PROCEEDINGS OF THE LATVIAN ACADEMY OF SCIENCES. Section B, Vol. 73 (2019), No. 3 (720), pp. 257–262.

DOI: 10.2478/prolas-2019-0041

INFLUENCE OF PLUM ROOTSTOCK ON FLOWERING INTENSITY DEPENDING ON CONCENTRATION OF DRY MATTER AND REDUCING SUGARS IN ANNUAL SHOOTS

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*The issue of the influence of rootstock on winter-hardiness of plum (*Prunus × rossica *Erem.) tree flower buds in the Baltic region is becoming important. The choice of rootstock is the main precondition for obtaining a high yielding and sustainable plum orchard. Freezing of flower buds is one of the most significant damages in winter for stone fruits. The aim of the investigation was to determine the relationship between concentration of dry matter and reducing sugars in annual shoots during winter and wintering ability of trees. The dynamics of reducing sugar concentration in one-year-old shoots during winter was investigated during two successive seasons in two locations. Orchards were planted in 2001 in Latvia and in Estonia. The well-known plum cultivar 'Kubanskaya Kometa' (*Prunus rossica *Erem.) was grafted on eight clonal rootstocks ('St. Julien A', 'Brompton', 'Ackermann', 'Pixy', GF8/1, G5/22, GF655/2, and 'Hamyra') and eight generative propagated rootstocks ('St. Julien INRA 2', 'St. Julien d'Orleans', 'St. Julien Noir', 'Brompton', 'Wangenheims Zwetsche', 'St. Julien Wädenswill', 'Myrobalan' and *Prunus cerasifera *var.* divaricate*). Shoot samples were harvested two times during winter — at the end of January and at the end of March. Dry matter concentration (mg·g^{-1}) and the concentration of reducing sugars (mg·g^{-1} DM) by Fehling's solution method was determined. Tree flowering intensity was scored using a scale from 1 to 5, where 1 = no flowers and 5 = abundant flowering. Dry matter concentration in plum shoots varied among rootstocks, years and growing location. In Pūre, Latvia, the largest differences in dry matter concentration were found for trees grafted on 'St. Julien INRA2' (in 2011–2012) and 'Brompton' cuttings (in 2012–2013) but in Polli, Estonia for trees grafted on G5/22 (in 2011–2012) and 'Myrobalan' (in 2012–2013). One of the most stable rootstock/graft combinations in the trial when GF655/2 was used as rootstock, where dry matter concentration was between 491 and 525 mg·g^{-1}, and reducing sugars between 37.5–49.2 mg·g^{-1}, and flowering intensity between 2.5 and 4.*

Key words: *'Kubanskaya Kometa',* Prunus × rossica*, rootstocks, winter-hardiness.*

INTRODUCTION

The most sensitive parts of stone fruits during winter are the flower buds. Freezing of flower buds is regarded as one of the most significant causes of damage to stone fruits in winter. It has become more important to increase winter hardiness of plum flower buds to ensure stable and high yields in changing climate conditions. One of the major factors ensuring winter hardiness is compatibility between rootstock and graft. The lack of appropriate plum rootstocks in Latvia and Estonia has caused the necessity to investigate several West European rootstocks, which are known to ensure high quality yields.

The right choice of a rootstock is a key point in establishing successful plum orchards. The compatibility between cultivar and rootstock, and good interaction between them promote yield, size and quality of fruits as well as rootstock adaptation to unfavourable conditions. These parameters need to be tested when new rootstocks are introduced in a particular area (Baciu *et al*., 2012).

The most popular rootstock for plums in Latvia and Estonia is Caucasian plum (*Prunus cerasifera* Ehrh. var. *divaricata* C. K. Schreid). It does not ensure the requirements of intensive orchards due to its excessive vigour (Grzyb *et al*., 2010; Rozpara *et al*., 2010; Markuszewski and Kopytowski, 2013) and incompatibility with some European cultivars (Lepsis *et al*., 2004). Fluctuation of dry matter concentration in trees during winter is one of the factors that characterise compatibility between rootstock and cultivar (Dekena *et al*., 2013) and scion winter cold resistance (Snyder and De Melo-Abreu, 2005). Winter hardiness is also related to the water concentration in plant shoots (Snyder and De Melo-Abreu, 2005). Differences in dry matter concentration occur in cultivars grafted on different rootstocks, as well as between rootstocks (Gaudillere *et al*., 1992). Rootstock vigour affects on the concentration of carbohydrates in the trees (Weibel *et al*., 2011). In the investigations in Pūre, it was found that fluctuation of dry matter concentration in shoots of plum cultivar 'Victoria' differed between trees grafted on different rootstocks (Dekena *et al*., 2013).

