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Triticale yield formation and quality influenced by different N fertilisation regimes

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Abstract. Two different field trials with triticale were carried out in a field of the Department of Field Crop Husbandry of the Estonian Agricultural University, situated near Tartu, in 2000/2001–2002/2003. In the first trial, the winter triticale cultivars 'Modus' and 'Tewo' were used to investigate the influence of different N fertilisation regimes on triticale yield formation and yield quality. Seven N fertiliser treatments in four replications in the first year and 11 fertiliser treatments in three replications in the second and third year were tested, by varying total nitrogen dosages and time of application. Nitrogen was applied as NH_4NO_3 at different plant development stages (EC30, EC47). In the second trial, 10 winter triticale cultivars were investigated ('Modus', 'Tewo', 'Lasko', 'Dagro', 'Ulrika', 'Lamberto', 'Vision', 'Fidelio', 'Lupus', and 'Prego') to select out cultivars of earlier maturing and higher tolerance to pre-harvest sprouting. Winter triticale parents – the winter rye 'Vambo' and the winter wheat 'Kosack' were used as the control.

The yield level and quality of winter triticale grains were most of all affected by weather conditions and then by cultivars and N application regimes. Nitrogen fertiliser application at the plant development stage EC47 decreased significantly the height of stems (r = -0.459***), which is the principal prerequisite for preventing lodging, and increased significantly grain protein content (1.69 and 1.8% as the average of three years in 'Modus' and 'Tewo' grains, respectively). Unlike spikes of wheat, all of these winter triticale cultivars started to germinate before general physiological maturity. The longer was the period from anthesis to general physiological maturity, the higher was the percentage of germination during the period (r = 0.727*). The higher was the moisture content in seeds of triticale 26 days after the EC65 (length of the period wheat reached physiological maturity), the higher was the germination percentage in spikes (r = 0.733*). Triticale cultivars with higher 1,000 kernel weight values reached physiological maturity later. An average germination before harvest time correlated positively with test weight (r = 0.608*).

Key words: triticale, N application regime, protein content, physiological maturity, pre-harvest sprouting

INTRODUCTION

For modern, environmentally safe crop production, high levels of N fertiliser utilisation have gained increased importance, in addition to maintenance of a high level of kernel yield (Sticksel et al., 1999). Winter triticale has been a very high-yield crop in Estonian conditions (Alaru et al., 2001), however, similarly to cool and wet regions of

Western Europe (Haesaert & De Baets, 1996a), one of the most limiting factors in Estonia for further development of triticale is the sensitivity of triticale to sprouting in humid conditions. Yield losses due to lodging and pre-harvest sprouting caused by application of high nitrogen fertiliser amounts as an early single dressing are quite usual. Growth regulators are normally used to prevent lodging of winter triticale cultivars which have tall and week stems (Haesaert & De Baets, 1996b). Another way to avoid lodging is by moderate fertilising or N fertiliser application at different stages of plant development. Since triticale is a relatively new cereal and its production area is still small, very little research has been conducted on the yield formation of triticale, affected by split application of nitrogen fertilisers. Experiments with the winter triticale cultivar 'Crado' revealed that nitrogen application at the end of the rapid rate of spikelet initiation and at anthesis increased both the length of the shoot and the length of the shoot apex, which, however, did not result in a relationship between the effects of nitrogen application and spikelet number (Ewert & Honermeier, 1999).

Susceptibility of mature kernels to pre-harvest sprouting is seen in triticales (comes probably from rye) caused by their high α-amylase activity (Sodkiewicz et al., 1996), whereas lodging increases the possibility much more. Therefore it is very important, in a changeable climate like in Estonia, to cultivate cultivars with earlier maturing to minimise the risk for the critical seed-filling period. In ripening grains of some cultivars, *α-Amy1* genes produce high levels of the enzyme even in the absence of rain (Mares & Gale, 1990).

Nitrogen fertiliser application at different plant stages has an essential effect on the height of stems and grain yield quality. The first aim of this study was to investigate the influence of different N fertilisation regimes on the yield formation and yield quality of the triticale cv. 'Modus' and 'Tewo' in Estonian climatic conditions. The second aim was to select out winter triticale cultivars of earlier maturing and higher tolerance to pre-harvest sprouting.

