BIOLOGY OF INDIVIDUAL DEVELOPMENT IN TRITICALE (X *Triticosecale* Wittmack) IN COMPARISON WITH WHEAT AND RYE*

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The process of the growth and development of a set of winter triticale varieties (X *Triticosecale* Witt.), winter rye (*Secale cereale* L.) and winter wheat (*Triticum aestivum* L.) was studied by means of observing the BBCH stages and phases of organogenesis of the shoot apex using the Kuperman scale supplemented by the double ridge phase. The rye showed the most intensive growth and development under autumn conditions as well as after the onset of the spring vegetative growth. The rate of growth and development in triticale was closer to rye than to wheat, which was significantly slower in both. The Lasko triticale variety was different by a very fast development up to winter as well as in early spring. This made it exposed to a great risk of damage by frost. The length of vernalization of a set of older varieties from the year 1990 and of new triticale varieties registered in 2007 was determined by the conventional method. It has been confirmed that varieties with short vernalization have a fast development up to the beginning of winter as well as from the onset of the spring vegetative growth, provided that they are not sensitive to autumn and early spring short days that can inhibit their development. In 1990 the varieties with medium and short vernalization prevailed, while in 2007 the proportion of varieties with short vernalization increased and one third of the varieties had a long vernalization.

triticale (X *Triticosecale* Witt.); vernalization; rate of development; wheat; rye

INTRODUCTION

Triticale – a new cereal species, continues to be in the centre of interest from different directions of research as indicated by the numbers of publications recorded in databases. Our attention has been focused on the peculiarities of the biology of individual development compared with the parent components – wheat and rye.

The fundamental process of life – growth, can be measured exactly by means of growth analysis, which had been developed by the British school of physiology (J. D. Watson). Thus, the external growth changes are evaluated by the growth stages. They are most frequently evaluated according to the scale originally prepared by Feekes (1941), later transformed into the decimal code and now denoted as BBCH (Biologische Bundesanstalt, Bundessortenamt and Chemical Industry), Meier (1997). Developmental changes begin to manifest themselves during a certain period of the growth by the formation of generative organs; in cereals it is the base of the spike, which is the shoot apex of the main stem. The process of its differentiation can be observed in the specific, morphologically defined, phases of organogenesis – stages according to which the process of development can be judged.

In the past, the Kupermanová scale, which was described by Petr et al. (1988), was used predominantly. However, the so-called "double ridge" phase is now used most frequently for the determination of the transition into the generative period (Kazdáj 2003). This transition occurs under certain temperature and light conditions. In the winter forms of cereals the period of low temperatures action is usually called vernalization. This period of low temperatures is necessary in order to set off the transition into generative period. Intensity of vernalization is a requirement for a specific range of low temperatures. Varieties with a narrow range of vernalization temperatures are sensitive to vernalization (e.g. –1 to +3 °C). Varieties with a broad range of vernalization are less sensitive (e.g. +3 to +10 °C). Great need for vernalization at low range temperatures retards the development. These factors have an important relationship to a number of properties, e.g. length of the vegetation period, earliness and lateness of the variety, to the length of the period of formation of different yield-forming elements, and hence also to the level of the yield (Petr, 1975; Košner, Pánková, 1997a). The less the need for vernalization is covered, the more the vegetative period and the period of shooting are prolonged.

In the past the relationship between the length of vernalization and frost hardiness (Hänsel, 1959; Schmalz, 1956) or tendency to overwintering (Schmütz, 1976) were also considered as significant. It seems that these relationships are not manifested in the new varieties as distinctly they are in the older sets of varieties. The peculiarities of the development in wheat and rye are relatively well known (Košner, Pánková, 1997b). The authors described some of these qualities earlier (Petr, Hnilička, 2002). In this study they had investigated the peculiarities of individual development in triticale – the cross-breed of wheat and rye in which, apart

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from the dynamics of the development during the vegetative period, they also studied also the length of vernalization in most of the varieties registered in the Czech Republic. This was the aim of this work.

MATERIAL AND METHODS

Observation of the stages of growth and phases of organogenesis of the shoot apex during the entire growth period was the basic method used for the study of the growth and development of the plants. The international phenological decimal scale for cereals denoted as BBCH was used to record the growth. To study the development, the original scale of organogenesis of the shoot apex after Kupermanová was used. It was supplemented by a phase which determined more precisely the transition into the generative „double ridge". In order to make the study of plant development more accurate, the length of apex and/or the height of setting above the tillering nodule were also measured.

