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Susceptibility of one-year-old shoots of scab-resistant apple cultivars to low temperatures in laboratory tests during four winters (1999/2000 – 2002/2003)

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ABSTRACT

One-year-old shoots from 15 scab-resistant apple cultivars grafted on M.9 were frozen artificially at temperatures from -15ºC to -35ºC during four successive winters from 1999/2000 to 2002/2003. During the winter of 1999/2000 the shoots were tested only once, in the next two winters 3 times, and twice in the winter of 2002/2003. All the trees from which the shoots were collected were planted in the orchard in the spring of 1995. The injuries caused by low temperatures were assessed by means of a survival test. The results obtained showed that the damage of one-year-old shoots depended mainly on the degree of hardiness of the trees during the dormant period and the cultivar. The injuries suffered by the shoots after freezing during the four successive winters (1999 – 2003) showed that the cultivars

‘Florina’, ‘Ligolina’, and ‘Ligol’ had winter hardiness similar to that of the standard cultivar ‘Novamac’. The remaining cultivars were more susceptible to low temperatures than ‘Novamac’. All the cultivars had lower winter hardiness at the end of the mild winters of 2001 and 2002 in comparison with the more severe 2003 one.

INTRODUCTION

The interest in the new scab-resistant apple cultivars is still growing (Czynczyk 1996, Fisher and Fisher 2000, Kruczyńska 2000 and 2002). So far, the proportion of scab-resistant cultivars in newly established apple orchards has been increasing (Przybyła 1997, Żurawicz 1998, Niemczyk 1999, Ugolik et al. 2001). The economic value of scab-resistant apple cultivars for new plantings depends mainly on organoleptic properties and their attractiveness (Kruczyńska et al. 1999, Kruczyńska 2000, Kruczyńska 2003). It is mainly for these reasons that the newly introduced scab-resistant apple cultivars are being tested by many research centres (Osterreicher 1996, Fischer et al. 1998, Sosna and Gudarowska 2001, Ugolik et al. 2001). The research work is also focused on the resistance of the scab-resistant cultivars to frost in our rather changeable climate. The mild winters of recent years in Poland have made it impossible to carry out an assessment of frost damage of one-year-old shoots and trees in field conditions. Hence, it was necessary to carry out frost resistance assessment tests on one-year-old shoots by subjecting them to low temperatures in laboratory conditions.

MATERIAL AND METHODS

The study involved one-year-old shoots cut from trees of 15 scab-resistant apple cultivars grafted on M.9 rootstock and growing in the Experimental Orchard at Dąbrowice (Tables 1 to 4). The experimental apple trees were planted in the spring of 1995. During the winter of 1999/2000 shoots for the tests were collected only once, while in the following two winters this was done three times (at the beginning, in the middle, and at the end of winter). During the winter of 2002/2003 shoots for the low temperature treatments were collected twice (in the middle and at the end of the winter). The dates of the freezing tests during the successive winters are given in Tables 1 to 4. The shoots to be tested were cut immediately prior to freezing, in lots of 16 shoots from 4 trees (i.e. 4 shoots randomly taken from one tree).

The degree of the damage to one-year-old shoots caused by low temperatures was assessed by means of a survival test (Hołubowicz 1978). The freezing and thawing of shoots was carried out at the rate of 5ºC per hour. The degree of the

damage of shoots kept at about 20ºC and at high air humidity over a period of two weeks was assessed on the 5-point scale, on which 1 – means no injuries, 2 – shoot slightly damaged, 3 – shoot on the brink of survival, i.e. able to regenerate, 4 – shoot strongly damaged, and 5 – dead shoot. The degree of frost damage of one-year-old shoots of the scab-resistant cultivars was assessed by comparing them with the standard cultivar 'Novamac', which resistance to frost in the field is known.

The results were analyzed using the variance analysis method. The analysis was carried out on values transformed with the function y = sqr (x) + sqr (x + 1), where x is the number of points in the injury scale from 1-5. To assess the value of the differences, Duncan's test at the significance level of 5% was used.

