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Influence of selected retardants on the quality of winter wheat grain

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Abstract. Growth regulators, or retardants, play a significant role in the crop protection system, minimizing the risk of lodging. The phenomenon of lodging contributes to qualitative losses and deterioration of grain quality. In this paper, the effect of retardant type, its rate and date of application, on selected quality features of winter wheat grain was evaluated.

The study was carried out at the IUNG Experimental Station in Osiny with winter wheat cultivar 'Roma', grown after root crops. The experiment was conducted on the soil of the good rye complex. The three-year study was conducted using the method of randomized split-plot with a control treatment, in four replications.

The formulas of retardants (Cycocel 460 SL – chlormequat and Terpal C 460 SL – chlormequat + ethephon), application date (full tillering and first and second node stage) and application rate (maximum and minimum recommended by the Institute of Plant Protection) were the test factors.

The reaction of wheat to the examined factors depended on the type, rate and timing of retardant application. Statistically significant differences in grain glassiness, gluten quality and the activity of amylolytic enzymes, were found vs. the values of the control sample. The application of retardants had no statistically significant effect on grain bulk density, ash content and total protein and gluten content.

Keywords: winter wheat, retardants, grain quality

INTRODUCTION

Wheat is the cereal of greatest economic importance, both worldwide and in Poland. The grain is used mainly for consumption and for feed purposes. The awareness of a proper diet, based on fine quality cereal products is an indispensable element of health care. In modern agriculture, wheat production technology is treated comprehensively (Podolska, Sułek, 2002). One of the components of proper cornfield care is plant protection against lodging. Growth regulators, i.e. retardants, play an important role in the crop protection system, reducing the risk of lodging (Matysiak, Adamczewski, 2009). The phenomenon of lodging contributes to qualitative and quantitative losses in grain yield. The amount of the loss largely depends on the degree of lodging and the date of its occurrence (Łęgowiak, 2002; Stanisławski, 1977). The highest reduction in yield is caused by the lodging of cereals during the earing period – the beginning of milk stage, causing a decrease in ear productivity, a decrease in the weight of 1000 grains and an increase in the number of tailings. The only method that potentially allows reduction or elimination of this phenomenon is the use of synthetic growth regulators (Adamczewski, Praczyk, 1997).

In the light of scientific research, retardation compounds protect the plant from stress in various ways. These substances mainly shorten the stem, though they can also modify other plant characteristics. Chlormequat chloride, trinexapac-ethyl, ethephon and prohexadione-calcium intensify the tillering and the number of ear-bearing culms, stimulate root growth, have a beneficial effect on the functioning of the photosynthetic apparatus, increase the diameter of the culm (Matysiak, Adamczewski, 2009). In general, the use of these substances under expected abiotic stress conditions is not advisable, but there are studies on the effects of CCC and trinexapac-ethyl under prolonged drought stress conditions confirming that retarded plants maintain a constant photosynthetic efficiency, photochemical activity and cell hydration (Feng et al., 2002; McCann, Huang, 2007).

Lodging may become a serious problem. It involves the plants falling over, bending over in the lower internodes, or breaking the stem in its central or peduncle part. Lodging at or after the final milk-ripe stage mainly contributes to the deterioration of the grain quality standards. Furthermore, lodging makes mechanical harvesting more difficult

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and thus increases the cost of harvesting. Lodged cereals are more susceptible to disease. With increased air humidity, high soil moisture and lack of access of light deep into the field, there is a high probability of the development of fungal diseases (Matysiak et al., 2012). Cereals growing on very good soils, intensively fertilized with nitrogen, are particularly at risk of being lodged. Above conditions are encouraged by mild winter summers with moderate rainfall and warm, humid weather in May and early June. Under these circumstances, the cereal fields are dense and, additionally, if they are high, even slight precipitation combined with wind may lead to lodging. With predictable yields of more than 6 t ha^{-1}, the probability of lodging happens to be very high and synthetic growth regulators application become necessary (Leszczyńska, Cacak-Pietrzak, 2004; Leszczyńska, Grabiński, 2003). If the weather conditions during the wheat growing season are unfavourable for lodging, the effectiveness of the applied retardants is less than expected.

