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Tolerance of peach flower buds to low sub-zero temperatures in winter

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Abstract

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After each of three consecutive winters, 2010/2011, 2011/2012 and 2012/2013, the extent of frost damage to flower buds was studied in 25 genotypes of peach growing in the collection of varieties in the Experimental Orchard in Dąbrowice near Skierniewice (central Poland). The lowest temperatures during those winters were quite similar: –22.3°C (February 22, 2011), –23.3°C (February 3 and 4, 2012), and –21.4°C (March 24, 2013). However, after the winters of 2010/2011 and 2011/2012 the extent of damage to peach flower buds was much larger than after the 2012/2013 winter. This was caused by different weather patterns during those winters. During the 2010/2011 and 2011/2012 winters, before the occurrence of the lowest temperature, there were periods of above-zero temperatures, which resulted in a reduction in tolerance of flower buds to severe winter frosts. During the 2012/2013 winter, sub-zero temperatures persisted for most of the time, which helped the flower buds to maintain high tolerance to low sub-zero temperatures until late March.

Keywords: frost damage; winter hardiness; peach breeding; winter dormancy

Peach (*Prunus persica* (L.) Batsch) is a native species of the eastern regions of China (Scorza, Okie 1991; Rieger 2006). It comes from a continental climate zone and undergoes a relatively short period of endodormancy – the period in which flower buds will not begin the development process even if the weather conditions are favourable. In order to break this dormancy, peach flower buds must accumulate a sufficient number of chill units (Richardson et al. 1974). Most varieties of peach require 100–1,000 chill units. Varieties suitable for cultivation in areas such as the northern parts of the US and southern parts of Canada require at least 750–1,000 chill units to complete endodormancy. On the other hand, varieties that require fewer chill units are suitable for growing in warmer climates (Scorza, Sherman 1996). In countries located at different latitudes, the process of accumulating chill units and the course of winter dormancy associated with it vary. At latitudes above 45° N and S, the accumulation of the necessary number of chill units to complete endodormancy may already occur in the autumn, especially in the varieties that require less chilling. If, after the completion of this stage of winter dormancy, periods of above-zero temperatures happen to occur, the flower buds may

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initiate development processes before the arrival of another wave of winter frosts. On the other hand, at latitudes below 30°N and S, peach flower buds may not receive sufficient doses of chilling in the winter and may not be able to complete endodormancy, which adversely affects tree growth and fruiting.

In Poland, which is located between the latitudes of 49° and 55°N, the accumulation of chill units by peach flower buds usually begins in September. By the end of December, the buds usually will have received a sufficient number of these units, and their endodormancy ends (Jakubowski 1993, 2000). After completing endodormancy, the buds enter the stage of ecodormancy. If, under ecodormancy, there are periods during which the air temperature rises above 4.4°C (Richardson et al. 1974), peach flower buds are then considered to accumulate hourly units of growth-promoting temperature, the so-called growing degree hours (GDH) and lose their tolerance to low sub-zero temperatures.

The min. temperature that peach flower buds can withstand in winter depends on many factors and is in the range from –23°C to –29°C (Campbell, Hadlle 1960; Weaver et al. 1968), or even –30°C (Layne 1984). During very severe winters, the flower bud is the organ of the peach tree that is most frequently damaged by frost.

Therefore, the extent of frost damage to flower buds determines the northern boundary of the peach-growing zone in the northern hemisphere and the southern boundary in the southern hemisphere. During severe winters in Poland, significant frost damage often occurs to peach flower buds, and every few years also to the shoots and even the peach trees themselves (Jakubowski 1986). Extensive damage to peach flower buds usually occurs at a temperature between –24°C and –26°C (Szewczuk et al. 2007, 2010). However, during some winters, even if the air temperature drops to –28°C, only some of the flower buds become frostbitten and the trees are still able to produce a satisfactory fruit crop in the summer (Szymajda et al. 2013). The extent of damage to peach flower buds thus depends on the weather pattern during the winter and on the genetically determined characteristics of the cultivar. Other factors affecting the tolerance of peach flower buds to winter frosts include the methods of growing and maintaining peach trees, as well as the intensity of fruiting in the previous year (Flore et al. 1983; Byers, Marini 1994).