Carbohydrates produced in the leaves of trees are transferred to shoots, fruits, roots and other parts, and then utilised for growth of various organs. Any excess amount of carbohydrates is stored and used for the initial growth of shoots in the spring (Yoshioka *et al*., 1988; Weibel *et al*., 2011). Concentration of different carbohydrates in shoots plays a significant role in tree winter hardiness (Krasova *et al*., 2013). Soluble carbohydrates are protecting substances during winter. Significant increase of concentration of carbohydrates occurs with decrease of air temperature, starting already during autumn (Ashworth *et al.*, 1993). With a progressive decrease in temperature, starch is gradually converted into sugars. A higher sugar concentration promotes cell hardiness in stress conditions and influences tree cold resistance. The sugar ratio can fluctuate during winter (Morin *et al*., 2007).

The aim of the study was to determine the relationship between concentration of reducing sugars and dry matter in the annual shoots during winter and flowering intensity in spring.

MATERIALS AND METHODS

Plum (*Prunus* × *rossica* Erem.) cultivar 'Kubanskaya Kometa' is broadly grown in Latvian and Estonian orchards. Investigation on plum were conducted in the Institute of Horticulture in Pūre in Latvia and in the Polli Horticultural Research Centre in Estonia. Cultivar 'Kubanskaya Kometa' was grafted on 16 different rootstocks: eight clonal ('St. Julien A', 'Brompton', 'Ackermann', 'Pixy', GF8/1, G5/22, GF655/2, and 'Hamyra', and eight seedling rootstocks ('St. Julien INRA 2', 'St. Julien d'Orleans', 'St. Julien Noir', 'Brompton', 'Wangenheims Zwetsche', 'St. Julien Wädenswill', 'Myrobalan', and *Prunus cerasifera* var. *divaricate*). The experimental orchards were established in 2001. The trial was established in four replications randomly with three trees per plot. Plants were planted at 3 × 5 m spacing. The soil was loam, with dolomite parent rock in Pūre and sandy clay in Polli.

Concentration of dry matter and reducing sugars in shoots was determined during two winter seasons (2011–2012 and 2012–2013). Five full-length annual shoot samples per plot were randomly taken twice during winter — at the end of January and at the end of March. Samples were analysed in the laboratory of Latvia University of Life Sciences and Technologies. Shoots were weighed and dried in a ventilated drying oven at 60 °C for 72 hours until constant weight was reached. Dry matter (DM) concentration was expressed as $mg \cdot g^{-1}$ fresh weight. Reducing sugars concentration was determined by Fehling's solution method and expressed as $mg \cdot g^{-1}$ DM (Pleshkov, 1976). The intensity of tree flowering was evaluated in orchards using a 5-point scale, where 1 = no flowers and 5 = abundant flowering.

Meteorological data were obtained from meteorological stations in both locations. Patterns of air temperature fluctuations were similar in the two locations. Minimal and maximal air temperatures during the winters of 2011–2012 and 2012–2013 are shown in Figures 1 and 2.

The winter in 2011–2012 had a warm December, and was followed by a cold period at the end of January when air temperature decreased to –20 °C in both locations. February

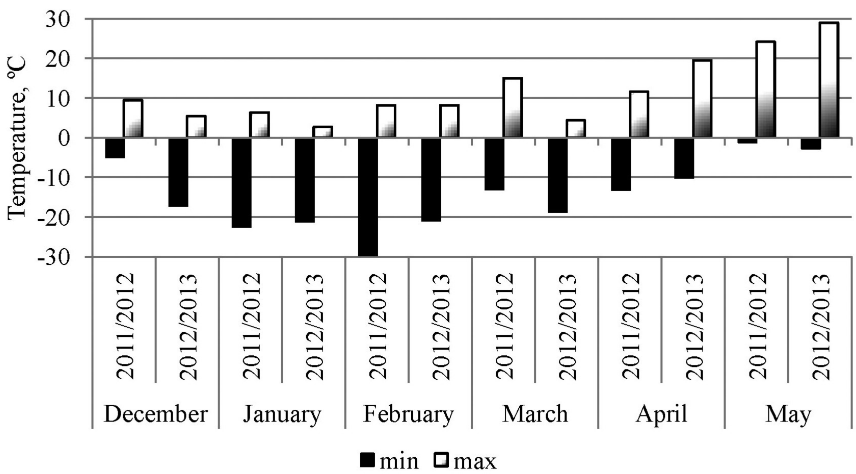

Fig. 1. Minimal and maximal air temperatures during winter of 2011–2012 and 2012–2013 in Pūre, Latvia.