As a rule, retardation agents in cereals inhibit stem elongation growth, making them shorter and stiffer, increase the diameter and thicken the cell wall of the stem, making the plant more stable. Under the influence of most recommended growth regulators, cereal plants develop thicker and wider leaf blades with an intense dark green colour. Depending on the way the retardant functions, either the lower internodes (e.g. with Cycocel 460 SL and others containing the active substance chlormequat chloride or CCC) or the upper ones (preparations containing ethephon e.g. Cerone 480 SL) are shortened. Preparations containing ethephon should be applied at a later stage. They have a positive effect on the orientation of the cellulose fibres that make up the cell wall, by inducing the development of wider and shorter cells (IOR-PIB, 2019). Research shows that the reduction in culm length can be up to 40%. Cecefon 465 SL contains both of the mentioned active substances. One of the most recent growth regulators is trinexapacethyl known as Moddus 250 EC. In wheat cultivation it is recommended for use with CCC (Ilumae, 2002). In order to prevent lodging, breeders attempt to help producers by offering short straw varieties (COBORU, 2018). Potentially, such cultivars have a greater stem resilience. When cultivating these types of cultivars, it is possible to increase the sowing rate and apply higher doses of nitrogen fertilizer, yet a lower yielding potential, poorer tillering and less resistance to drought has to be reckoned with than when cultivars with long straw are grown.

Retardants should be applied to winter wheat cultivars that have a higher susceptibility to lodging and in the areas with an increased pressure from eyespot and high frequency of lodging (COBORU, 2018). Growth regulators significantly reduce lodging by shortening the straw. They also cause a faster lignification of the lower internodes and reduce the susceptibility of winter wheat to culm base diseases. The dosage depends on the cultivar, the amount of precipitation during the ear-formation phase, soil fertility and nitrogen fertilization (Kościelniak, Dreczka, 2009). For cultivars with high and very high resistance to lodging, retardants should be applied mainly on very fertile soils and with nitrogen fertilization over 100 kg ha^{-1}, while for cultivars with medium or lower resistance to lodging – on very fertile and fertile soils and with nitrogen fertilization rate over 80 kg ha^{-1}.

The dose of the applied preparation depends on the degree of lodging hazard. In case of higher hazard, apply the upper dose from the recommended range (IOR-PIB, 2019). The effectiveness of applied retardant is also determined by the course of weather conditions after the treatment. If, after applying the growth regulator, the air temperature does not exceed 6–7 degrees Celsius, then its operation is poor. If the air temperature after the retardant treatment is maintained between 15–18 degrees Celsius and there is strong insolation, greater effect might be expected. Studies indicate that for effective action of preparations containing CCC the temperature of at least 10 degrees Celsius for 5–10 days after treatment is beneficial (Adamczewski, Praczyk, 1997).

Research on implementation of retardants focuses mainly on determining their crop protection role. The aim of the study was to evaluate the effect of the retardant type, its dose and date of application on selected quality features of winter wheat grain.

MATERIALS AND METHODS

The experimental material consisted of winter wheat grain of the cultivar 'Roma' obtained from a three-year field experiment conducted at the IUNG-PIB Experimental Station in Osiny (51°35', 21°55') on the soil of a very good rye complex. The study was carried out using the randomized split-plot design with a control treatment, in four replications. The studied factors were: I – type of retardant (Cycocel 460 SL – active substance chlormequat, and Terpal C 460 SL – active substance chlormequat + ethephon), II – time of application (full tillering stage, BBCH 22-23 and first node, BBCH 31 and second node stage, BBCH 32) and III – dose (maximum and minimum recommended by Institute of Plant Protection – IOR-PIB, 2019). For Cycocel the maximum dose was 3.5 l ha^{-1}, and for Terpal 2.5 l ha^{-1}. The minimum doses were respectively: 2 and 1.5 l ha^{-1}.

Root crops were grown prior to wheat. Nitrogen fertilization was applied as ammonium nitrate at 120 kg ha^{-1} as three split applications: 60 kg ha^{-1} at the beginning of vegetation, 40 kg ha^{-1} at the shooting stage and 20 kg ha^{-1} at the heading stage. Phosphorus and potassium were provided in the form of superphosphate and potassium salt in autumn, the dose depended on the supply of these elements in the soil. Also 1–2 herbicide treatments and 2–3 fungicide treatments were applied. The wheat seeding density was 4.5 million units per 1 ha. The area of experimental plots was 30 m^2. Meteorological conditions during the study period were similar. Average monthly air temperatures (from March to July) in the three vegetation seasons were higher than that achieved from long-term measurements. The sums of precipitation (in May and June) were lower, and in July (especially in the 1st and 2nd vegetation season) they exceeded the long-term average.