MATERIALS AND METHODS

Field trial, experimental details

Two different field trials were carried out in a field of the Department of Field Crop Husbandry of the Estonian Agricultural University, situated near Tartu (58° 23´N, 26°44´E), in 2000/2001–2002/2003. Nitrogen fertiliser influence on the grain yield and yield quality of winter triticale was investigated. Seven fertiliser treatments in four replications in the first year and 11 fertiliser treatments in three replications in the second and third year were tested, by varying total nitrogen dosages and time of application (Table 1). In the first trial, Nitrogen was applied as NH_4NO_3 at different plant development stages (EC30, EC47; according to Tottman, 1987). The winter triticale cultivars 'Modus' and 'Tewo' were sown, in the first decade of September, by machine to a depth of 3–5 cm, with 15 cm between the rows and a density of 400 seeds per m^{-2} on a *Stagnic Luvisol* (WRB classification) soil (sandy loam, humus 2.1, pH_{KCL} 6.0). In the second trial, 10 winter triticale cultivars ('Modus', 'Tewo', 'Lasko', 'Dagro', 'Ulrika', 'Lamberto', 'Vision', 'Fidelio', 'Lupus', and 'Prego') were used to investigate the rate of dry matter accumulation during the seed filling period and their susceptibility to pre-harvest sprouting.

Table 1. N application at different plant stages.

2001			2002–2003		
Treatment	N total kg ha^{-1}	N application times	Treatment	N total kg ha^{-1}	N application times
		EC30 + EC47			EC 30 + EC 47
1	0	0 + 0	1	0	0 + 0
2	60	60 + 0	2	60	0 + 60
3	90	90 + 0	3	60	30 + 30
4	90	60 + 30	4	60	60 + 0
5	90	30 + 60	5	90	0 + 90
6	120	120 + 0	6	90	30 + 60
7	120	90 + 30	7	90	60 + 30
			8	90	90 + 0
			9	120	0 + 120
			10	120	60 + 60
			11	120	120 + 0

The parents of winter triticale – the winter rye ‘Vambo’ and winter wheat ‘Kosack’ – were used as the control. 60 kg N ha^{-1} was applied as NH_4NO_3 at the tillering stage of plants.

The experimental plots of both trials were 10 m^2, of which 9 m^2 were harvested by combine to assess grain yield. The experiments were performed in a randomised block design with 4 and 3 replications in 2000/2001 and 2001/2002–2002/2003, respectively. Samples of 5 spikes on 9 sampling dates in the seed-filling period (17.07.03, 21.07.03, 24.07.03, 28.07.03, 31.07.03, 04.08.03, 07.08.03, 10.08.03 and 22.08.03) were collected from each cultivar to determine their tolerance to sprouting. At the same time, seed dry matter content was measured from sampling of 10 spikes (5 kernels from external flowers of middle spikelets of each spike) at different maturity stages (EC72-75, EC75-76, EC77-78, EC80-83, EC85-86, EC88, EC89, EC90 and EC92, respectively).

The spike germination test was performed by using random samples of 5 spikes from each cultivar, which were placed between two humid filter papers. A paper strip in contact with a waterbed continuously moistened the filter papers around the spikes (Haesaert & De Baets, 1996). The germination temperature was 20°C. After 6 days the germination was assessed (the total seed number and number of germinated seeds per spike were counted).

Yield structure elements

Plants from an area of 0.15 m^2 were taken from each plot before harvest. The shoot length and spike length of these plants were measured, as well as the number of ear-bearing tillers plant^{-1} and the number and weight of kernels plant^{-1} were determined. Lodging was determined on 3 August in 2001, grain harvest on 7 August 2001, 29 July 2002, and 22 August 2003. The total grain yield of the plots was determined and converted to 86% dry matter content.

Yield quality measurements

Kernels from each plot harvested in 2001 at the EC 92 were analysed for physical characteristics (kernel diameter, area, volume, 1,000 kernel weight), and protein content (Tecator Kjeltec apparatus, N x 6.25) at the Department of Dairy and Food Science of The Royal Veterinary and Agricultural University.