Desciption of phases in organogenesis of the shoot apex of cereals:

I. The apex is a simply undifferentiated, hemispherical structure 0.3–0.5 mm. This phase is found during germination, emergence and tillering.

II. The shoot apex starts to elongate. It is still simple in shape but is now 0.5–0.8 mm.

III. The apex is distinctly prolonged (0.7–1.5 mm) and the starts to form ridges.

IV. The formation of spikelet primordium is typical of this phase. It was supplemented by a phase which determined more precisely the transition into the generative period – „double ridge". Later the apex becomes flattened, and the shape of the future ear can be recognized. Beginning of shooting.

V. Characteristic of this phase is the formation of floret primordia and their further differentiation.

VI. Further differentiation of stamens and pistils occurs and the formation of those structures, which will cover the spikelets and florets, continues.

VII. The formation of sexual organs, anthers and pistils ceases.

In order to make the study of plant development more accurate, the length of apex and/or the height of setting above the tillering nodule were also measured.

The plants of winter wheat, winter rye and winter triticale originated from a stand established on the same date, i.e. on 3 October 2004, after the same red clover forecrop. A set of ten varieties was investigated in wheat: Šárka, Apache, Sulamit, Mladka, Meritto, Karolinum, Cubus, Versailles, Bill and Ilias. The varieties Dankowskie Nowe and Picasso were studied in winter rye, while in triticale the varieties were as follows: Disco, Kolor, Marko, Modus, Presto, Sekundo, Lupus, Tricolor and Ticino.

Twenty plants taken from the stand in monthly intervals were classified by their size and every fifth plant was selected for analysis. The growth stage and also the phase of organogenesis on the main stem were determined after dissecting out the shoot apex. Average values were then recorded in Table 1.

The method of vernalization

The length of vernalization in a set of triticale varieties was studied up to 62 days of action of low temperatures. Samples of 80–100 grains, i.e. approximately 3.5–5 g were dipped in distilled water the day before being placed in a refrigerator, and they were left at room temperature to germinate. Plates with grains were then placed in a refrigerator with the temperature of +3 to +4 °C. Every day or every other day the moisture of grains in the plates was recorded, together with the temperature in the refrigerator. The grains were moistened in distilled water as needed. The changes of temperature in the refrigerator were recorded by the Therm Datalggen measuring device. The intervals between successive placements (of the plates with grains) in the refrigerator ranged from seven to 62 days. After this time elapsed all vernalized varieties were sown on the same day together with the non-vernalized control. The control had the grains germinated for 48 hours at room temperature. The germinated plants were planted on 16th May 2007, 20 identically germinated grains were sown into vegetation pots into the depth of 1.5–2.0 cm and then covered with sifted earth. Germination was checked and several pots were additionally sown with extra 2–3 plants. Up to the harvest time the number of plants ranged from 18 to 20 plants per pot. Plants were watered regularly and identically throughout the experiment. After the shooting stage we monitored earing (the number of plants with swollen sheath, cracked sheath), which included the onset of earing and the number of fully earing plants respectively. This was the main criterion of the index of generative development (IGD) and was expressed in percentage against the number of plants per pot. The calculation of this index of generative development was carried out using the following formula:

$$IGD = \frac{\text{percentage of earing plants}}{\text{the number of days from emergence to earing}}$$

Its advantage consists of having the time of earing (rate and uniformity of earing) included within one period of vernalization. Reaching the value of 1 meant that more than 50% of plants had eared in each variety. With late earing a higher percentage of earing plants reached the value of 1. A longer period of earing within a variety indicates a lower efficiency of the given period of vernalization. Using the IGD values, we determined the length of vernalization relatively objectively.