After the winter wheat harvest, the grain was analyzed for quality characteristics: bulk density, weight of 1000 grains, size, shape and uniformity, glassiness, ash content, total protein content by Kjeldahl method (nitrogen to protein conversion factor – 5.25), amount and quality of gluten in the Glutomatic apparatus, falling number by Hagberg-Perten method (Jakubczyk, Haber, 1983; PN-93 /A-7404/02). The results were processed statistically by Statistica 7.1 (StatSoft, Tulsa, OK, USA), using (ANOVA, and the differences were estimated for significance with Tukey's test at α=0.05.

RESULTS

The results are presented as a three-year average, since no significant interaction was found between the experimental factors and years of study. The grain samples were characterized by a high weight of 1000 grains (50.6 g on average) and by good size and uniformity (93% on average) (Table 1). Cycocel, regardless of the dose and phase of application, did not affect the weight of 1000 grains. This trait was differentiated under the influence of Terpal application, but statistically significant differences occurred only between the samples obtained from the treatment involving the minimum dose at the first node stage and the maximum dose in the second node stage. Similarly, as in the case of 1000 grain weight, statistically significant differences were found between some samples for grain size and uniformity, but in all treatments (regardless of the type, dose and time of retardant application) grain size and uniformity remained similar to those in the control treatment. The bulk density of grain averaged 80,6 kg hl^{-1} and did not depend on the applied anti-lodging protection. However, a large variation occurred in the structure of endosperm. The share of glassy grains in the control samples was 42%. The greatest decrease in grain glassiness occurred in treatments protected with Cycocel at the maximum dose at the second node stage and at the minimum dose at the first node stage. Statistically significant increase in grain glassiness, in reference to the control sample, was observed in the samples from the treatments in which Cycocel was applied at the minimum dose in the stages of full tillering and second node and at the maximum dose in the stage of first node and also after application of Terpal at the maximum dose in stages of the first and second node.

The ash content in the grain samples tested was 1.57 on average and did not depend on the method of protection against lodging (Table 2). The highest amount of total protein (15.7%) was found in grain from the control treatment, but the differences in the amount of this component between samples from individual treatments were not statistically significant. The gluten content of grain samples ranged from 27.4 to 29.4% and the gluten indexes (IG) from 9 to 27. The retardants administered had no significant effect on the amount of gluten. Under the influence of Terpal (except for the maximum dose in the full tillering stage) and Cycocel preparation used at the minimum dose

Table 1. Physical properties of wheat grain depending on retardant used.

Factors			Test weight ($kg\ hl^{-1}$)	Weight of 1000 grains (g)	Selectness and uniformity (%)	Glassiness (%)
I retardant	II stage	III dose				
	Control		81.1 a	50.7 a	93 ab	42 b
Cycocel	1	min	80.4 a	50.2 a	93 ab	48 c
	2		79.6 a	50.7 a	92 a	34 a
	3		80.1 a	51.0 a	92 a	48 c
	1	max	80.0 a	50.8 a	94 b	42 b
	2		80.2 a	51.2 a	94 b	52 c
	3		79.8 a	50.3 a	93 ab	33 a
	Control		81.1 a	50.7 ab	93 ab	42 a
Terpal	1	min	81.0 a	51.1 ab	94 b	44 a
	2		80.6 a	52.0 b	92 ab	47 a
	3		80.6 a	50.2 ab	92 ab	45 a
	1	max	80.3 a	51.0 ab	94 b	46 a
	2		80.4 a	50.1 ab	92 ab	56 b
	3		80.8 a	49.0 a	91 a	57 b

1 – tillering, 2 – 1st node, 3 – 2nd node stage
min, max – retardant dose (min – minimum, max – maximum)
Values in the same column followed by different letters are significantly different

Table 2. Chemical properties of wheat grain depending on retardant used.