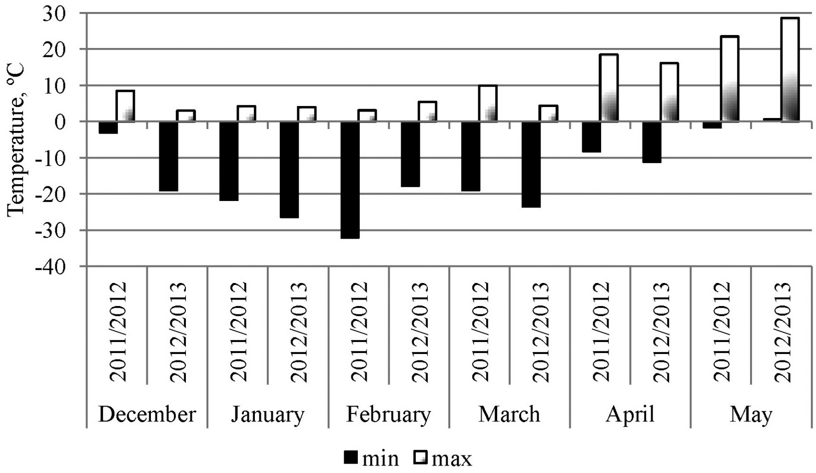

Fig. 2. Minimal and maximal air temperatures during winter of 2012–2013 and 2012–2013 in Polli, Estonia.

was cold, when in Polli temperature dropped below –30 °C. Significant fluctuation of air temperature between negative and positive values was observed in March.

The winter in 2012–2013 was cold. Minimal air temperature in December in Polli was –19.1 °C and in Pūre –17.1°C, but in January –26.4 °C and –21.1 °C, respectively. It should be noted that in Polli during March, when tree dormancy has ended, air temperature dropped below –20 °C. In the 1st decade of May, frost reaching –2.7 °C was recorded in Pūre.

Data were analysed using descriptive statistics, ANOVA and Pearson correlation. Differences between the means were tested by the least significant difference (LSD) at significance level 95%.

RESULTS

Dry matter concentration in shoots in winter 2011–2012 in Pūre was higher in January than in in March (Table 1). This means that water concentration in annual shoots was relatively low in January, which can be explained by the relatively high air temperature in December. The smallest difference between dry matter concentration in January and March in Pūre was observed for trees grafted on 'Myrobalan' (477–483 $mg{\cdot}g^{-1}$), 'Hamyra' (507–500 $mg{\cdot}g^{-1}$) and 'Brompton' cuttings (513–502 $mg{\cdot}g^{-1}$). The widest differences in dry matter concentration during winter of 2011–2012 occurred in trees grafted on 'St. Julien INRA 2' (536–500 $mg{\cdot}g^{-1}$) and G5/22 (537–505 $mg{\cdot}g^{-1}$).

Significant correlation was not observed ($r_{yx} = 0.38$, n = 16 in January and $r_{yx} = 0.46$, n = 16 in) between dry matter concentration and flowering intensity in March in Pūre for both years.

In 2012–2013, the difference in dry matter concentration in shoots between January and March in Pūre was not large (Table 2). The highest concentration of dry matter was observed in shoots from trees grafted on 'St. Julien Noir' (548–539 $mg{\cdot}g^{-1}$). In shoots from trees grafted on 'Brompton' cuttings, dry matter concentration in January was 523 $mg{\cdot}g^{-1}$, which dropped to 475 $mg{\cdot}g^{-1}$ at the end of March. This large change is difficult to explain. Flowering

Table 1

FLOWERING INTENSITY, DRY MATTER AND REDUCING SUGARS CONCENTRATION IN PLUM SHOOTS IN PŪRE, LATVIA WINTER PERIOD OF 2011–2012

