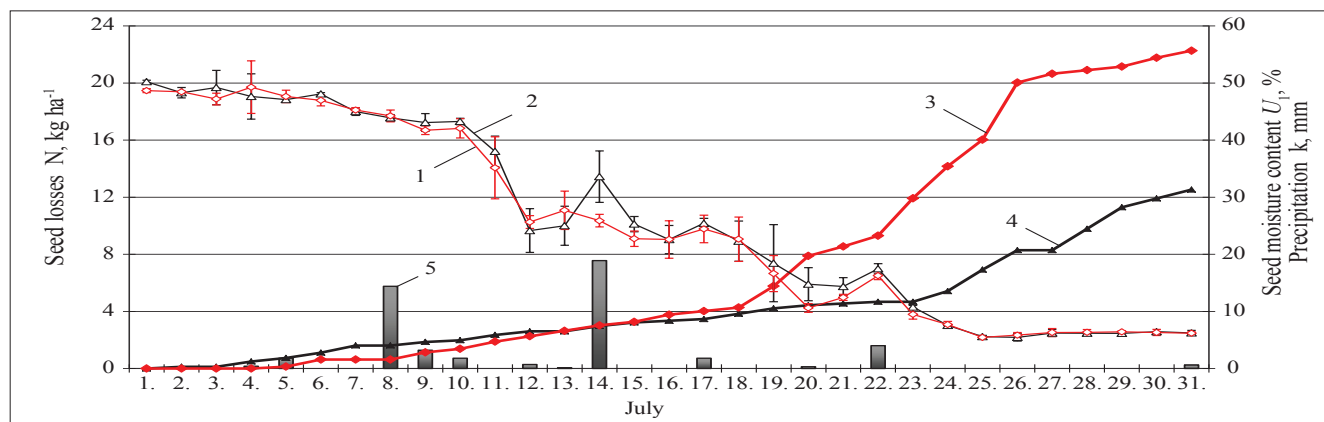
On July 1, the pod shattering started at the top of stems of both rapeseed hybrid varieties. Under favourable weather conditions, the non-treated rapeseed variety *PR45D01* and treated with pod sealant showed similar shattering losses over the first decade of July, and amounted for 1.38 kg ha<sup>-1</sup> and 1.98 kg ha<sup>-1</sup>, respectively (Figure 4). In this period, the rapeseed variety *PR45D03* treated with pod sealant showed shatter loss by 1.36 kg ha<sup>-1</sup> higher than non-treated rapeseed (Figure 5). This was due to the direction of winds in respect to the plot under consideration. In production field, the rapeseed harvesting took place on July 20, when the seed moisture content was approximately 15%. The seed moisture content of rapeseed in experimental plots was < 15% by then. In that case, the total shattering losses of control rapeseed *PR45D01* were by 3.42 kg ha<sup>-1</sup> higher than that of the treated with pod sealant (Figure 4), whereas the different in shattering losses of rapeseed *PR45D03* amounted for only 0.14 kg ha<sup>-1</sup> (Figure 5). Dispersion analysis of findings showed no substantial difference between average shattering losses of rapeseed *PR45D01* treated with pod sealant and non-treated over the period from July 1 to July 19, and analogous being true for comparison of shattering losses of rapeseed *PR45D03* over the period from July 1 to July 22. Further, the difference of previously mentioned losses was substantial. With the delay in rapeseed harvest by 11 days, the shatter loss of rapeseed *PR45D01* was by 9.70 kg ha<sup>-1</sup> higher when compared to the rapeseed treated with pod sealant (Figure 4). Treatment with pod sealant reduced the total seed losses of rapeseed variety *PR45D03* by 12.80 kg ha<sup>-1</sup>.

Comparison of shattering losses of dwarf rapeseed hybrid *PR45D01* for 2007 and 2008 showed that weather conditions had more significant effect on natural seed losses than pod sealant. However, pod sealant reduced shattering losses when seed moisture content was below 15%.