Factors			Ash content (% s.m.)	Protein total (% s.m.)	Total gluten (%)	Gluten index	Falling number (s)
retardant	stage	dose					
	Control		1.59 a	15.7 a	28.4 a	19 bc	372 a
Cycocel	1	min	1.60 a	15.3 a	28.7 a	15 a	356 a
	2		1.55 a	14.8 a	28.6 a	16 ab	351 a
	3		1.56 a	14.8 a	28.3 a	17 ab	356 a
	1	max	1.57 a	15.6 a	29.3 a	21 cd	408 b
	2		1.58 a	15.0 a	28.9 a	27 e	361 a
	3		1.60 a	14.8 a	27.5 a	23 d	367 a
	Control		1.59 a	15.7 a	28.4 a	19 c	372 bc
Terpal	1	min	1.54 a	14.8 a	28.2 a	9 a	402 c
	2		1.56 a	15.0 a	29.4 a	9 a	369 bc
	3		1.56 a	15.0 a	28.4 a	12 ab	377 bc
	1	max	1.57 a	14.7 a	29.1 a	18 c	331 a
	2		1.55 a	14.7 a	27.4 a	11 ab	350 ab
	3		1.58 a	15.0 a	28.8 a	14 b	363 ab

1, 2, 3, min, max – see Table 1
Values in the same column followed by different letters are significantly different

in all stages there was a decrease in IG value in comparison with the control treatment. Statistically significant increase of the IG value was found in the treatments protected by Cycocel at the maximum dose in phases of first and second node. The values of falling number ranged from 331 to 408 s. A statistically significant increase of falling number, vs. the control sample, occurred following the application of Cycocel at the maximum dose in the full tillering stage Conversely, the application of Terpal at the maximum dose in the full tillering stage caused a decrease of the falling number.

DISCUSSION

The weight of 1000 grains expresses the degree of grain filling and depends on water, starch and protein content. It is an important indicator for seed selection (Jakubczyk, Haber, 1983). The examined grain was characterized by a high weight of 1000 grains (50.7 g on average), indicating its potentially high sowing value. The high nutrient content ensure proper germ development and thus a higher yield. Cycocel, regardless of the dose and phase of application, did not affect the weight of 1000 grains. Variability in the weight of 1000 grains appeared under the influence of Terpal, but statistically significant differences were found only between the samples obtained from the treatment protected with the minimum dose at the first jointing stage and the maximum dose at the second jointing stage (value 52.0 and 49.0 g, respectively). The results of studies on the effect of retardants on the mass of 1000 grains are divergent. Some authors (Gruzdev, 1984; Pisulewska, 1997) have stated that chlormequat may have a positive effect on this trait (increase from 2 to 6%), while others (Cox, Otis, 1989) believe that ethephon may have a similar effect. An earlier study Leszczyńska and Cacak-Pietrzak (2004) found a downward trend in the weight of 1000 grains regardless of the type of retardant used (chlormequat, chlormequat + ethephon). Studies conducted by other authors (Dziamba, 1987; Jończyk, 1998; Kuś, Jończyk, 1997) point out that single doses of chlormequat may slightly reduce the weight of 1000 grains (by about 1–2%), similarly to chlormequat used together with fungicides (Cichy, 1997; Zając et al., 1992).

The very high grain size and uniformity values (93% on average) also prove that the grain is of very fine quality. Other studies (Kandera, 1980) show that retardants may cause a decrease in size and uniformity of the grain. In this study, there were no significant differences in size and uniformity between the grain derived from the control treatment and the grain originating from protected treatments, but differences were found within individual treatments (depending on dosage and phase of application). In the author's earlier studies (Leszczyńska, Cacak-Pietrzak, 2004) retardants did not considerably affect the size and uniformity of grain.

The bulk density depends on the grain plumpness, the grain filling degree and grain structure, the thickness of the tegument, as well as the quantity and quality of impurities. Large, fully ripened grains with a well-filled compact endosperm and smooth tegument are generally characterized by a high bulk density (Jakubczyk, Haber, 1983). The grain samples tested were characterized by high bulk density. Other authors (Gruzdev, 1984; Kandera, 1980) found that retardants do not cause major changes in bulk density, which was confirmed by the results of this study. In previously conducted studies by Leszczyńska and Cacak-Pietrzak (2004), Terpal also did not affect the bulk grain density, whereas Cycocel generally caused a slight decrease. In other research on the effect of chlormequat used together with fungicides variation were noticed in bulk density of grain, but depending on the cultivar there was an increase or decrease in comparison with the control sample (Cichy, 1997).