In the studies by Szalay et al. (2000, 2010), conducted in the climatic conditions of Hungary, peach flower buds had the highest level of tolerance to low sub-zero temperatures in December. In that month, damage up to 50% of flower buds (LT_{50} value) occurred in the temperature range from –18°C to –26°C, depending on the cultivar and year of the study. Later, their frost resistance decreased. In February, this extent of damage to the buds was already caused by temperatures from –15°C to –20°C, in early March from –11°C to –18°C, and in the second half of March even by temperatures in the range from –5°C to –12°C.

Poland is located in a transitional climate zone, and during the winter months of January, February and March there are periods of thaw, which cause dehardening of peach flower buds and a decrease in their tolerance to low sub-zero temperatures. After the periods of thaw, frosts can occur in February, and sometimes in March, often below –20°C, and damage the flower buds, which results in fruit crop losses. This kind of weather pattern was observed in Poland during three consecutive winters when the study described here was conducted.

The aim of the study was to assess the extent of damage to flower buds of selected peach genotypes under ecodormancy, caused by severe winter frosts in February and late March during three consecutive winters of 2010/2011, 2011/2012 and 2012/2013.

MATERIAL AND METHODS

Experimental location and plant material. The study was conducted in the spring after each of three consecutive winters – 2010/2011, 2011/2012 and 2012/2013. The objects studied were trees of peach varieties and clones growing in the collection of varieties in the Experimental Orchard in Dąbrowice, belonging to the Research Institute of Horticulture in Skierniewice (central Poland, 145 m above sea level, latitude 51°54'N, longitude 20°06'E). Assessments of the extent of frost damage to flower buds were performed for 25 peach genotypes. They included 12 cultivated varieties – Redhaven, Reliance, Inka, Iskra, Harnaś, Wacław, Harblaze, Superqueen, Saturn, Doniecka Żółta, Velvet, Elberta; 9 clones bred at the Institute of Horticulture in Skierniewice – 6A-9DN, 6A-35DN, 6A-50DN, B6/B1, B2/03, No. 3884, No. 3847, No. 3756, No. 3844; and 4 seed genotypes – Mandżurska, Siberian C, BN-1, BN-8 (Table 1).

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Table 1. Winter damage to peach flower buds and its effect on subsequent flowering and fruiting of trees