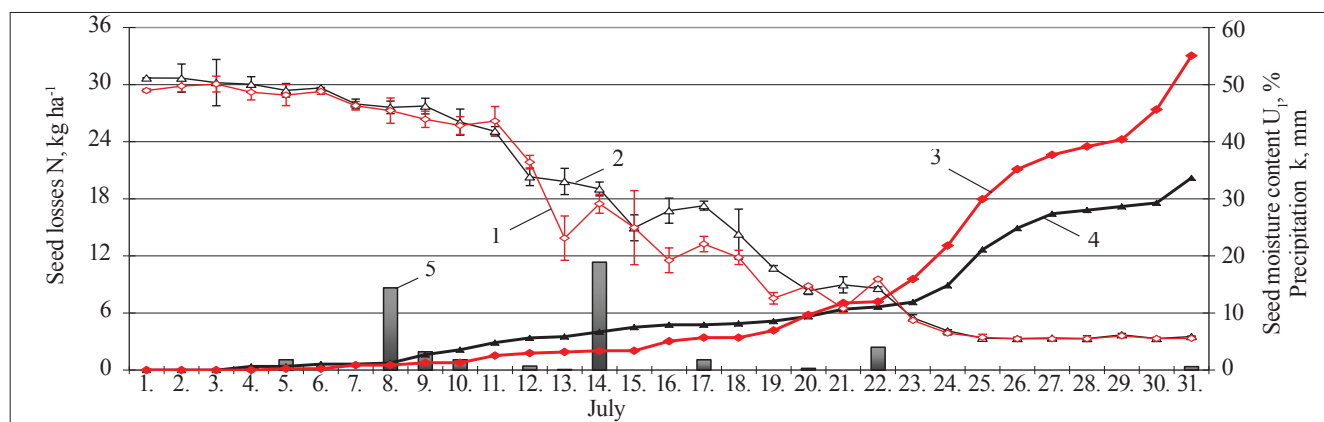
In 2009, the shattering losses of linear winter rapeseed variety *Sunday* were investigated. Rapeseed maturity was delayed. Over the period from July 22 to July 30, the seed moisture content of control rapeseed and rapeseed treated with pod sealant has decreased similarly – by 22.04% and 21.71%, respectively. The seed moisture content of the treated rapeseed was slightly higher than that of control for the entire period of observation, however, the difference was not substantial. The first pod shattering of the non-treated rapeseed and rapeseed treated with pod sealant occurred on July 22 when the seed moisture content amounted for approximately 30% (Figure 6). In production field, rapeseed was harvested on July 30 when the seed moisture content amounted for ap-



**Fig. 3.** The dynamics of seed moisture content ( $U_1$ ) and total seed losses ( $N$ ) of winter rapeseed variety *PR45D01* for July 2007: non-treated rapeseed: 1 – seed moisture content, in %; 3 – total seed losses, in  $\text{kg ha}^{-1}$ ; rapeseed treated with pod sealant: 2 – seed moisture content, in %; 4 – total seed losses, in  $\text{kg ha}^{-1}$ ; 5 – precipitation



**Fig. 4.** The dynamics of seed moisture content ( $U_1$ ) and total seed losses ( $N$ ) of winter rapeseed variety *PR45D01* for July 2008: non-treated rapeseed: 1 – seed moisture content, in %; 3 – total seed losses, in  $\text{kg ha}^{-1}$ ; rapeseed treated with pod sealant: 2 – seed moisture content, in %; 4 – total seed losses, in  $\text{kg ha}^{-1}$ ; 5 – precipitation



**Fig. 5.** The dynamics of seed moisture content ( $U_1$ ) and total seed losses ( $N$ ) of winter rapeseed variety *PR45D03* for July 2008: non-treated rapeseed: 1 – seed moisture content, in %; 3 – total seed losses, in  $\text{kg ha}^{-1}$ ; rapeseed treated with pod sealant: 2 – seed moisture content, in %; 4 – total seed losses, in  $\text{kg ha}^{-1}$ ; 5 – precipitation

proximately 8%. Then, the total shatter loss in rapeseed plot treated with pod sealant amounted for 3.15 kg ha<sup>-1</sup>, whereas that in control – 4.11 kg ha<sup>-1</sup>. Under highly favourable weather conditions and delay in harvesting for 15 days (on August 14), the total shattering losses were almost identical, i.e., increased to 11.52 kg ha<sup>-1</sup> in rapeseed plot treated with pod sealant, and to 12.10 kg ha<sup>-1</sup> in control plot. After 5 more days they, respectively, amounted for 42.64 kg ha<sup>-1</sup> and 71.49 kg ha<sup>-1</sup>. This difference is statistically reliable. Under production conditions, in case of favourable weather conditions, at full maturity of winter rapeseed, the harvesting can be delayed for up to 5 days. Then, rapeseed treatment with pod sealant is impracticable.