RESULTS AND DISCUSSION

The artificial freezing of shoots during the winter of 1999/2000 (4 February, 2000) was preceded by their exposure to minimum outside temperatures below zero, already from the middle of December (Fig. 1a). A few days before the freezing of shoots the minimum air temperature in orchard dropped to -15ºC. Despite the temperature drop, no damage to control shoots in the orchard was found (Table 1). In the freezing test there were no serious frost injuries at -20ºC, but shoots of ten out of the fifteen cultivars were already showing a small degree of damage (Table 1). The freezing temperature of -25ºC proved to be critical (injuries >3) for the standard cultivar, such as 'Novamac', 'Freedom' and 'Pinova' as well as for the newly introduced cultivars such as 'Sawa', 'Egeria', 'Medea', 'Odra', and 'Melfree'. At -30ºC shoots of all the cultivars were very severely damaged. Among them the least damaged were shoots of 'Novamac', 'Ligolina', and 'Pinova'. The low susceptibility to freezing of shoots collected from 'Novamac' trees agrees with the data by Kruczyńska (1998), and Kruczyńska et al. (1999).

The winter of 2000/2001 was also mild. Temperatures around 0ºC prevailing over a long period of time were not favourable for the development of winter hardiness by the trees. Control shoots (no freezing treatment) and those frozen at -15ºC, which were collected from the orchard at the beginning of the winter (6 December, 2000), showed no injuries. However, minor symptoms of wood browning were found at -20ºC. On December 6, at -25ºC, the least damaged (below 3) were shoots of 'Novamac', 'Ligol', 'Sawa', 'Egeria', and 'Odra'. At that temperature the most damaged (above 4) were shoots of 'Pinova', 'Free Redstar', and hybrid U 1165 (Table 2).