Kernels of each plot harvested in 2002 and 2003 were analysed to determine 1,000 kernel weight, test weight and protein content (Tecator Kjeltec apparatus, N x 6.25) at the Estonian Agricultural University.

Correlation, regression and variance analyses (ANOVA) were used in data processing.

Climatic conditions

Meteorological data were taken from a meteorological station situated in Eerika near the experimental field (Fig. 1). All winter triticale cultivars tolerated our wintercold. As the grain yield formation and yield quality of winter triticale were most affected by the post-hibernation period, the temperature and precipitation data of the period of 2001–2003 has been presented in this paper. Temperatures during the entire seed-filling period in 2001 were higher by 3.5°C than the average of many years; in 2002 temperatures during the entire post-hibernation growth period were much higher than the average of many years. In 2003 temperatures from the beginning of May up to the second decade of July (plant development stages EC30–EC70) were lower than the average of many years, and therefore plants matured very slowly. There was much more precipitation in 2003 than on average. The total amount of precipitation was higher by 109 mm in the post-wintering vegetation period of triticale in 2003 than the average of many years. The rainy conditions in July 2001 caused crop lodging in all trials with N fertilisation and extensive harvest losses.

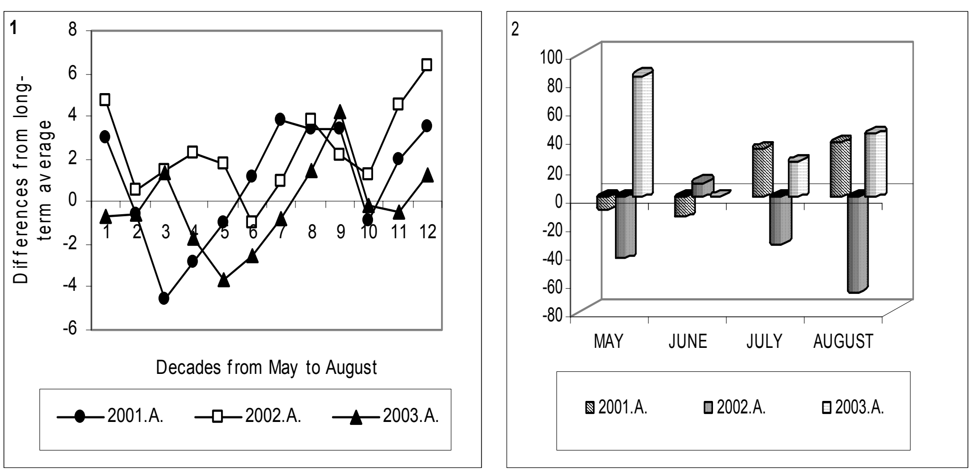

Fig. 1. Differences of temperature (1) and precipitation (2) data in 2001–2003 from the average of many years. Effective temperature > 5°C.

RESULTS AND DISCUSSION

Influence of different N amounts and application regimes on yield formation and quality

Winter triticale yield formation and quality was most affected by the year (2001–2003) and the cultivar ('Modus' and 'Tewo') and then by the N application regime and N amount (Table 2).

Table 2. Influence of different factors on triticale (cv. 'Modus' and 'Tewo') yield formation and quality in the years 2001–2003.

	Year	Cultivar	N_{total}	N_{regime}
Height of shoot	*	***	-	***
Height of spike	-	-	-	**
Ear-bearing tillers plant^{-1}	***	**	-	*
Yield	***	-	-	*
Test weight	***	-	-	-
TKW	***	**	-	-
Protein content	**	*	-	-

TKW – thousand kernel weight;
*, **, *** - significant at P > 0.5, 0.01, 0.001, respectively.

Weather conditions during the three years were very different, therefore, the influence of the year on the data of grain yield and yield quality in data processing (correlation analysis) was very strong. The highest level of grain yield was in 2002 (dry and warm from anthesis up to harvest) and the lowest in 2003 (cold spring and humid summer). In 2001–2003, the grain yield levels in the control variant (without nitrogen) for the cultivar 'Modus' were 3963, 5821, 3438 kg ha^{-1} and for the cultivar 'Tewo' 3746, 5253 and 3638 kg ha^{-1}, respectively. Higher grain yields were accompanied by a decreased content of grain protein. According to Simmonds (1995), there is a strong negative relation between grain yield and protein content. Our trial showed the same (r = -0.730***; n = 51). The protein content values in the control variant of 2001–2003 were 11.6, 8.4 and 13.2 % for the cultivar 'Modus' and 13.4, 9.3 and 14.9 % for the cultivar 'Tewo', respectively.

