Winter wheat response to spring frost and their implications on future breeding goals

Marcin Rapacz*, Barbara Jurczyk, Magdalena Wójcik-Jagła,
University of Agriculture in Krakow, Plant Breeding, Physiology and Seed Science
*email: marcin.rapacz@urk.edu.pl

Introduction

With the increasingly noticeable warming of the global climate, it might seem that the problem of winterhardiness will lose its importance. However, this is a misconception - although some of the factors impairing overwintering, such as extremely cold winter temperatures, will disappear, new ones will appear. Various models of future climate warming predict higher average temperatures during the winter, which will likely result in early start of spring vegetation. As a consequence, winter plants will be exposed to spring frosts (which, according to the models, will still occur) not only after de-acclimation but also in the generative phase of development, which can be a significant cause of yield reduction.

Plant Material and Methods

The experiments were performed in 2021 and 2022. Each year 100 winter wheat accessions from Polish breeding companies were grown in pots in the field. Half of the plants were exposed to controlled spring frost in the beginning of heading (BBCH51, Hack et al. 1992). The freezing was applied in three consecutive cycles: the pots were transferred around 12:00 PM to a freezing chamber at +5°C. Then, at 2:00 AM, the temperature started to decrease to -5°C (2021) or -4°C (2022) at a rate of 3°C per 1h. At 7:00 AM, the temperature was raised to 5°C also at a rate of 3°C/h. After repeating the cycle three times, the plants were moved from the vegetation chamber to field conditions in the evening. For the control variant, plants were moved at the same time to a vegetation chamber with a temperature of 5°C and put to field conditions together with the plants after freezing. In the preliminary study performed on three randomly chosen accession different freezing schemes were applied at three growth stages as indicated in **Fig. 1.**

Freezing tolerance was assessed as the decrease in seed yield relative to control plants. After the end of vegetation, the stems and ears were counted, manually threshed and cleaned with a blower. Then, the kernels were counted and weighed. The weight of 1,000 grains (TGW), the number of grains per ear, the density of ears per m^2 and the grain yield in t/ha were calculated. For the selection of tolerant plants purpose two different approches are used as shown in **Fig. 3 and 4.**

Results and discussion

The study indicated that plants later entering the generative stage will be less sensitive to freezing (**Fig. 1**). The sensitivity to freezing markedly increase in the beginning of flowering (even 75% yield loss). In core experiments an average about 20% yield loss due to spring frost was observed (**Table 1**). In general freezing caused irreversible damage to the spikelets, and the growth of extra stems and spikes was observed, which was however not effective for maintaining yield stability (**Fig. 2, Table 1**). In 2021, when the freezing temperature was lower, the decrease in grain weight was also noted.

Freezing tolerance at the generative stage varies between accessions offering prospects for conducting effective selection of breeding materials (**Fig. 3 and 4, Table 2**). The different compensatory regrowth response was also observed between accessions.

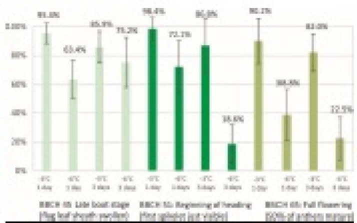

Fig. 1. The relative reduction of winter wheat yield by freezing in different generative growth stages and with different schemes of treatment. Vertical bars represents confidence intervals for P=0.05.

Fig. 2. Typical effects of freezing damages in generative stage after three weeks of regrowth

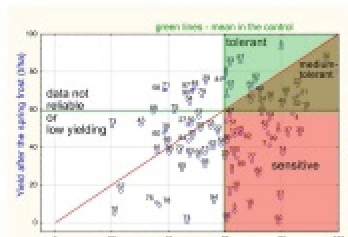

Fig. 3. Selection of winter wheat accessions towards freezing tolerance in generative stage based on yield change after freezing (2021 experiment)

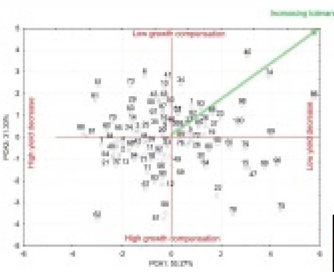

Fig. 4. Selection of winter wheat accessions towards freezing tolerance in generative stage based on PCA analysis of yield components affected by freezing (2022 experiment)

Table 2. Variable loads in PCA from Fig. 4.

Variable	PCA 1	PCA 2
Change in stem number	0.072	0.250
Change in ears number	0.099	0.234
Change in grains / ear	0.250	0.007
Change in yield	0.256	0.003
Change in grains / ear	0.182	0.090
Change in yield / ear	0.140	0.199
Change in TGW	0.000	0.217

Conclusions

- Spring frosts in generative stage can markedly decrease yielding of winter common wheat (*T. aestivum*).
- The selection of tolerant varieties is possible.
- Selection should be based on both maintaining yield stability and avoiding compensatory regrowth.

Literature reference

Hack et al. (1992) The extended BBCH-scale, p. 1

Table 1. The relative reduction of yield components in 100 wheat accessions affected by freezing in BBCH51. Statistical significance at: P=0.05*, P=0.01** and P=0.001***.

Year	Stems / m^2	Ears / m^2	Grains / ear	TGW (g)	Yield (t/ha)
2021	138.7%***	134.2%***	70.5%***	85.6%**	73.6%***
2022	103,9%*	103.5%*	78.1%***	99.0%	80,2%***

Funding

The research was funded by the Ministry of Agriculture and Rural Development (Poland) Decisions no: KS.zb.802.12.2021 and DHR.hn.802.13.2022.