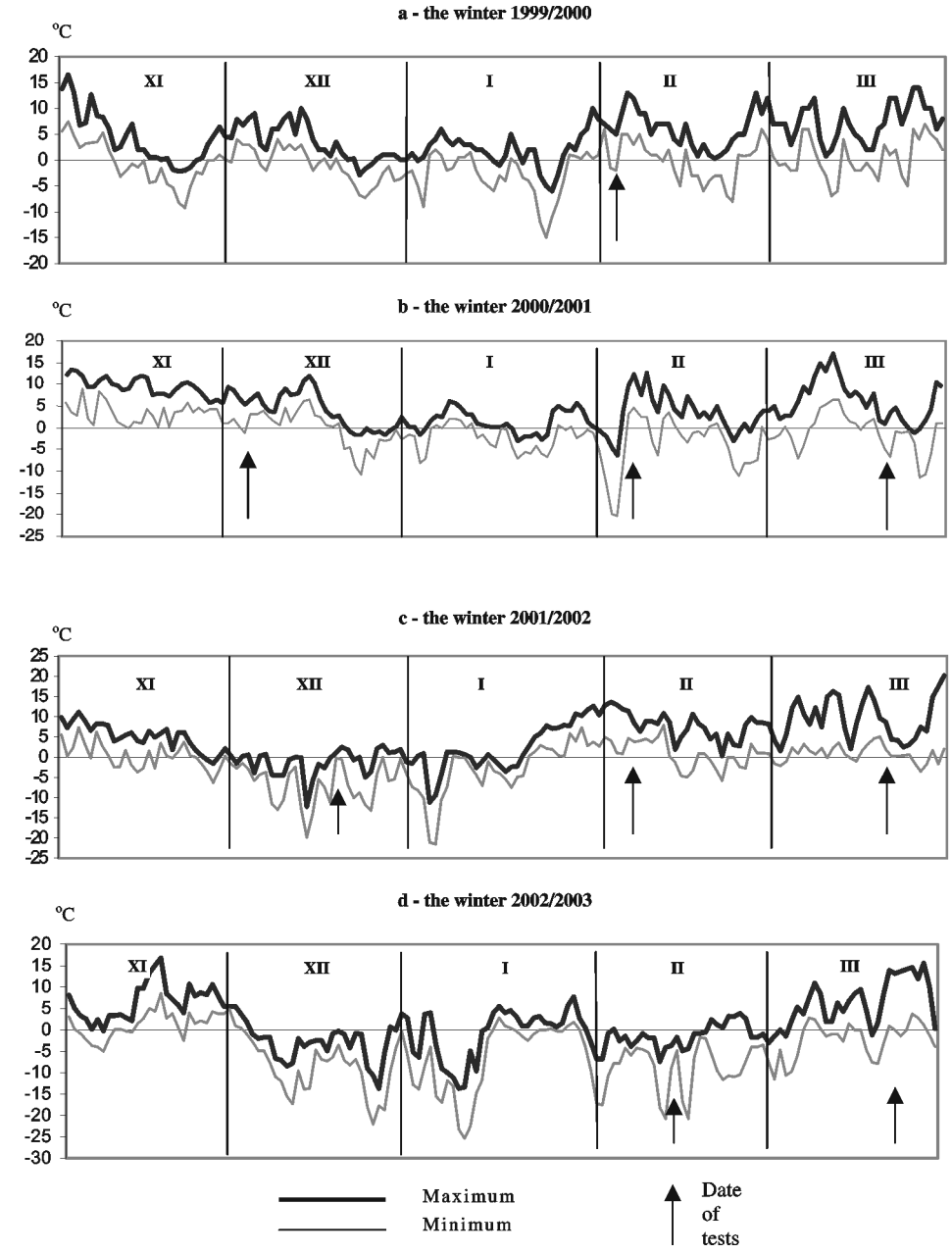

Figure 1. Diagram of minimum and maximum temperatures in Skierniewice during

Table 1. Frost injury to one-year-old shoots of 15 scab-resistant apple cultivars according to survival test in the middle of winter 2000 (5-point scale where: 1 – no injures, 3 – shoot injured, but able to regenerate, 5 – dead shoot)

Cultivar	Date and temperatures of freezing			
	04.02.2000			
	Non-frozen control from orchard	-20°C	-25°C	-30°C
'Novamac'	1.00 a	1.00 a	3.65 e	3.77 a
'Freedom'	1.00 a	1.33 bcd	3.57 e	4.85 d
'Pinova'	1.00 a	1.00 a	3.72 e	4.05 abc
'Florina'	1.00 a	1.05 ab	2.23 b	4.44 bcd
'Ligol'	1.00 a	1.55 c-f	1.76 a	4.10 abc
'Lodel'	1.00 a	1.67 def	2.77 cd	4.65 d
'Redkroft'	1.00 a	1.42 cde	2.72 cd	4.10 abc
'Sawa'	1.00 a	1.75 ef	3.67 e	4.42 bcd
'Egeria' (I-125-D2)	1.00 a	1.55 c-f	3.55 e	4.90 d
'Medea' (I-147-D2)	1.00 a	1.90 f	3.90 e	4.69 d
'Odra' (V-136-D2)	1.00 a	1.31 bc	3.79 e	4.49 bcd
'Ligolina' (XIX-133-D1)	1.00 a	1.05 ab	2.67 cd	4.00 ab
'Free Redstar' (hybrid D 3)	1.00 a	1.36 cd	2.59 c	4.57 cd
'Melfree' (hybrid D 7)	1.00 a	1.79 f	3.02 d	4.92 d
Hybrid U 1165	1.00 a	1.00 a	1.69 a	4.10 abc

Averages followed by the same letter do not differ significantly at p = 0.05 (Duncan's multiple range test)

The average temperatures in January and February 2001 (Fig. 1b) were favourable for the development of winter hardiness by the trees. In the first days of February, the minimum temperature dropped to -20ºC. However, the shoots artificially frozen at -25ºC (on February 7, 2001) survived this without major injuries. The temperature of –25ºC proved to be critical only for hybrid U 1165 and 'Melfree', and at -30ºC shoots of all the cultivars showed very severe injuries above 4 (Table 2).

The third freezing treatment (19 March, 2001) was preceded by mild outside temperatures around 0ºC. The artificial freezing at -15ºC did not cause any damage to shoots. However, the freezing of shoots at -20ºC caused slight injuries, 'Freedom', 'Pinova', 'Free Redstar', and 'Redkroft' being affected more seriously (above 3). At -25ºC, shoots of all the cultivars were very severely damaged. At that temperature shoots of 'Ligolina', 'Odra', 'Pinova', and 'Ligol' proved to be the hardiest (Table 2).