Test weight and 1,000 kernel weight were in strong positive correlation with grain yield (r = 0.864*** and 0.824***, respectively; n = 51).

The influence of different cultivars on grain yield level as the average of three years was insignificant, but the influence on grain yield quality was significant (Table 2). The cultivar 'Modus' has better tillering capability, a significantly higher number of ear-bearing tillers plant^{-1} and grain yield. The cv. 'Tewo' has on average a 1.3 % higher protein content and a much higher protein yield.

Separated application of nitrogen fertiliser had two aims – to prevent lodging by decreasing the height of shoots and increase grain protein content. The triticale cultivars 'Modus' and 'Tewo' are long-stemmed and high-yielding cultivars. It is possible to affect the height of their stems by separated application of nitrogen fertiliser. Winter triticale had shorter stems and better lodging tolerance when N doses in spring at the EC 30 were below 60 kg ha^{-1} (r = 0.459 ***; n = 51).

Higher doses of N and its application in spring at the EC30 stage of triticale increased the number of ear-bearing tillers plant^{-1} and grain yield (r = 0.267* and 0.328*, respectively; n = 51). Nitrogen fertiliser application at the EC30 increased the number of ear-bearing tillers plant^{-1} by up to 32% and the grain yield by up to 17% as the average of three years. Supplements of N in early spring support shooting and plant density and therefore lodging of plants. N fertiliser application at later stages of triticale plants increased significantly test weight, protein content; and it is very important for enhancing triticale feed nutritional value. Nitrogen at the EC47 increased grain protein content as the average of the years 2001–2003 for the cv. 'Modus' by 1.69 and for cv. 'Tewo' by 1.8%, respectively. N application in two parts increased grain protein content more, when doses were higher at the EC 47. N fertiliser application at the plant development stage EC47 had significantly negative correlation with the height of shoots and spikes (r = -0.459***, -0.359**, respectively; n = 51). Yoshihira and coworkers (2002) concluded that unlike roots of wheat, those of triticale and rye continue to grow after the flowering stage, and the degeneration of roots of triticale and rye is delayed compared to that of wheat roots. This is thought to be the reason for the higher N absorption values of triticale at the flag leaf stage.

Triticale is known as a crop having rather a high grain yield level at low N input (Varughese et al., 1996). Our experiments with separated N application to winter triticale revealed that doses higher than 90 kg N ha $^{-1}$ did not increase kernel yield further. The influence of N amount, expressed as the average of three years, on grain yield, test weight, 1000 kernel weight and protein content was insignificant.

The effect of nitrogen fertiliser was considerable when years were analysed separately. The influence of N amount and application time on several grain yield structure elements and yield quality in single years was different. For example in 2003, the protein content was significantly higher, influenced by N fertiliser (determination indices for N amount and application time were 4.2 and 95% for the cultivar 'Modus', and 12.9 and 86% for the cultivar 'Tewo', respectively). In 2002 (dry year) the influence of nitrogen fertiliser was insignificant for the cultivar 'Modus', and significant for the cultivar 'Tewo' (the determination index of N amount was 38.0 % and that of N application time 56.4%, respectively).

Results of the trial with the cultivars

The aim of the second trial – the trial for comparison of the cultivars – was to pick out cultivars with faster rates of development and cultivars more tolerant to pre-harvest sprouting. The rate of plant development stages of all crops mostly depends on climatic conditions, particularly on temperature data. It is in accordance with Santieri and coworkers (2002) who found that the duration of triticale grain filling period was mainly controlled by environmental conditions and not correlated with grain yield. Temperatures during all seed-filling periods of winter crops in 2001 were higher than the average of many years, whereas, in 2002, temperatures during the whole post-hibernation growth period were much higher than the average of many years. Because of that plants developed much faster in 2002 and the harvest time came 10 days earlier than in 2001. In 2003 temperatures were lower than the average of many years and, therefore, plants matured very slowly and harvest time arrived 15 days later than in 2001 and 23 days later than in 2002 (Fig. 2_1).