RESULTS AND DISCUSSION

Observation of the process of growth and individual development in several varieties of triticale, rye and wheat showed that the fastest growth occurs in winter rye and

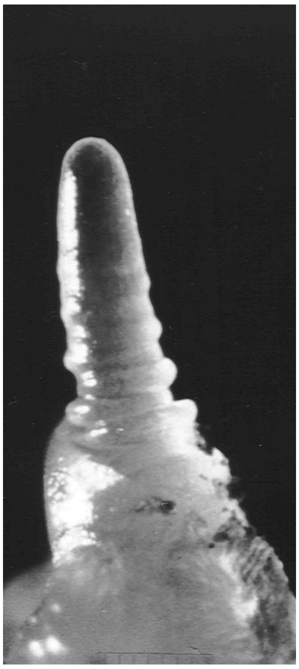

Photo 1. Shoot apex of wheat at the phase of double ridge. Microphoto J. Petr

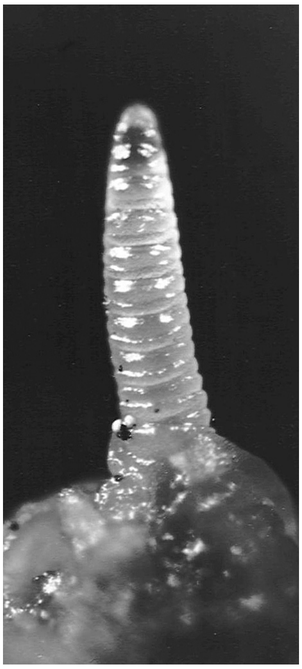

Photo 2. Shoot apex of triticale at the phase of double ridge. The size 0.6 mm. Microphoto J. Petr

then in triticale. In the triticale varieties that were studied, the process of growth was rather similar to that of rye, whereas wheat was growing slowly. Microphenological investigation of the shoot apex also revealed faster development in winter rye, whereas triticale was somewhere between rye and winter wheat.

Winter rye was the most advanced in the autumn period. Differentiation of the shoot apex usually progressed to the 3rd phase of organogenesis. However, in winter rye we never found the phase of development in the shoot apex that would signal, in as early as autumn, the transition to generative period, i.e. creation of the "double ridge" phase (Photos 1 and 2) when initials of the spikelet ridges are establishing, i.e. the onset of the former IVth phase at which the spikelet ridges are visible.

In autumn the differences between rye and triticale do not appear significant, although one year we found in the Lasko variety a great number of ridges, and even a double ridge phase. This again proves that this variety does not have a need for a long vernalization and is not inhibited by shorter autumn days. We will see later that the variety required a very short period of vernalization of only 20 days. Short vernalization was recorded in the following new varieties: Ticino, Lupus, Marko, Triamant and Presto. A fast development before the start of winter may be risky and can be associated with a lower resistance to winter conditions, as we discovered during the unfavourable winters of recent years (particularly in the winter of 2002/2003). On the other hand, it is usually advantageous under the conditions of mild winters when the high productivity of this variety, particularly the spike productivity, is manifested. This has been confirmed in many countries of Western Europe with mild maritime winters where the Lasko variety produced outstanding yields (e.g. in England), and this factor eventually opened the way to a wide distribution of triticale in Western Europe.

Regeneration of the spring vegetative growth occurs earlier in winter rye, which also has the fastest initial development and growth. It is followed by triticale. These findings are supported by the survey of the stages of growth and phases of organogenesis, and of the length of the growing apex (Table 1, Figs 1 and 2). By the end of

Table 1. Phenological and microphenological investigation of a set of varieties of winter triticale, rye and wheat

Species		15. 11.	10. 12.	20. 2.	25. 3.	25. 4.	12. 5.	28. 5.	13. 6.
Triticale	Stage	13–22	14–23	23–24	25	32	39	59	65
mean of cultivars	Phase	II.	II.–III.	III.	III.–IV.	IV.	V.–VI.	–	–
Rye	Stage	12–22	14–23	23–25	27	33	45	69	71
mean of cultivars	Phase	II.	II.–III.	III.	III.–IV.	IV.–V.b	VI.–VII.	–	–
Wheat	Stage	13–16	14–21	22–23	23	29	39	51	59
mean of cultivars	Phase	II.	II.	II.–III.	III.	IV.	VI.–VII.	–	–