Table 2. Frost injury to one-year-old shoots of 15 scab-resistant apple cultivars according to survival test during winter 2000 – 2001 (5-point scale where: 1 – no injures, 3 – shoot injured, but able to regenerate, 5 – dead shoot)

Cultivar	Date and temperatures of freezing											
	06.12.2000				07.02.2001				19.03.2001			
	Non-frozen control from orchard	-15°C	-20°C	-25°C	Non-frozen control from orchard	-20°C	-25°C	-30°C	Non-frozen control from orchard	-15°C	-20°C	-25°C
'Novamac'	1.00 a	1.15 a	1.36 a-d	2.69 b	1.00 a	1.20 ab	1.99 def	4.22 abc	1.00 a	1.00 a	2.67 cde	4.67 ef
'Freedom'	1.00 a	1.12 a	2.44 f	3.99 cd	1.00 a	1.00 a	1.85 def	4.42 a-d	1.00 a	1.00 a	3.26 efg	5.00 f
'Pinova'	1.00 a	1.00 a	1.62 cde	4.32 d	1.00 a	1.00 a	2.22 fg	4.95 e	1.00 a	1.10 a	3.81 g	3.80 bc
'Florina'	1.00 a	1.00 a	1.05 a	3.34 c	1.00 a	1.46 ab	2.78 h	4.95 e	1.00 a	1.00 a	1.81 ab	4.17 cd
'Ligol'	1.00 a	1.05 a	1.37 a-d	2.62 ab	1.00 a	1.29 ab	2.07 ef	4.25 abc	1.00 a	1.00 a	2.16 abc	3.92 bcd
'Lodel'	1.00 a	1.00 a	1.87 e	3.54 cd	1.00 a	1.18 ab	1.22 ab	4.47 bcd	1.00 a	1.05 a	1.87 ab	4.73 de
'Redkroft'	1.00 a	1.00 a	1.40 a-d	3.62 cd	1.00 a	1.41 ab	1.60 cd	4.32 a-d	1.00 a	1.00 a	3.03 def	4.32 de
'Sawa'	1.00 a	1.00 a	1.22 abc	2.64 ab	1.00 a	1.22 ab	1.37 bc	4.42 a-d	1.00 a	1.05 a	2.56 cd	4.00 bcd
'Egeria' (I-125-D2)	1.00 a	1.00 a	1.12 ab	2.58 ab	1.00 a	1.48 ab	1.77 de	4.65 de	1.00 a	1.00 a	2.24 abc	5.00 f
'Medea' (I-147-D2)	1.00 a	1.00 a	1.12 ab	3.87 cd	1.00 a	1.00 a	1.00 a	4.60 cd	1.00 a	1.00 a	2.27 abc	4.92 f
'Odra' (V-136-D2)	1.00 a	1.00 a	1.00 a	2.04 a	1.00 a	1.53 ab	1.82 de	4.27 a-d	1.00 a	1.00 a	1.69 a	3.59 ab
'Ligolina' (XIX-133-D1)	1.00 a	1.12 a	1.87 e	3.72 cd	1.00 a	1.17 ab	2.62 gh	4.27 a-d	1.00 a	1.00 a	1.77 ab	3.24 a
'Free Redstar' (hybrid D 3)	1.00 a	1.00 a	2.62 f	4.25 d	1.00 a	1.00 a	1.12 ab	4.15 ab	1.00 a	1.40 b	3.64 fg	4.84 f
'Melfree' (hybrid D 7)	1.00 a	1.19 a	1.67 de	3.92 cd	1.00 a	1.54 b	3.02 h	4.07 a	1.00 a	1.00 a	2.77 cde	5.00 f
'Hybrid' U 1165	1.00 a	1.00 a	1.00 a	4.15 cd	1.00 a	1.51 ab	3.07 h	4.12 ab	1.00 a	1.00 a	2.32 bc	5.00 f