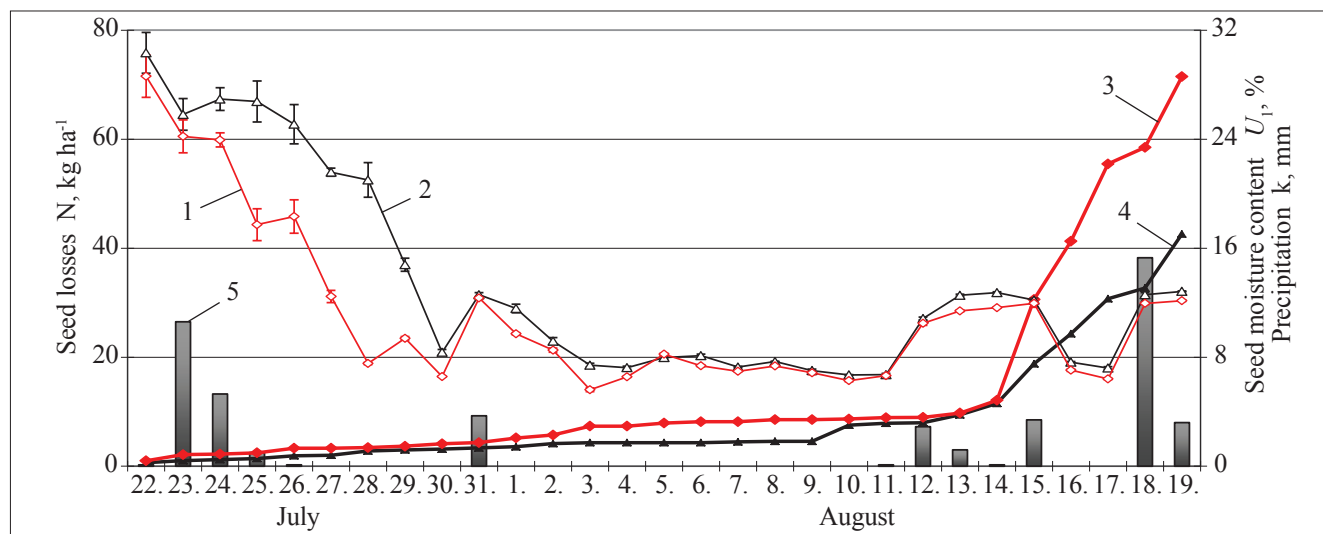
In 2008, under rapeseed production conditions the study was performed of the effect of pod sealant on yield of spring rapeseed variety *Jūra*, and on total seed losses resulting from straw separation and chaff cleaning by crop combine harvester. Before harvesting (on September 9), the weight of 1000 seeds was found to amount for 3.87±0.22 g in rapeseed cultivar treated with pod sealant, and for 4.07±0.15 g in the control (seed moisture content 11.4%), biological yield, respectively, was 4.5±0.8 t ha<sup>-1</sup> and 4.6±0.1 t ha<sup>-1</sup>. Rapeseed was harvested leaving stubble of 0.24 m in height, which amounted for 37% of total stem weight.

After the combine harvester *Case IH 9120* has threshed three full grain tanks of rapeseed *Jūra* treated with pod sealant, and afterwards the same amount of control rapeseed, seeds of each grain tank were weighted at the warehouse, and the resulting difference in yield was found to be not

substantial. When harvesting control rapeseed and rapeseed treated with pod sealant, using combine harvester *Case IH 9120*, the total seed losses resulting from straw separation and chaff cleaning were investigated, too. Rapeseed cultivar treatment with pod sealant had no substantial effect on total seed losses resulting from straw separation and chaff cleaning. The total seed losses were found to be the least under the rapeseed flow of 8 kg s<sup>-1</sup> fed into the combine harvester. In case of lower rapeseed flow, the cleaning shoe is insufficiently loaded, whereas feeding more rapeseed results in part of seeds with chaffs being blown off the upper sieve (Figure 7).