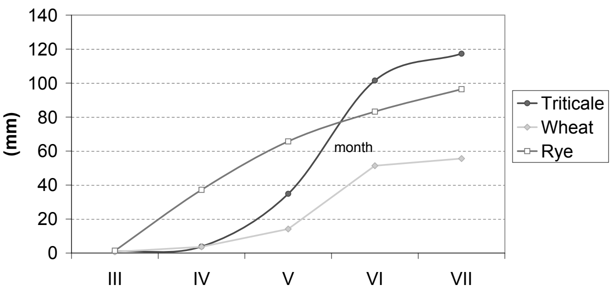

Fig. 1. Lenght of shoot apex 1st year

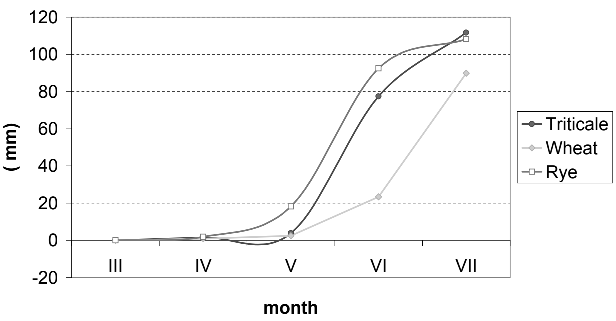

Fig. 2. Lenght of shoot apex 2nd year

April there was a difference in the length of apex in winter rye compared to triticale and wheat of about four times the length of wheat apex. However, later, from mid May, the prolongation growth of the spike in triticale continues faster. Due to a much longer vegetation period than that of rye, the growth of triticale continues and the final length of its spike may therefore exceed the length of the spike of rye or wheat.

The phase of development of plants under early regeneration of the spring vegetative growth has an advantage in the formation of a potentially higher yield but it also has certain risks of possible damage caused by frost if arctic air returns in early spring. A favourable consequence of the early regeneration is the support of the production of extra tillers, and the prolongation of the period of differentiation of the spike basis in the IIIrd and IVth phases of organogenesis when longer spikes are being established with a greater number of spikelet bases and eventually also florets. This has an effect on potential productivity, but the actual yield depends on the conditions during the subsequent vegetative growth.

The risk of damage due to spring frosts comes at an advanced stage of the plant development when the shoot apex has gone through the critical "double ridge" phase and passed into the generative period, thus losing the actual frost hardiness (P e t r et al., 1991). In such cases the plants tend to get damaged at temperatures of only a few degrees below the freezing point. The most developmentally advanced stems freeze. The tillers that had not gone through the above-described critical limit will survive. We see such cases more frequently in winter barley and some West-European wheat cultivars and lately also in West-European triticale cultivars (P e t r et al., 1983).

Modern breeding achieves the required frost resistance by a suitable combination of parent pairs, without any clear links to the adaptation responses such as vernalization and the length of day. The developmental and growth processes are associated significantly with the level of physiologically active substances, e.g. gibberellins and growth inhibitors. Gibberellins are phytohormones which support apical dominance, and hence they can affect the prolongation of the growing apex. Low temperatures activate the gibberellins synthesis enzyme (P r o c h á z k a , Š e b á n e k et al., 1997). It is presumed that varieties with a low need of vernalization have a higher level of gibberellins, so they may have a faster development into the onset of winter and the spring vegetative growth can commence earlier. It is also known that high levels of gibberellins may reduce the resistance to winter conditions.

Vernalization in triticale

As outlined above, we had studied the rate of growth and individual development and we recorded the species and variety differences. The length of vernalization or its intensity can participate in this. Likewise, the short autumn or early spring day can affect the varieties with a greater photoperiod sensitivity. The control of development in some varieties is based on their strong need of vernalization and lower photoperiod sensitivity or, by contrast, on the stronger inhibition caused by a short day. However, the present, alternative forms of triticale do not have such strong links to vernalization and the length of day Under the conditions of mild winters they overwinter owing to the inhibition of development by a short autumn day (M a h f o o z i et al., 2000).

After the introduction of triticale varieties we studied the vernalization in varieties of that time by a classic method (Š t o l c o v á , 1991). The experiment was based on evaluation of the time of earing and the number of eared plants. In the Lasko, Malno, UH 116 and UH 127 varieties a great number of plants were earing even in the non-vernalized control with continuous illumination at the tem-