For explanation see Table 1

The winter of 2001/2002 was rather mild (Fig. 1c), except December and January being the coldest months. Temperatures around 0ºC in November were favourable for the development of good winter hardiness by the trees. The artificial freezing of shoots at the beginning of the winter of 2001/2002 (17 December, 2001) was carried out a few days after the minimum temperature had fallen to -19.9ºC (13 December, 2001). Despite this temperature drop, no damage to control shoots in the orchard was found (Table 3). There were also no serious frost injuries at -20ºC, but the shoots of four out of the fifteen cultivars were already showing a slight degree of damage. The temperature of -25ºC proved to be critical (injuries >3) for the majority of the cultivars. At that temperature the least affected were shoots of 'Florina', 'Lodel', and 'Sawa'. At -30ºC the shoots of all the cultivars were very severely damaged (above 3.9). The relatively low susceptibility to low temperatures of shoots of 'Novamac', 'Florina', 'Lodel', and 'Freedom' agrees with the data by Kruczyńska et al. (1999), and Czynczyk and Hodun (2001).

The freezing of shoots at -15ºC, carried out in the middle of the winter (6 February, 2002) after a few warm days, did not cause any injuries. However, the treatment at -20ºC caused very severe frost penetration in the shoots. At that temperature the least affected were 'Ligolina', 'Florina', 'Freedom', 'Lodel', and 'Free Redstar'. The temperature of -25ºC was critical for all the cultivars (Table 3).

The third freezing test (25 March, 2002) was also preceded by mild temperatures above 0ºC. The freezing temperature of -15ºC already caused slight injuries to shoots. The least affected were shoots of 'Novamac', 'Florina', 'Ligolina', hybrid U 1165, and 'Odra'. The freezing at -20ºC caused severe damage to ten out of the fifteen cultivars tested. The least affected shoots were 'Novamac', 'Florina', 'Lodel', hybrid U 1165, 'Odra', and 'Redkroft'. The freezing temperature of -25ºC proved to be critical for shoots of all the cultivars. At that temperature the least affected were shoots of 'Ligolina'. These results agree with the data obtained by Czynczyk et al. (2003).

The winter of 2002/2003 began early in the first ten days of December, with temperatures falling to -17ºC (10 December, 2002). The low temperatures in December and January were favourable for keeping the trees in deep winter dormancy (Fig. 1d). For that reason it was decided not to freeze shoots at the beginning of the winter. The freezing test was carried out in the middle of winter (11 February, 2003) when low temperatures were still persisting. Among the control shoots taken directly from the orchard no symptoms of frost damages were found. At -25ºC, the most severe symptoms of low frost damage were found in shoots of 'Egeria', 'Ligolina', 'Medea', and 'Freedom'. At -30ºC the most severely affected were shoots of 'Ligolina', 'Freedom', and 'Ligol', while at -35ºC – 'Medea', 'Egeria', 'Ligolina', and 'Freedom' were significantly more damaged than the standard cultivar 'Novamac' (Table 4). At -35ºC the least affected were shoots of 'Odra' and 'Redkroft'.

Table 3. Frost injury to one–year–old shoots of 15 scab-resistant apple cultivars according to survival test during winter 2001 – 2002 (5-point scale where: 1 – no injures, 3 – shoot injured, but able to regenerate, 5 – dead shoot)