Different patterns of response to spring frost in winter barley and their implications on future breeding goals

Magdalena Wójcik-Jagła*, Barbara Jurczyk, Marcin Rapacz

University of Agriculture in Krakow, Department of Plant Breeding, Physiology and Seed Science

*email: magdalena.wojcik-jagla@urk.edu.pl

Introduction

There are two types of cold de-acclimation, with potentially different genetic and physiological backgrounds: 1) "Passive" de-acclimation independent of environmental conditions - the highest level of frost resistance occurs in most plants in the middle of winter and from then on frost resistance gradually decreases. This may be related to the onset of generative development or to the consumption of storage materials accumulated by plants before winter. 2) "Active" de-acclimation - plants de-acclimate as a result of higher temperatures, such as during warm temperature episodes in winter.

In this study a response to passive (spring) de-acclimation and subsequent spring frost was studied in two-years semi-controlled experiment in 200 winter barley accessions.

Plant Material and Methods

The experiment was performed in two years: 2021 and 2022. Each year 100 winter barley accessions obtained from four Polish breeding companies were grown in pots in the field. Half of the plants were exposed to controlled spring frost in the beginning of heading (phase BBCH51, Hack et al. 1992). The freezing was applied in three consecutive cycles: the pots were transferred around 12:00 to a freezing chamber at +5°C. Then, at 2:00 a.m., the temperature started to decrease to -4°C (2021) or -5°C (2022) at a rate of 3°C per 1h. At 7:00, the temperature was raised to 5°C also at a rate of 3°C/h. After repeating the cycle three times, the plants were moved from the vegetation chamber to field conditions in the evening. For the control variant, plants were moved at the same time to a vegetation chamber with a temperature of 5°C. They were moved to field conditions at the same time as the frozen variant. Frost tolerance was assessed as the decrease in seed yield relative to control plants. After the end of vegetation, the ears were counted and manually threshed, and cleaned with a blower. Then, the kernels were counted, and then weighed. The weight of 1,000 kernels, the number of grains per ear, the density of blades and ears per m^2, and the grain yield in t/ha were calculated. The selection of tolerant accessions was based on two different strategies, each used in different year of the study (Fig. 3 and 4).

Results and discussion

The results confirm the serious problems that can be associated with the effects of spring frost affecting cereals at the generative growth phase. The study indicated up to 25-30% yield loss in winter barley (Table 1). Barley at frost temperatures higher than critical (causing a decrease in yield) reduces tillering, and deformation of ears is observed (Fig. 1), but these disadvantages are compensated for by increasing the number of kernels per ear (at the expense of their weight). As a result, yield losses may be insignificant (year 2021, Table 1). If, on the other hand, the spikelets are damaged, the plants compensate for the damage by forming additional shoots. However, this strategy is not agriculturally advantageous, as the newly formed ears mature later than those that were present on the plant at the time of the frost (Fig. 2).

The direct implication of the observed immense role of growth compensation in barleys reaction to spring frost was the change in selection strategy. The selection of tolerant accessions was based on yield in 2021 (Fig. 3), and on multidimentional principal component analysis (PCA) in 2022 (Fig. 4, Table 2). In both cases the accessions grouped in the upper right quarter of the graph are considered the most tolerant to spring frost (Fig. 3 and 4).

Table 1. Effect of spring frost on the yield of winter barley in 2021 and 2022. Mean values for all tested accessions. Statistically significant differences are marked with asterisks for P=0.05 *, P=0.01 ** and P=0.001 ***.

Year	Density of stems per m^2		Density of ears per m^2		Number of kernels per ear		1000 kernels weight (TKW) [g]		Yield [t/ha]	
	control	frost	control	frost	control	frost	control	frost	control	frost
2021	1416	1194***	701	619*	15.4	18.6*	37.9	33.4***	40.8	38.5
2022	1887	2008**	843	742**	11.2	9.3*	41.6	40.7	41.0	28.5***

Fig 1. Deformation of ears observed in barley after spring frost.

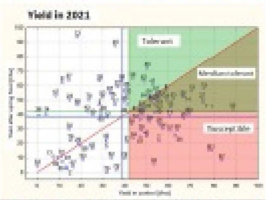

Fig 3. Selection of tolerant accessions in 2021 based on yield. Green lines refer to mean values in control conditions, and blue lines refer to mean values after spring frost.

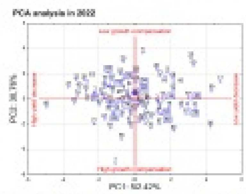

Fig 4. Selection of tolerant accessions in 2022 based on principal component analysis (PCA) showing diverse response of barley accessions to spring frost.

Fig 2. Formation of additional shoots in barley after spring frost.

Table 2. Variable input into principal components (PC) resulting from PCA shown in Fig.4. Red font refers to variables with the biggest input into principal components.

Variable input in PCA shown in Fig 4	Change in stem number	Change in ear number	Change in kernel number	Change in yield	Change in kernels per ear	Change in yield per ear	Change in TKW
PC 1	0.067	0.048	0.238	0.259	0.162	0.172	0.054
PC 2	0.277	0.345	0.022	0.004	0.127	0.159	0.067

Conclusions

1. Spring frost can lead to significant yield loss in winter barley.
2. Spring frost tolerance at the generative stage (passive de-acclimation tolerance) is genotypically diverse in the studied species.
3. The selection of spring frost-tolerant winter barley lines should be aimed at lines showing a low yield loss after a frost event with a low level of growth compensation.

Literature references

Hack et al. (1992) The extended BBCH-scale, p. 1

Funding

The research was funded by the Ministry of Agriculture and Rural Development (Poland), Decisions no: KS.zb.802.12.2021 and DHR.hn.802.13.2022.