Genotype	Damaged flower buds (%)			Flowering intensity*			Fruiting intensity**			Average 2011/2013 (%)		
	2011	2012	2013	2011	2012	2013	2011	2012	2013	damaged	flowering	fruiting
Redhaven	74.5^{ef***}	79.8^{de}	12.8^{fghi}	3	3	8	4	7	8	55.7$^{i–l}$	4.7	6.3
Reliance	61.5^{cd}	74.8^{cd}	14.0^{hi}	3	5	8	3	7	8	50.1^{fgh}	5.3	6.0
Inka	79.3^{efg}	92.8^{g}	6.5^{bc}	4	2	8	7	5	8	59.5^{lm}	4.7	6.7
Iskra	73.8^{e}	88.0$^{d–g}$	8.8^{cde}	3	4	8	4	6	8	56.8^{jkl}	5.0	6.0
Harnaś	60.8^{cd}	79.3^{de}	2.3^{a}	4	3	8	8	7	8	47.4^{efg}	5.0	7.7
Wacław	84.8$^{e–h}$	95.3^{g}	10.0$^{d–g}$	4	2	8	7	3	8	63.3^{mn}	4.7	6.0
Harblaze	78.0^{efg}	90.3^{fg}	9.5$^{c–f}$	3	3	8	5	4	8	59.3^{lm}	4.7	5.7
Superqueen	91.8^{h}	96.8^{g}	10.0$^{d–g}$	2	2	8	2	2	8	66.2^{n}	4.0	4.0
Saturn	45.3^{a}	79.5^{de}	14.8^{i}	6	4	8	6	6	8	46.5^{def}	6.0	6.7
Doniecka Żółta	85.3^{efgh}	82.0^{def}	27.3^{k}	3	4	6	6	4	8	64.8^{n}	4.3	6.0
Velvet	88.3^{gh}	89.8^{fg}	18.8^{j}	3	3	8	5	4	8	65.6^{n}	4.7	5.7
Elberta	76.3^{ef}	87.3^{efg}	8.8^{cde}	4	3	8	6	4	8	57.4^{kl}	5.0	6.0
6A-9 DN	51.5^{abc}	61.0^{b}	11.3$^{e–h}$	3	5	8	3	7	8	41.3^{bc}	5.3	6.0
6A-35DN	58.3^{cd}	60.8^{b}	3.0^{a}	4	6	8	4	7	8	40.7^{bc}	6.0	6.3
6A-50DN	60.0^{cd}	73.3^{cd}	2.3^{a}	4	5	8	7	7	8	45.2^{cde}	5.7	7.3
B6/B1	61.0^{cd}	95.0^{g}	4.8^{ab}	3	2	8	3	3	8	53.6$^{h–k}$	4.3	4.7
B2/03	56.3^{bcd}	68.8^{bc}	6.5^{bc}	5	5	8	7	6	8	43.8^{cde}	6.0	7.0
No. 3884	46.3^{ab}	72.5^{cd}	6.5^{bc}	5	4	8	7	8	8	41.8^{cd}	5.7	7.7
No. 3847	73.8^{e}	79.3^{de}	4.5^{ab}	3	4	8	7	8	8	52.5^{hij}	5.0	7.7
No. 3756	83.3$^{e–h}$	82.5^{def}	14.5^{hi}	3	4	8	5	7	8	60.1^{lm}	5.0	6.7
No. 3844	74.3^{ef}	73.0^{cd}	4.8^{ab}	3	5	8	5	8	8	50.7^{fgh}	5.3	7.0
Mandżurska	74.3^{ef}	68.3^{bc}	12.5$^{f–i}$	3	7	8	4	7	8	51.7^{ghi}	6.0	6.3
Siberian C	85.8^{fgh}	77.3^{cd}	13.3^{ghi}	3	4	8	3	7	8	58.8^{lm}	5.0	6.0
BN-1	63.0^{d}	40.5^{a}	7.0^{bcd}	5	7	8	6	8	8	36.8^{b}	6.7	7.3
BN-8	44.8^{a}	41.5^{a}	8.5^{cde}	5	5	8	6	7	8	31.6^{a}	6.0	7.0
Average	69.3	77.2	9.7	3.6	4.0	7.9	5.2	6.0	8.0	52.0	5.2	6.4

*ranking scale: 1–9 (1 – no flowering, 3 – poor flowering, 5 – moderate flowering, 7 – abundant flowering, 9 – very abundant flowering); **ranking scale 1–9 (1 – no fruiting, 3 – poor fruiting, 5 – moderate fruiting, 7 – abundant fruiting, 9 – very abundant fruiting); ***means in columns followed by the same letter do not differ significantly according to Duncan's *t*-test ($P \leq 0.05$)

Assessment of the extent of frost damage to flower buds. The assessments were conducted on April 13–14, 2011 and 2012, and on April 30, 2013. They took place during the swelling stage in healthy buds, but before the shedding of frostbitten buds. During the assessments, the flower buds were divided into two groups: undamaged buds – becoming swollen, with green living tissue visible on a longitudinal cross-section (Fig. 1a,c), and damaged buds – with arrested development and evidence of brown damaged tissue on a longitudinal cross-section (Fig. 1a,b). Each genotype was assessed on the basis of a sample of 2 or 4 healthy trees (depending on the number of trees in the collection), grafted on Mandżurska peach seedlings and planted in area of 0.4 ha in the spring of 2006 at a spacing of 4.5 × 2.5 m.

- When flower buds were assessed on four trees, counting was performed on eight branches, on a sample of 50 buds per branch (two branches per replication).
- When assessing flower buds on two trees, counting was performed on four branches, on a sample of 100 buds per branch (one branch per replication).