Cultivar	Date and temperatures of freezing											
	17.12.2001				06.02.2002				25.03.2002			
	Non-frozen control from orchard	-20°C	-25°C	-30°C	Non-frozen control from orchard	-15°C	-20°C	-25°C	Non-frozen control from orchard	-15°C	-20°C	-25°C
'Novamac'	1.00 a	2.66 de	4.55 gh	4.05 ab	1.00 a	1.05 a	4.21 ab	4.92 a	1.00 a	1.37 a	1.82 a	4.92 c
'Freedom'	1.00 a	1.78 ab	3.74 def	4.30 a-d	1.00 a	2.38 def	4.10 ab	4.65 a	1.00 a	2.37 c-g	3.32 def	4.41 b
'Pinova'	1.00 a	1.35 a	3.67 def	5.00 e	1.00 a	2.26 def	4.17 ab	4.77 a	1.00 a	2.92 g	3.77 f	5.00 c
'Florina'	1.00 a	2.22 b-e	2.65 b	3.92 a	1.00 a	1.37 ab	4.04 ab	4.90 a	1.00 a	1.67 ab	2.09 ab	4.54 b
'Ligol'	1.00 a	2.21 b-e	4.12 fgh	5.00 e	1.00 a	2.71 ef	4.57 ab	4.90 a	1.00 a	2.29 c-f	3.82 f	5.00 c
'Lodel'	1.00 a	2.04 b-e	2.91 bc	4.07 abc	1.00 a	1.12 a	4.05 ab	4.70 a	1.00 a	2.22 cde	2.57 bc	5.00 c
'Redkroft'	1.00 a	2.16 b-e	3.27 cde	4.66 b-e	1.00 a	1.05 a	4.13 ab	4.90 a	1.00 a	2.46 d-g	2.67 bcd	5.00 c
'Sawa'	1.00 a	1.86 abc	2.09 a	4.45 a-e	1.00 a	2.09 cde	4.42 ab	5.00 a	1.00 a	2.32 c-f	3.44 ef	5.00 c
'Egeria' (I-125-D2)	1.00 a	1.67 ab	4.15 fgh	4.67 cde	1.00 a	2.85 f	4.49 ab	4.85 a	1.00 a	2.29 c-f	3.66 f	5.00 c
'Medea' (I-147-D2)	1.00 a	2.55 cde	3.11 bcd	4.32 a-d	1.00 a	1.64 bc	4.39 ab	4.82 a	1.00 a	2.85 fg	3.86 f	5.00 c
'Odra' (V-136-D2)	1.00 a	2.80 e	3.92 efg	5.00 e	1.00 a	1.26 ab	4.52 ab	4.90 a	1.00 a	1.94 bcd	2.73 b-e	5.00 c
'Ligolina' (XIX-133-D1)	1.00 a	2.09 b-e	3.19 bcd	4.62 b-e	1.00 a	1.95 cd	3.82 a	4.90 a	1.00 a	1.49 ab	3.30 def	3.85 a
'Free Redstar' (hybrid D 3)	1.00 a	1.82 abc	4.72 h	5.00 e	1.00 a	2.77 f	4.02 ab	4.70 a	1.00 a	2.34 c-g	3.23 c-f	5.00 c
'Melfree' (hybrid D 7)	1.00 a	2.01 bcd	4.74 h	4.80 de	1.00 a	1.55 abc	4.45 ab	4.90 a	1.00 a	2.77 efg	3.82 f	5.00 c
Hybrid U 1165	1.00 a	2.08 b-e	4.32 fgh	5.00 e	1.00 a	2.38 def	4.70 b	4.68 a	1.00 a	1.89 bc	2.32 ab	4.92 c

For explanation see Table 1

Table 4. Frost injury to one-year-old shoots of 15 scab-resistant apple cultivars according to survival test during the end of winter 2003 (5-point scale where: 1 – no injures, 3 – shoot injured, but able to regenerate, 5 – dead shoot)

Cultivar	Date and temperatures of freezing							
	11.02.2003				25.03.2003			
	Non-frozen control from orchard	-25°C	-30°C	-35°C	Non-frozen control from orchard	-15°C	-20°C	-25°C
'Novamac'	1.00 a	1.41 ab	3.12 ef	3.39 bcd	1.00 a	1.00 a	1.41 a	2.62 a
'Freedom'	1.00 a	2.22 fgh	3.54 fg	4.07 efg	1.00 a	1.00 a	1.95 bcd	4.37 bcd
'Pinova'	1.00 a	1.52 bc	2.49 cd	3.79 def	1.00 a	1.00 a	2.60 e	4.55 d
'Florina'	1.00 a	1.62 bcd	1.67 a	3.17 ab	1.00 a	1.00 a	2.15 cde	2.62 a
'Ligol'	1.00 a	1.72 b-e	3.39 fg	3.74 c-f	1.00 a	1.00 a	2.30 def	4.05 bcd
'Lodel'	1.00 a	1.36 ab	2.10 bc	3.64 b-f	1.00 a	1.00 a	2.75 fg	4.10 bcd
'Redkroft'	1.00 a	1.12 a	1.75 ab	2.75 a	1.00 a	1.00 a	1.40 a	4.62 d
'Sawa'	1.00 a	1.90 c-f	3.12 ef	3.97 efg	1.00 a	1.00 a	1.66 ab	4.20 bcd
'Egeria' (I-125-D2)	1.00 a	2.65 h	3.19 ef	4.17 fg	1.00 a	1.10 b	2.44 def	3.74 bc
'Medea' (I-147-D2)	1.00 a	2.22 fgh	3.14 ef	4.47 g	1.00 a	1.00 a	3.20 g	4.37 bcd
'Odra' (V-136-D2)	1.00 a	1.95 d-g	2.50 cd	2.85 a	1.00 a	1.00 a	2.17 cde	4.35 bcd
'Ligolina' (XIX-133-D1)	1.00 a	2.39 gh	3.87 g	4.15 fg	1.00 a	1.00 a	2.39 def	4.12 bcd
'Free Redstar' (hybrid D 3)	1.00 a	1.66 bcd	2.00 ab	3.82 def	1.00 a	1.00 a	2.86 f g	4.42 cd
'Melfree' (hybrid D 7)	1.00 a	1.92 c-f	3.21 ef	3.56 b-e	1.00 a	1.00 a	2.74 fg	4.02 bcd
Hybrid U 1165	1.00 a	2.14 efg	2.80 de	3.22 abc	1.00 a	1.00 a	1.75 abc	3.62 b