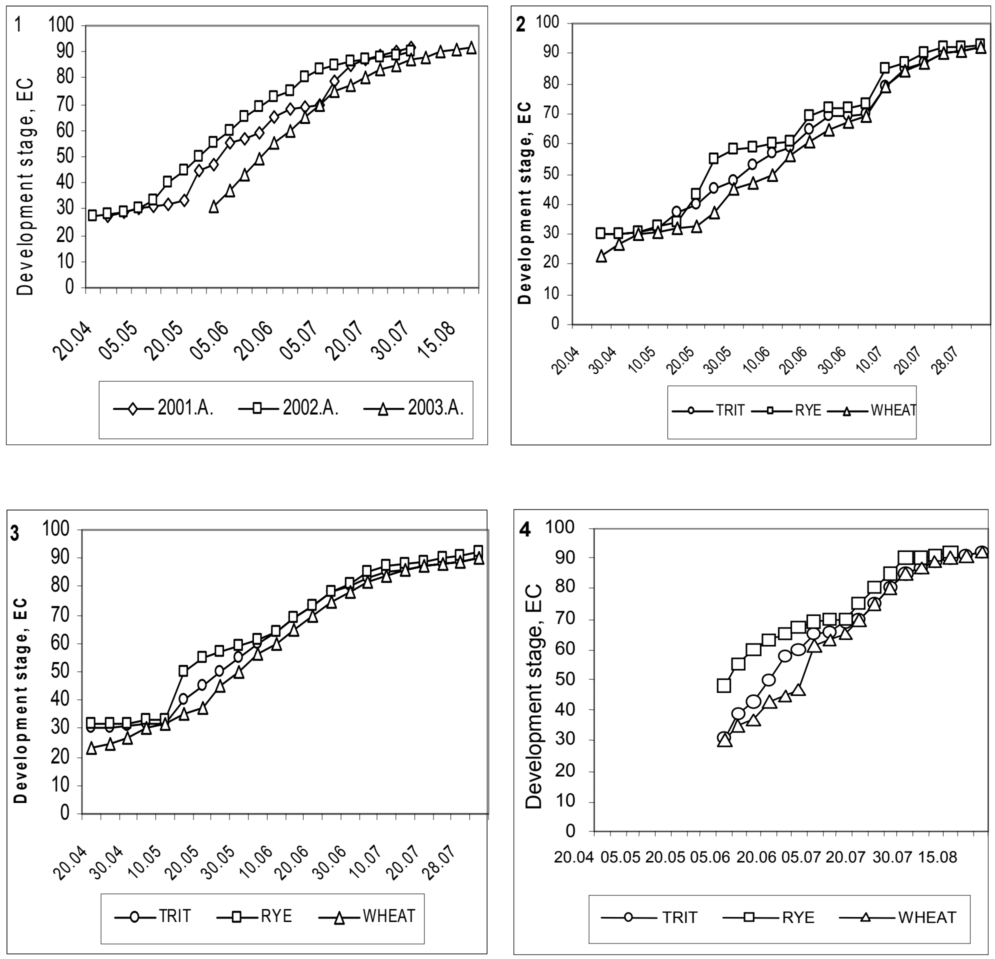

Fig. 2. Development rates of winter triticale (as the average of cultivars) in 2001–2003 (1) and development rates of different winter crops in 2001–2003 (2–4), respectively.

The plant development rate correlated strongly with the accumulation rate of the sum of effective temperatures (r = 0.993***; n = 6). An effective temperature is a temperature above 5°C, whereas this is the useful temperature for plants (Põiklik, 1986). The biomass of plants at the development stage EC65 did not have any effect on harvest time.