Each genotype was therefore assessed on the basis of a sample of 400 flower buds. The damaged buds were counted on branches located on two op-

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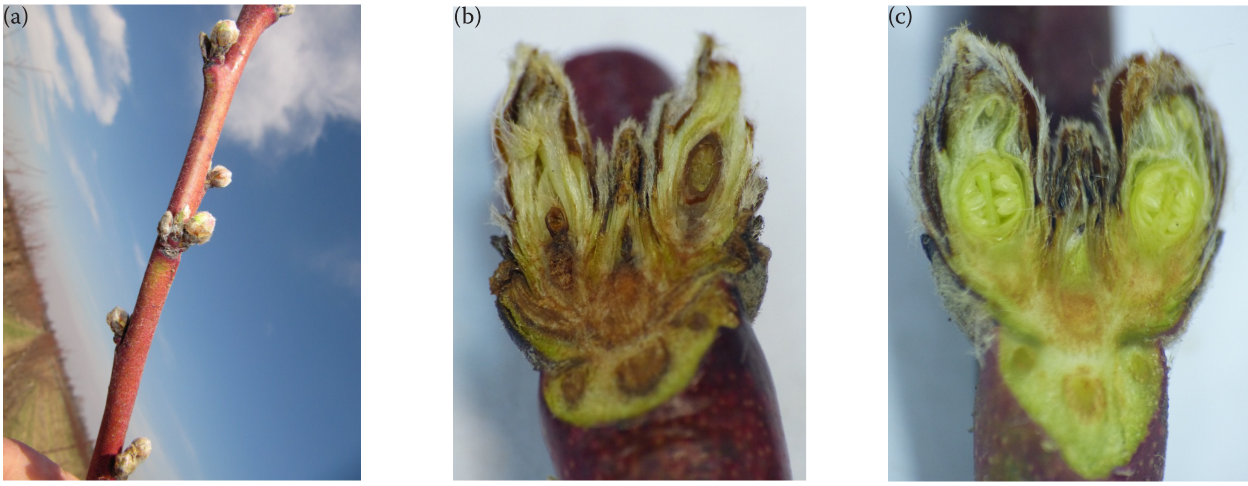

Fig. 1. Assessment of peach flower buds: (a) a dead bud (left) and a swollen living bud (right); (b) longitudinal section of damaged buds showing brown damaged tissue; (c) longitudinal section of living buds with green living tissue

posite sides of the tree crown, at a height of 1.5 to 2.0 m aboveground.

Accumulation of chill units (CU) and growing degree hours (GDH). Doses of chilling accumulated by peach flower buds were calculated by using the model developed by Richardson et al. (1974), according to which 1 h exposure of buds to a certain temperature gives the following result: temperatures in the range of 2.5°C to 9.1°C = 1.0 chill unit (CU), and temperatures in the range of 1.5°C to 2.4°C or 9.2°C to 12.4°C = 0.5 chill units. At temperatures below 1.4°C and in the range of 12.5°C to 15.9°C, no accumulation of chill units took place. On the other hand, 1 h exposure of flower buds at 16.0°C to 18.0°C gives a negative effect of –0.5 chill units, and a temperature above 18.0°C = –1.0 chill unit. The beginning of the accumulation of chill units was marked by the date from which the accumulation of CUs was continuous, with only rare occurrence of temperatures counteracting the effects of chilling.

From the day by which peach flower buds had accumulated 1,000 chill units (beginning of ecodormancy), as the air temperature increased above 4.4°C, the hours with temperatures conducive to growth (growing degree hours – GDH) were counted according to the model developed by Richardson et al. (1974). In order to ensure that the flower buds had completed endodormancy, on the day that marked the accumulation of 1,000 chill units, approx. 30–60 cm long and 7 to 10 mm thick shoots were cut off from trees of the cv. Redhaven and Elberta. The base ends of those shoots were submerged in a 5% sucrose solution and placed in a greenhouse at 25 ± 1°C during the day (16 h) and 18 ± 1°C at night (8 h). After 5 and 10 days, the aqueous sugar solution was changed and the base ends of the shoots were trimmed. After 14 days, at least from 30% to 50% of the buds of each cultivar had reached Baggiolini's stage B or C, indicating swollen buds with discernible bright scales and buds with visible segments of the calyx, respectively (Baggiolini 1952). This proved that endodormancy had been completed.