Table 2. Survey of the length of vernalization

Cultivar	Length of vernalization set of cultivars 1990	Cultivar	Length of vernalization set of cultivars 2007
Salvo	40–50 days	Lupus	17days
Bolero	40 days	Marko	17 days
Largo	40 days	Gutek	30 days
Grado	30–40 days	Inpetto	49 days
Korm	30–40 days	SW Talentro	49 days
BR 2	30–40 days	Kitaro	40 days
Dagro	30 days	Ticino	not responding to vernalization
Ugo	30 days	Triamant	26 days
Presto	20–30 days	Presto	26 days
Lasko	20 days	Sekundo	30 days
Malno	20 days	Kolor	44 days
UH 127	10–20 days	Modus	30 days
UH 116	10–20 days	Disco	44 days
Wheat	40–50 days*	Wheat	50*
Rye	45 days*	Rye	45 days*

* Cultivars of this period

perature of 15°C. This confirms an overall weak response of these varieties to vernalization and it is probably also a certain response to the photoperiod conditions, because initiation of the transition into the generative period is associated with this response (K r e k u l e , 1983). Results of this experiment are outlined in Table 2.

In 2006 we studied four varieties of triticale – Presto, in which the length of vernalization lasted 20 days, in Kitaro it was 30 days, and in Triamant 20 days. In Ticino the plants did not respond to vernalization. In 2007 we tested 13 varieties. In the Presto cultivar vernalization has been confirmed at 20–30 days, and a similarly short vernalization was recorded in the Lupus and Marko varieties (17 days) in which non-vernalized plants also eared, though rarely. The Kitaro cultivar in this experiment responded to longer vernalization. The manifestation of the Triamant variety was very weak. The Ticino variety had an extraordinary response, because vernalization did not manifest, as the control, non-vernalized, plants eared (Photos 3 and 4).

This explained the behaviour of this variety in the critical years of 2002/2003, when according to the results of the State varietal experiments it overwintered the worst. It is probably an overwintering spring variety or an alternative character of this variety, but it is not a type of the Czech alternative varieties that responded to vernalization only on a short day (P e t r , 1960**)**.

We can also check the total differences in the length of vernalization in the old, original triticale varieties. From Figs 3 and 4 it is clear that in the year 1990 the varieties with medium and shorter vernalization were predominant.

In this way the share of varieties with a short vernalization was not only preserved but it increased from 54% in 1990 to 63% in 2007. A significant change occurred in the representation of varieties with a vernalization of 30–40 days, which is also considered as a relatively short vernalization. In 1990 this group included 38% and in 2007 only 8% varieties. By contrast, during that year the share of varieties with a need of longer vernalization increased from 8% to 30%. These are relatively significant differences that may be manifested in the changes of physiological properties, e.g. in the process of the yield formation. If we compare these results in triticale with winter wheat (the trials in the years 2004 and 2005, not yet published), a greater share of the varieties with longer vernalization was evident in triticale. For example, there were 42% of varieties with 45–50 days of vernalization, 37% with vernalization lasting 50–55 days, and 8% of varieties, with the length of vernalization over 60 days. There were only 13% with the length of vernalization shorter than 45 days. Concerning winter rye – in the varieties of the population – the length of vernalization is relatively stable and ranges between 45 and 55 days.

Photo 3. Non-vernalized varieties (control): K 7 Ticino – all plants eared, K 10 Sukundo, K 1 Lupus, K 2 Marko, plants are earing rarely, K 13 Disko plants are not earing. Photo J. Petr

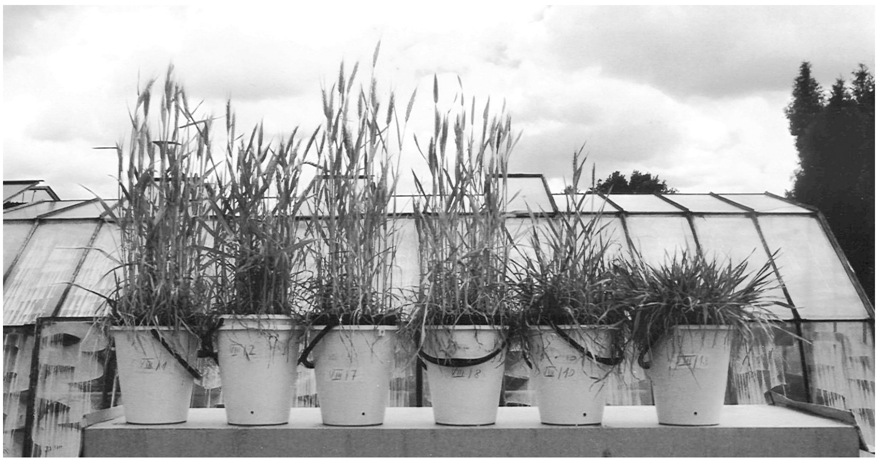

Photo 4. Treatment VIII – plants vernalizing only 17 days – all plants of the varieties No. 1 Lupus, No. 2 Marko, No. 7 Ticino, No. 8 Triamant were earing. In the variety Sekundo (No. 10) plants were earing only rarely. No plant was earing in the variety Disco. Photo J. Petr