## Discussion

Comparison of shattering losses of winter rape, non-treated and treated with pinolene based pod sealant, for the period of 2007–2009, showed that first pod shattering occurred when the seed moisture content was below 50%. Pod shattering was observed only for fully matured siliquae located at the top of the stem. When the seed moisture content drops to 20%, pod shattering becomes more intensive in both control cultivar, and rapeseed cultivar treated with pod sealant. In Lithuania, the harvesting of winter rape can be started at the seed moisture content < 15%, in Germany – < 16% is recommended (Klüßendorf-Feiffer, 2009). German researchers suggest harvesting rape in the morning and in the evening, when pods are more resistant to mechanical impacts. Seeds of rape are considered fully matured when

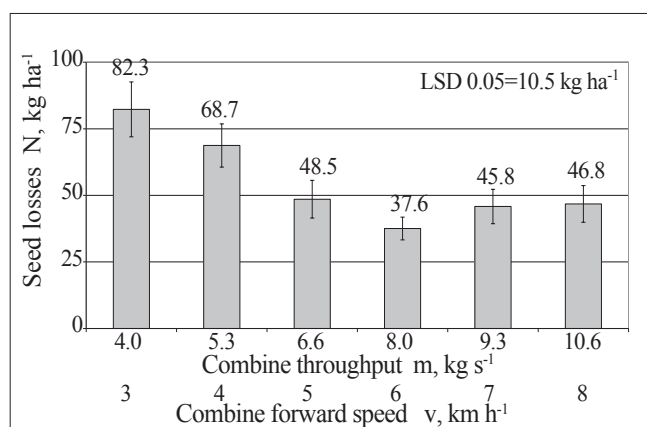


**Fig. 6.** The dynamics of seed moisture content ( $U_1$ ) and total seed losses ( $N$ ) of winter rapeseed variety *Sunday* for particular days of July and August 2009: non-treated rapeseed: 1 – seed moisture content, in %; 3 – total seed losses, in kg ha<sup>-1</sup>; rapeseed treated with pod sealant: 2 – seed moisture content, in %; 4 – total seed losses, in kg ha<sup>-1</sup>; 5 – precipitation



their seed moisture content reaches 10% (Rathke et al., 2006). In case of delayed rapeseed harvesting, more pods reach full maturity at the bottom of stems, resulting in increased yields (Ott et al., 2011), however under favourable weather conditions, the shattering losses increase, too. For this reason, gain in yield is not achieved. Authors do not seem to associate shattering losses with seed moisture content of rapeseed. In Lithuania, under adverse weather conditions, if rape harvesting is started at seed moisture content of 10%, approximately 170 kg ha<sup>-1</sup> of seeds are shatter lost by then, and under favourable conditions – about 10 kg ha<sup>-1</sup>. Polish scientists (Tys et al., 2003) report that under adverse weather conditions, harvest delay of rapeseed variety *Bolko* for 8 days results in shatter loss of 425 kg ha<sup>-1</sup>, and under favourable conditions – only 85 kg ha<sup>-1</sup>. Shattering losses for the rapeseed variety *Maral* amount, respectively, for 80 kg ha<sup>-1</sup> and 25 kg ha<sup>-1</sup>.

Wind speed has a more significant effect on shattering losses than rainfall or harvest delay. Research carried out in Finland showed that the wind speed of 8 m s<sup>-1</sup> caused shattering losses in the amount of 25 kg ha<sup>-1</sup> per day (Pahkala and Sankari, 2001). In case of rapeseed harvest delay of 10 days, the effect of wind speed on shattering losses increased by three times. Under Lithuanian weather conditions, the wind speed of 17 m s<sup>-1</sup> caused shattering losses of winter rape



**Fig. 7. The effect of rapeseed *Jūra* flow fed into the combine harvester on total seed losses resulting from straw separation and chaff cleaning:** width of the cutting table 9.1 m, threshing rotor speed 650 min<sup>-1</sup>, ventilator speed – 810 min<sup>-1</sup>, clearances between sieve scale in the upper sieve 12 mm, in the bottom sieve – 1 mm, seed moisture content 11.4%, stem moisture content – 37.6%, the average yield 3.2 t ha<sup>-1</sup>

<sup>a,b</sup>no statistically reliable difference exists between the average values in columns marked with the same letter, at a confidence reliability level of 95%

variety *Valesca* in the amount of 23.7 kg ha<sup>-1</sup> per day, and 34.07 kg ha<sup>-1</sup> the next day.