Intensity of tree flowering and fruiting. Assessments were performed using a 1–9 ranking scale, where 1 represents lack of flowering/fruiting, 3 – poor flowering/fruiting, 5 – moderate flowering/fruiting, 7 – abundant flowering/fruiting, 9 – very abundant flowering/fruiting.

History of temperature variations. In the collection of clones and varieties in which the study was conducted in the months of September through May, the pattern of air temperature variations was recorded by means of temperature recorders mounted on peach trees at a height of about 2.0 m above ground.

Statistical analysis. The results were analysed using one-way analysis of variance. To assess the significance of differences between means, the Duncan's *t*-test was used at a 5% significance level.

RESULTS AND DISCUSSION

During the three successive years of the study, the lowest recorded winter temperatures were quite

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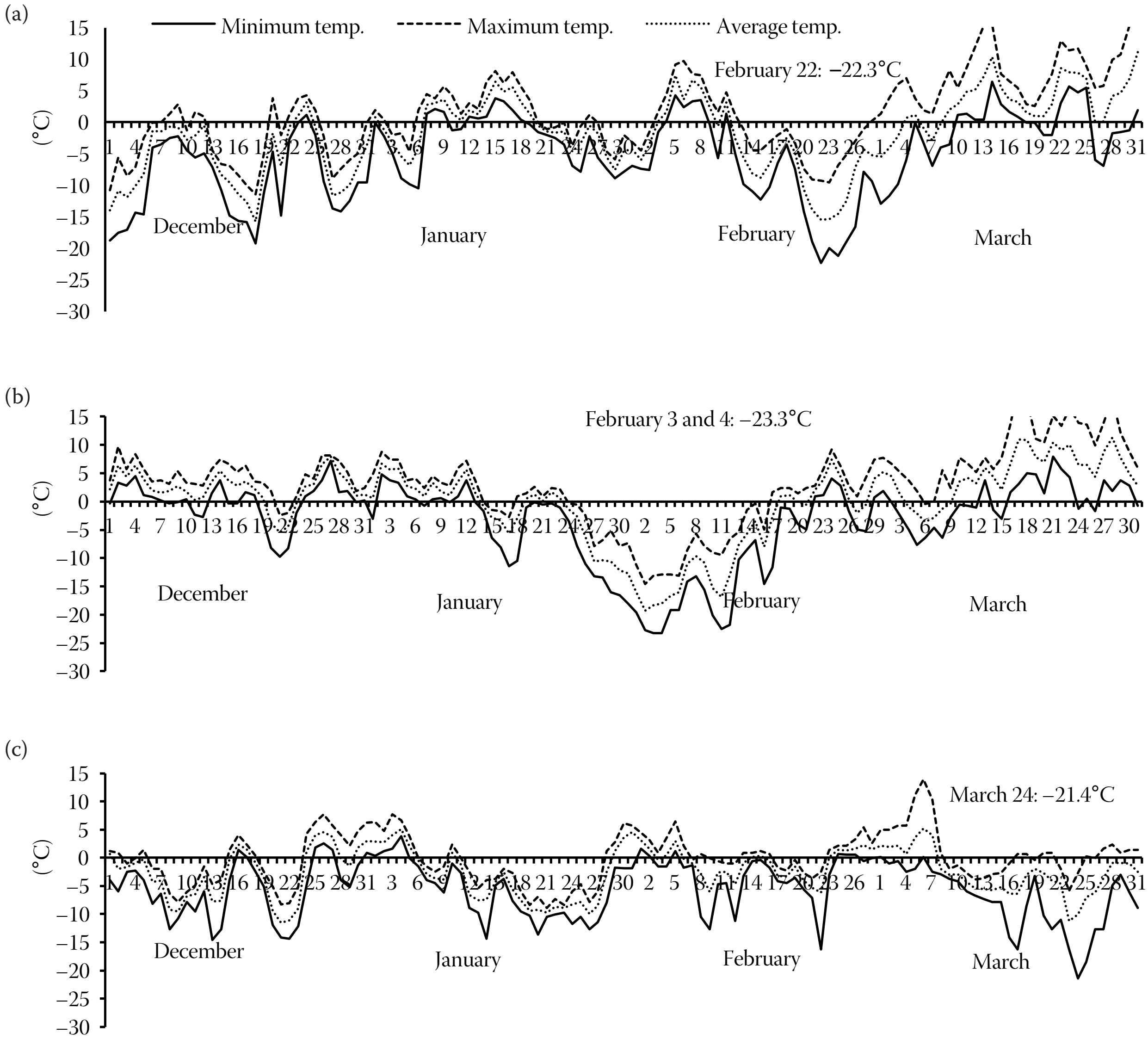