For explanation see Table 1

The freezing of shoots at -15ºC at the end of winter (25 March, 2003) caused no frost injuries. However, at -20ºC, shoots of 'Lodel', 'Pinova', 'Medea', 'Melfree', and 'Free Redstar' were damaged to a significantly greater extent than those of 'Novamac'. At -25ºC the most severely damaged were shoots of 'Redkroft', 'Pinova', and 'Free Redstar'. At that temperature the least affected shoots were those of the standard cultivar 'Novamac' and 'Florina'. Relatively less affected were also shoots of hybrid U 1165 and of the new cultivar 'Egeria'.

CONCLUSIONS

On the basis of the results obtained over the four-year-period the following conclusions can be drawn:

1. The results of the freezing treatments of one-year-old shoots in laboratory conditions indicate that there were considerable changes in the degree to which they were affected by low temperatures during successive winters. The degree of frost damages depended mainly on the degree of winter hardiness of the trees during the dormant period and the cultivar.

During the four successive winters shoots of 'Florina', 'Ligolina', and 'Ligol' showed on average sufficient resistance to frost, similar to that of the standard cultivar 'Novamac'. The remaining cultivars were more susceptible to low temperatures than 'Novamac'. All the cultivars had lower resistance to frost at the end of the mild winters of 2001 and 2002 in comparison with more severe winter in 2003.

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OCENA WRAŻLIWOŚCI NA NISKIE TEMPERATURY NOWYCH PARCHO-ODPORNYCH ODMIAN JABŁONI W WARUNKACH LABORATORYJNYCH

Streszczenie: Pędy jednoroczne 15 parchoodpornych odmian jabłoni rosnących na M.9 traktowano w warunkach laboratoryjnych ujemnymi temperaturami od -15^{o}C do -35^{o}C w okresie czterech kolejnych zim (1999 – 2003). W okresie zimy 1999/2000 pędy mrożono w jednym terminie, w kolejnych dwóch zimach – w trzech terminach i podczas zimy 2002/2003 – dwukrotnie. Wszystkie drzewa, z których ścinano pędy posadzone zostały wiosną 1995 roku w sadzie Doświadczalnym w Dąbrowicach. Ocenę stopnia przemarznięcia pędów jednorocznych w warunkach laboratoryjnych wykonywano metodą testu przeżyciowego. Otrzymane wyniki wykazały, że uszkodzenie pędów jednorocznych uzależnione było w głównej mierze od stopnia zahartowania drzew w okresie spoczynku zimowego i właściwości poszczególnych odmian. Pędy odmian ‘Florina’, ‘Ligolina’ i ‘Ligol’ w okresie czterech kolejnych zim wykazywały średnio dostateczną wytrzymałość na mróz zbliżoną do standardowej odmiany ‘Novamac’. Pozostałe odmiany były bardziej wrażliwe na niskie temperatury w porównaniu ze standardową odmianą ‘Novamac’. Na uwagę zasługuje dość niska wytrzymałość na mróz wszystkich odmian przy końcu lekkich zim w latach 2001 i 2002 w porównaniu z bardziej surową zimą 2003 roku.

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