Shattering losses of rapeseed can be reduced by using different adhesive pod sealants such as *Aventrol*, *Spodnam*<sup>®</sup>*DC*, *Agrovital*, etc. Researchers of use of such preparations report different and even contradictory results. Under adverse weather conditions (in 2007), the rapeseed variety *Elvis* treated with pod sealant *Aventrol* showed total shattering losses of 5.83 kg ha<sup>-1</sup>, and non-treated – 172 kg ha<sup>-1</sup> (Kosteckas et al., 2009). Under favourable weather conditions (in 2008), the rapeseed showed total shattering losses of 3.5 kg ha<sup>-1</sup> and 41 kg ha<sup>-1</sup>, respectively. In Germany, the winter rapeseed treated with pod sealants *Orvita* and *Cantus Gold* (Schulz, 2012) showed average shattering losses of 41 kg ha<sup>-1</sup> (in 2010) and 157 kg ha<sup>-1</sup> (in 2012) 12 days after the full maturity. Significant difference between findings was because in 2012 there were more precipitation and higher wind speed. Our research showed that in 2007, under adverse weather conditions, the shatter loss of fully matured linear rapeseed variety *Valesca* treated with pinolene based pod sealant was by 22.7 kg ha<sup>-1</sup> higher than that of control, whereas that of treated dwarf branchy hybrid was by 62.56 kg ha<sup>-1</sup> lower. In 2008 and 2009, under weather conditions favourable for maturation of rapeseed, the shattering losses of fully matured rapeseed treated with pod sealant and control rapeseed amounted for approximately 2 kg ha<sup>-1</sup> and varied in range of data error. After the seed moisture content decreased to 10%, the rapeseed treated with pod sealant showed by several times lower shattering losses than control rapeseed. Rapeseed should be treated with pod sealant if dry weather is expected, and in case of expected harvest delay due to rape maturation. However, it should be taken into consideration that treatment of rape cultivar results in siliquae being crushed by wheels of a tractor or self-propelled sprayer. Travelling through cultivar results in yield losses of approximately 1–2% (Feiffer and Wickenhagen, 2008). Given expenditure on fuel, pod sealant, wages, etc., crop treatment with pinolene based pod sealant or any other adhesive solution is recommended only in exceptional cases.

Before harvest, winter rape often happens to be flattened, with intertwined branches, and for this reason reels of combine harvester, active dividers successfully thresh out the seeds from only part of the pods. Research (Kosteckas et al., 2009) shows that the total shattering losses of winter rapeseed variety *Elvis* treated with pod sealant *Aventrol* were by 5.6 times lower when compared to yield of control rapeseed. In result of delayed rapeseed harvesting, the difference of the total seed losses increased 9 times. We were unable to find a reliable effect of the pinolene based pod sealant on rapeseed shattering losses. In 2008, we have examined the

effect of pod sealant on the total seed losses due to harvesting of spring rape variety *Jūra*. The cultivar under consideration was not weed-grown, not flattened, with pods fully matured, as the average seed moisture content amounted for 11.4%. The total seed losses due to harvesting varied in a wide range. For this reason, there were no evidence that pod sealant reduced seed losses resulting from straw separation and chaff cleaning during rapeseed harvesting. In both cases, the combine harvester throughput amounted for 11.10 ± 0.51 t h<sup>-1</sup> threshed grain.

## Conclusions

Treatment of winter rapeseed with pinolene based pod sealant had no substantial effect on dynamics on seed moisture content. The effect of abundant precipitation on seed moisture content of the control rapeseed and rapeseed treated with pod sealant was very similar, differences were not substantial.

Under adverse weather conditions, after the seed moisture content of rapeseed decreases to 18%, the rapeseed treated with pod sealant shows lesser shattering losses in comparison to the non-treated rapeseed.

Under dry weather conditions, after the seed moisture content of rapeseed reaches 10–15%, the rapeseed treated with pod sealant shows lesser shattering losses in comparison to the non-treated rapeseed. The more harvest is delayed the higher effectiveness of pod sealant is achieved.

When harvesting spring rapeseed under production conditions with the seed moisture content amounting approximately for 11%, the effect of pod sealant on seed losses was not substantial.

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