Fig. 2. Temperature log for three consecutive winters (a) 2010/11, (b) 2011/12 and (c) 2012/13

similar: –22.3°C on February 22, 2011, –23.3°C on February 3 and 4, 2012, and –21.4°C on March 24, 2013 (Fig. 2). However, the extent of damage to flower buds of the assessed peach genotypes was different each year (Table 1). The percentages of damaged buds recorded in the spring of 2011 and 2012 were much higher than those determined in the spring of 2013, amounting to 69.3%, 77.2%, and 9.7%, respectively (Table 1). In a study by Szalay et al. (2000), damage to peach flower buds on March 1 occurred at a temperature (LT_{50} value) between –11.5°C and –18.0°C, and in mid-March even between –7.5°C and –12.0°C. In this study, despite the fact that on March 24, 2013 the air temperature had fallen to –21.4°C, the damage to flower buds, on average for the tested genotypes, was not very extensive. The low percentage of damaged buds undoubtedly proves that at the time of the marked drop in temperature those buds were still thoroughly hardened and retained a high level of tolerance to severe frosts.

The process of hardening of fruit trees in the temperate climate zone can be divided into two stages. In the case of peach and apple trees, the first stage begins in the autumn and continues as the air temperature consistently decreases below 0°C. In the second stage, if the temperature remains below 0°C, the trees continue to undergo the process of hardening and further increase their tolerance to winter frosts. If, however, the air temperature during this period does not fall below 0°C, the trees do not enter the second stage of hardening (Howell,

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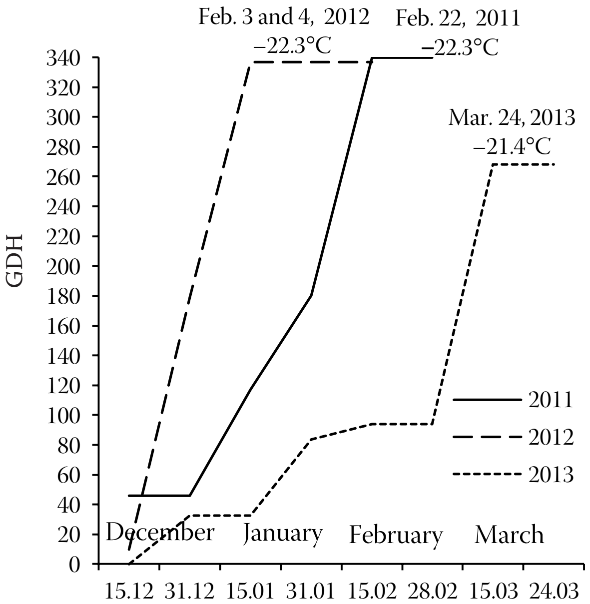

Fig. 3. Accumulation of growing degree hours (GDH) following the accumulation of 1,000 chill units (CU). GDH accumulation start date: Nov. 18, 2010, Dec. 14, 2011, Dec. 26, 2012

Weiser 1970; Szalay et al. 2010). In the winter of 2012/2013, temperatures often fell below –10°C, and most of the time remained below 0°C (Fig. 2c). This undoubtedly contributed to the hardening of the flower buds, and allowed them to maintain a high level of tolerance to winter frosts until the end of March.