There were no significant differences between the development rates of triticale cultivars in 2001 and 2002. As the spring of 2003 was cold and the start of regrowth period of winter crops delayed, differences between the development rates of triticale cultivars and between triticale and its parents – rye and wheat – were considerable (Fig. $2_{2\text{-}4}$). When comparing the length of the period from anthesis to the general physiological maturity of winter triticale cultivars with the same periods for wheat and rye it can be noticed that it was 6–12 days longer than that of wheat and 7–13 days shorter than that of rye. Physiological maturity, defined as a maximum kernel dry weight, determines the readiness of the crop for harvest. This stage of crop development is reached prior to the crop being ready for combining as the kernel is relatively soft (easily dented with a finger nail) and kernel moisture percentage is relatively high (Deckard, www.smallgrains.org). Some seeds in different triticale cultivars spikes started to germinate between filterpapers 7–13 days before general physiological maturity (Table 3 & 4). It was probably caused by the inconsistent maturity of seeds in the spike. The longer was the period from the EC65 up to general physiological maturity, the higher was the percentage of germination during the period (r = 0.727*; n = 10). The higher was the moisture content in the seeds of triticale 26 days after EC65 (this is the length of the period wheat reached physiological maturity), the higher was the germination in triticale spikes (r = 0.733*; n =10). The water relations play a fundamental role in the comprehension of seed biology, particularly in development and germination processes. The desiccation, however, is not a prerequisite for the beginning of germination before the end of performing since the embryo may become capable of performing its role in germination before the end of seed development (Villela, 1998). On the other hand, in recalcitrant species, seeds may pass from the development to the germinative stage without any quiescence period (Kermode, 1995).

Table 3. Physiological maturity of several winter triticale, rye and wheat cultivars in 2003.

Cultivar	Number of days from EC65 up to general PM*	Number of days from EC65 up to first germination	Moisture content of kernel at first germination, %
VAMBO	46	42	27
KOSACK	27	27	48
MODUS	33	26	50
TEWO	33	26	55
DAGRO	33	26	52
PREGO	33	26	55
FIDELIO	36	26	58
VISION	36	26	56
LUPUS	36	26	57
LASKO	39	26	63
LAMBERTO	39	26	56
ULRIKA	39	27	60

*PM – physiological maturity

Triticale cultivars with higher 1,000 kernel weight values reached physiological maturity later. The average germination before harvest time correlated positively with test weight (r = 0.608*; n = 10).

We can classify these 10 winter triticale cultivars by their maturity rates in 2003 into three groups: 1) cultivars with the highest maturity rates – 'Modus', 'Tewo', 'Dagro', 'Prego'; 2) cultivars with middle maturity rates – 'Fidelio', 'Vision', 'Lupus'; 3) cultivars with the lowest maturity rates – 'Lasko', Lamberto', 'Ulrika'. It is essential to continue the investigation of development rates of different triticale cultivars in several years to select cultivars suitable for Estonian conditions.

Table 4. Thousand kernel weight, moisture content and germination before general physiological maturity of some seeds in different triticale, wheat and rye cultivars in 2003.

Cultivar	1000KW at PM, g	Moisture content at PM, %	Average germination before general PM, %
VAMBO	33.2	20	7.4
KOSACK	43.1	43	0
MODUS	48.4	33	10.0
TEWO	43.2	32	20.8
DAGRO	45.2	43	12.8
PREGO	39.8	40	7.4
FIDELIO	47.7	47	23.6
VISION	46.0	38	17.2
LUPUS	52.4	45	18.1
LASKO	46.5	46	19.2
LAMBERTO	45.6	44	34.5
ULRIKA	47.6	43	31.7

CONCLUSIONS

1. The grain yield level and quality of winter triticale were most of all affected by weather conditions, then by cultivars and N application regimes.
2. Nitrogen fertiliser application at the plant development stage EC47 significantly decreased the height of stems, which is the principal prerequisite for preventing lodging, and considerably increased grain protein content.
3. Unlike spikes of wheat, those of all the winter triticale cultivars started to germinate before their general physiological maturity. The longer was the period from anthesis to general physiological maturity, the higher was the percentage of germination during the period. The higher was the moisture content in seeds of triticale 26 days after the EC65, the higher was germination in spikes. Triticale cultivars with higher 1,000 kernel weight values reached physiological maturity later. The average germination before harvest time correlated positively with test weight.

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