The ash content of the grain is important from the milling technology angle, as the flour ashiness depends to a large extent on it (Jakubczyk, Haber, 1983). The ash content in grain from the control treatment was relatively low (1.59%). In grain samples from crops protected by retardants, the ash content ranged from 1.54 to 1.60%, but these differences were not statistically significant, which is confirmed by previous results of Leszczyńska and Cacak-Pietrzak (2004).

The grain glassiness is an important factor for both milling and baking technology. In this study, grain glassiness in the control treatment was 42%. As in the studies by Leszczyńska and Cacak-Pietrzak (2004), both retardants used in the experiment had a statistically significant effect on the structure of endosperm. According to the dose and phase of retardant application in treatments protected with Cycocel, the glassiness ranged from 33 to 52%, while for grain treated with Terpal, it varied from 44 to 57%. Terpal applied at the maximum dose in the phases of first and second jointing caused a statistically significant increase in grain glassiness with respect to the control sample, whereas Cycocel had a different impact on this feature depending on the dose and date of application.

The overall protein content is of great importance when assessing the baking properties of wheat. It is a varietal feature, but the content of protein substances is also influenced by soil, climate and weather conditions, as well as by crop management practices (Jakubczyk, Haber, 1983). The protein content of grain from the control treatment was 15.7%, while in the treatments protected with retardants it ranged from 14.7 to 15.6%, but these differences were not statistically significant. The results obtained by other authors indicate a decrease or irregular changes in the total protein content after the application of retardants (Cichy, 1997; Kandera, 1980; Prusakova, Gruzdev, 1983). In the study of Leszczyńska and Cacak-Pietrzak (2004), Cycocel did not affect the total protein content, whereas Terpal, regardless of dose and phase of application, caused its decrease in comparison to the control treatment. An increase in the total protein content under the influence of retardants was found by other authors (Brzozowska et al., 1997; Dziamba, 1987; Gruzdev, 1984; Ma et al., 1994; Pisulewska, 1997; Zając et al., 1992).

The particular importance in developing the baking properties of wheat flour is attributed to gluten proteins, which act as structure-forming function in bread (Jakubczyk, Haber, 1983). In this study, the gluten content in the grain samples ranged from 27.4 to 29.4% and did not depend on the retardants tested in the experiment. The decrease in the amount of gluten under the influence of retardants is confirmed by the results of the following studies (Kandera, 1980; Leszczyńska, Grabiński, 2003; Leszczyńska, Cacak-Pietrzak, 2004). In the present research paper, as in the previous studies (Leszczyńska, Cacak-Pietrzak, 2004), the application of retardants led to modifications in gluten quality. Terpal generally deteriorated the quality of gluten (decrease in IG value), except for the maximum dose in the full tillering phase. The decrease in gluten quality occurred also after the application of Cycocel at the minimum dose in the full tillering phase, while the maximum dose of Cycocel, regardless of the time of application, had a favourable effect on the quality of gluten proteins.

The activity of amylolytic enzymes has a great influence on the baking value of wheat. All grain samples tested were characterized by low amylolytic activity (the falling number from 331 to 408 s). In the case of Cycocel, the application of the formulation at the maximum dose during the full tillering phase caused a statistically significant increase, whereas Terpal brought about a significant decrease in the falling number vs. the values in the control sample. Leszczyńska and Cacak-Pietrzak (2004) also found the amylotytic activity of the grain (increase in the falling number) to be reduced by Cycocel, whereas Terpal generally increased it slightly. In another study by Leszczyńska and Grabiński (2003), the increase in amylolytic activity was observed regardless of the type of retardant used (chlormequat, chlormequat + ethephon).

CONCLUSIONS

1. The quality of wheat grain depended on the type, time of application and retardant rate. Statistically significant differences in the grain glassiness, gluten quality and amylolytic enzymes activity occurred in relations to the control sample.
2. The application of Cycocel in first node stage and Terpal in first and second node stage, in maximum doses, caused an increase in the grain glassiness.
3. The highest gluten index values were found after application of the maximum dose of Cycocel in the first node stage and Terpal in the tillering stage.
4. Cycocel applied to wheat in the tillering stage and at the maximum dose increased the falling number.
5. The application of retardants had no statistically significant effect on the bulk density of grain, ash content, total protein content and the amount of gluten.

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