During ecodormancy, as the temperature rises above zero a rapid decrease occurs in the tolerance of peach flower buds to low sub-zero temperatures (Szalay et al. 2010). That, undoubtedly, was the case during this study. Periods of above-zero temperatures occurred in mid-January and early February in the winter of 2010/2011 (Fig. 2a), and in December and the first half of January in the winter of 2011/2012 (Fig. 2b). During the 2010/2011 and 2011/2012 winters, before the occurrence of the lowest temperature, peach flower buds had accumulated 340 and 337 growing degree hours (GDH), respectively (Fig. 3). In contrast, in the winter of 2012/2013, despite the marked decrease in temperature towards the end of March, the buds had accumulated only 268 GDH. This means that in 2011 and 2012, before the drop in temperature to the lowest level, the buds had received more heat, as a result of which they lost their tolerance to winter frosts more quickly than in 2013.

In the winter of 2010/2011, the lowest air temperature was recorded in late February, whereas in the winter of 2011/2012 it was in early February. During those winters, peach flower buds had received similar doses of heat before the occurrence of the lowest temperatures. It seems likely that for this reason the extent of damage to the buds during the two winters was similar – 69.3% in 2011 and 77.2% in 2012, on average for the assessed genotypes. However, in the winter of 2010/2011, despite the lowest temperature occurring at a later date, damage to the flower buds was slightly less extensive than in the 2011/2012 winter. This can be attributed to slightly different patterns of temperature variations during those winters. In the winter of 2010/2011, in December, early January and the second half of January, and in February prior to the temperature dropping to the lowest level, there were periods with low sub-zero temperatures (Fig. 2a) providing conditions conducive to the hardening of flower buds. Increased tolerance of peach flower buds to winter frosts as a consequence of the influence of sub-zero temperatures has been demonstrated by the results of a study conducted in Hungary (Szalay et al. 2010). Likewise, in this study, although there were periods of positive temperatures in mid-January and early February, which could have started the process of dehardening in the buds, they were then followed by periods of low negative temperatures. The low sub-zero temperatures interrupted the process of dehardening in the buds and may have initiated the process of rehardening in them. In contrast, during the 2011/2012 winter, in December and in the first half of January, positive temperatures (mostly between 0 and 5°C) persisted and were not conducive to effective hardening of the flower buds. There were only two instances of a larger temperature drop: to –9.8°C on December and to –11.5°C on January 17 (Fig. 2b). In the 2011/2012 winter, there were also fewer days with low temperatures below zero, as a result of which the flower buds may have been less hardened and consequently the extent of the damage they had suffered was greater than in the 2010/2011 winter.

As might have been expected, the genotypes that were recorded to have suffered less damage to flower buds yielded more abundantly than those whose flower buds had been damaged to a greater extent. It is surprising, however, that although the damage to flower buds was less severe, on average for

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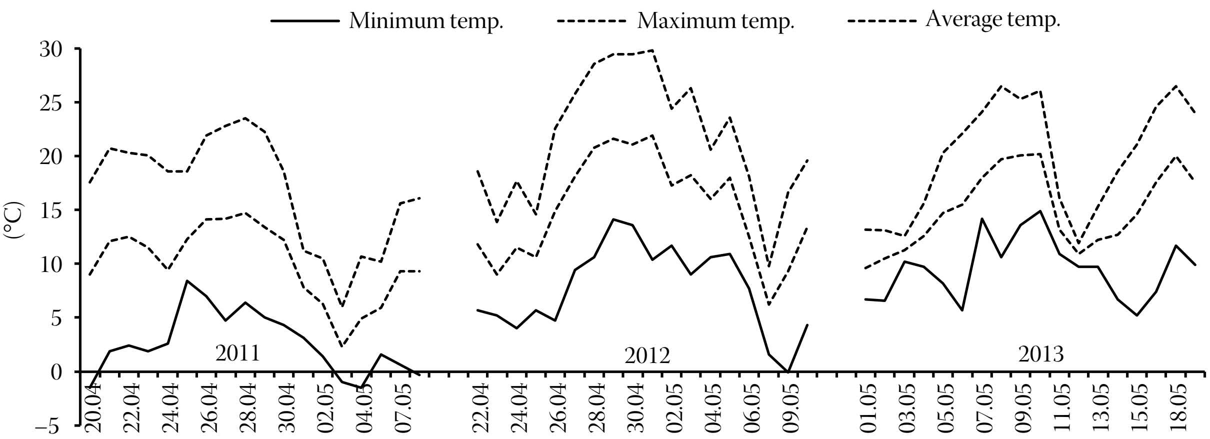