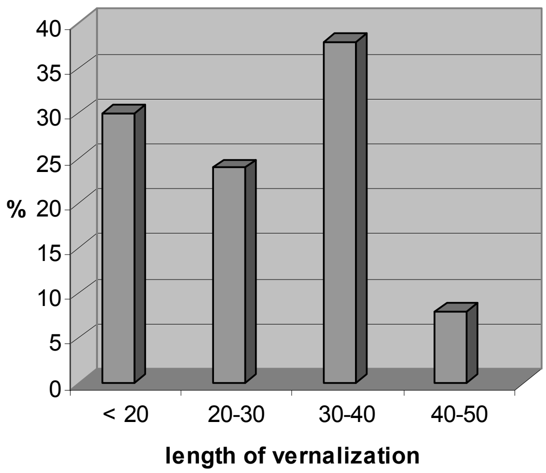

Fig. 3. The share of varieties with different vernalization from 1990 (%)

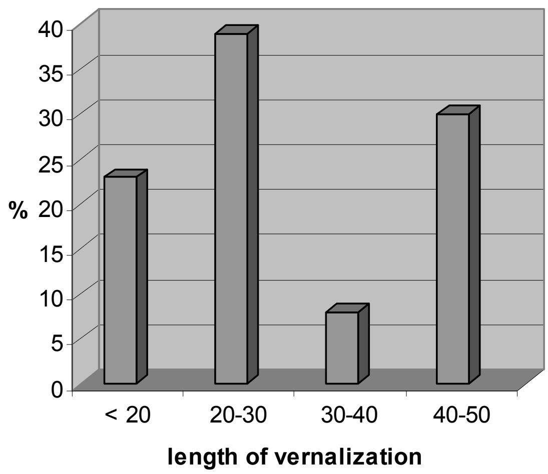

Fig. 4. The share of varieties with different vernalization from 2007 (%)

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Biologie individuálního vývoje tritikale (X *Triticosecale* Wittmack) ve srovnání s žitem a pšenicí.

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Byl sledován průběh růstu a vývoje souboru odrůd ozimého tritikale (*X Triticosecale* Witt.), ozimého žita a ozimé pšenice pomocí fází BBCH a etap organogeneze vzrostného vrcholu podle stupnice Kupermanové doplněné o etapu „dvojité rýhy“ (double ridge). Výsledky představují průměrné hodnoty souboru odrůd sledovaných v měsíčních intervalech na průměrných rostlinách. Nejrychlejší růst i vývoj mělo žito v podzimních podmínkách i po obnovení jarní vegetace. Tritikale se více blížilo žitu než pšenici, která měla růst i vývoj prokazatelně pomalejší. Jen odrůda tritikale Lasko se lišila velmi rychlým vývinem do zimy i v předjaří, což představuje riziko poškození mrazem.

Klasickou metodou byla zjištěna délka jarovizace souboru starších odrůd z roku 1990 a nových odrůd registrovaných v roce 2007. K hodnocení délky jarovizace v tomto roce byl použit index generativního vývoje stanovený z procenta vymetaných rostlin k danému datu a dělený počtem dní od vzejití do data hodnocení. Je to přesnější určení doby jarovizace, protože zahrnuje i dobu metání, resp. rychlost a jednotnost metání. Potvrdilo se, že odrůdy s krátkou jarovizací mají rychlý vývin do nástupu zimy i při obnovení jarní vegetace, pokud nejsou citlivé na podzimní a předjarní krátký den, který může vývoj inhibovat.

Podle délky převažovaly v roce 1990 odrůdy se střední a krátkou jarovizací, v roce 2007 se zvýšil podíl odrůd s krátkou jarovizací a jen třetina odrůd měla jarovizaci dlouhou.

tritikale (X *Triticosecale* Witt.); jarovizace; rychlost vývoje; pšenice; žito

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