Fig. 4. Daily temperatures during flowering and fruit setting in peach trees (full bloom: Apr. 22–23, 2011, Apr. 24–27, 2012, May 2–3, 2013)

the assessed genotypes, in the spring of 2011 than in the spring of 2012. The tested genotypes bore fruit more abundantly in 2012. It should be noted, however, that at the time of flowering in 2011 the weather was colder than in 2012, and spring frosts had even occurred, which may have damaged some of the flowers (Fig. 4). In contrast, the slightly higher temperatures in 2012 were more favourable to the fertilization of flowers and the setting of fruit, which certainly had a significant effect on the intensity of fruiting.

In addition to the weather factors, the resistance of peach flower buds to damage caused by severe winter frosts is also determined by the genetic makeup of the cultivars. Among the assessed genotypes, the lowest number of damaged flower buds, on average for the three years of the study, was found in the seed genotypes BN-8 and BN-1 (31.6% and 36.8%, respectively). These results are consistent with the results of the previous study, in which the buds of these genotypes were found to have high tolerance to winter frosts (Szymajda, Żurawicz 2014). Among the assessed clones, the lowest number of damaged buds, on average for the three years of the study, was in the genotypes 6A-35DN (40.7%) and 6A-9DN (41.3%), whereas among the cultivars it was in Saturn (46.5%) and Harnaś (47.4%). The most extensive damage to buds was found in the cultivars Superqueen (66.2%), Velvet (65.6%) and Doniecka Żółta (64.8%). The sensitivity of flower buds of the cultivars Superqueen and Velvet to winter frosts in Poland's climatic conditions was already demonstrated in a previous study by Szymajda et al. (2013).

The risk of damage to peach flower buds restricts the cultivation of varieties of this species in areas characterized by frosty winters (Quamme et al. 1982). Every few years in those areas there are winters during which flower buds become frostbitten, which leads directly to a reduction in fruit yield, and even to a complete loss of the crop. To reduce the risk of growing peach in seasonally cold climates, there is a need for breeding varieties with the highest possible tolerance to winter frosts. Because of the fact that frost tolerance of flower buds changes during the winter, breeding programmes should be aimed at obtaining winter-hardy genotypes that are: (a) tolerant to frosts when trees are in deep endodormancy; (b) tolerant to temperature fluctuations during ecodormancy, i.e. slow to lose their frost resistance during winter periods with temperatures above 0°C; (c) able to regain their tolerance to winter frosts under the influence of sub-zero temperatures following winter periods of thaw; (d) tolerant to low sub-zero temperatures during the period from bud swelling to flowering and the formation of fruitlets after fertilization. Such genotypes will be particularly useful for growing at latitudes above 45°N and S.

CONCLUSION

The present results show the tolerance of peach flower buds to low sub-zero temperatures changes in successive winter months; in Poland's climatic conditions it can vary considerably in different years. With stable sub-zero temperatures, the eco-

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dormancy stage in peach can be extended and the flower buds can maintain high tolerance to winter frosts even until the end of March. In contrast, periods of winter thaw during ecodormancy cause rapid dehardening of the buds. Of great importance, therefore, is the ability of flower buds to reharden under the influence of sub-zero temperatures, which helps them avoid becoming frostbitten in the event of severe frosts reoccurring. When assessing peach varieties for tolerance of their flower buds to low sub-zero temperatures, temperature variations prior to winter frosts should be taken into account, as well as the stage of winter dormancy during which the frosts have occurred. These factors have an important effect on the degree of hardening of peach flower buds and their ability to maintain their tolerance to low sub-zero temperatures.

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