Rootstocks	Parameter, $mg{\cdot}g^{-1}$				
	dry matter in January	dry matter in March	reducing sugars in January	reducing sugars in March	flowering, scores 1–5
Ackermann	520	492	40.0	37.9	2.1
St. Julien INRA2	537	500	37.2	34.7	2.8
Brompton seedlings	516	490	49.3	37.6	2.3
Myrobalan	477	483	40.8	39.4	2.2
GF 8/1	520	501	46.8	41.0	2.8
G 5/22	537	505	43.3	39.3	2.6
St. Julien d'Orleans	522	494	39.0	34.6	2.3
Brompton cuttings	514	503	43.5	40.4	2.3
St. Julien Noir	529	510	40.4	42.7	2.2
St. Julien Wädenswill	514	494	40.8	37.6	2.8
Wangenheims Zwetsche	519	485	44.3	41.6	2.5
St. Julien A	506	474	45.8	43.4	1.8
Pixy	519	498	39.6	34.5	2.4
Hamyra	507	501	46.3	37.8	2.5
P. cerasifera	532	514	35.2	37.6	2.3
GF 655/2	526	507	37.6	40.6	2.9
$LSD_{0.05}$	24.2	ns	**	2.87	ns

** the analysis was done without replications, ns, not significant

intensity on trees grafted on 'Brompton' cuttings (1.6 score) was also lower in spring of 2013 (Table 2). This winter was characterised by stable low temperature until April (Fig. 1). In general, in 2013 there were significant differences in tree flowering intensity for trees grafted on different rootstocks.

It was observed that trees grafted on different rootstocks reacted in different way to temperature fluctuations during the two winters. The highest flowering intensity was observed for trees grafted on 'Ackermann', 'St. Julien INRA 2', GF 8/1and 'Wangenheims Zwetsche'. The lowest flowering intensity and lowest dry matter concentration in March was observed for trees on 'Brompton' cuttings, 'St. Julien Noir', 'St. Julien A' and *P. cerasifera*.

Table 2

FLOWERING INTENSITY, DRY MATTER AND REDUCING SUGARS CONCENTRATION IN PLUM SHOOTS IN PŪRE, LATVIA IN WINTER OF 2012–2013

Rootstocks	Parameter, mg·g^{-1}				
	dry matter in January	dry matter in March	reducing sugars in January	reducing sugars in March	flowering, scores 1–5
Ackermann	520	515	33.1	43.7	4.5
St. Julien INRA2	507	507	40.4	43.6	4.0
Brompton seedlings	535	524	45.9	43.3	1.7
Myrobalan	497	507	45.0	43.7	2.0
GF 8/1	522	510	41.1	46.6	3.5
G 5/22	516	508	45.5	44.1	2.6
St. Julien d'Orleans	512	520	48.6	46.0	2.3
Brompton cuttings	523	475	48.7	53.8	1.6
St. Julien Noir	548	539	48.4	40.5	1.8
St. Julien Wädenswill	505	511	47.2	44.1	2.3
Wangenheims Zwetsche	515	379	47.8	43.7	2.9
St. Julien A	512	508	42.3	40.5	2.5
Pixy	516	511	48.3	44.7	2.2
Hamyra	502	496	47.3	51.4	1.7
P. cerasifera	510	507	46.1	40.7	1.8
GF 655/2	525	513	49.3	46.2	2.5
$LSD_{0.05}$	19.2	21.6	4.25	5.05	1.16

It is clear that rootstocks caused different reaction to temperature fluctuations during winter, shown by differences in DM concentration in the two years in shoots grafted on different rootstocks in Polli. Both minimal and maximal temperatures in Polli were lower than in Pūre. In the winter of 2011–2012, dry matter concentration in the annual shoots was higher in January and lower in March in shoots of trees grafted on all rootstocks, except on 'St. Julien A', where higher dry matter concentration was observed in March (Table 3). There were lower differences in dry matter concentration between January and March in winter of 2011–2012. The largest differences in dry matter concentration were observed for trees grafted on G 5/22 (536 mg·g^{-1} in January and 489 mg·g^{-1} in March). Also, the lowest flowering intensity in this year was observed for trees grafted on G 5/22.

In winter of 2012–2013 the dry matter concentration in March for the large part of rootstocks was higher than in January (Table 4) but in general it was higher than in 2011–2012. This can be explained by the reaction of trees on lower air temperature. The highest dry matter concentration was observed for trees grafted on 'St. Julien INRA 2' (520 mg·g^{-1} in January and 540 mg·g^{-1} in March) and 'Myrobalan' (587 mg·g^{-1}in January and 493 mg·g^{-1} in March).

Flowering intensity in 2013 in Polli differed between trees grafted on different rootstocks — there was no flowering for shoots grafted on 'St. Julien INRA 2'. Very low flowering intensity was observed for shoots on 'Hamyra', *P. cerasifera* and 'GF 8/1'.

Table 3

FLOWERING INTENSITY, DRY MATTER AND REDUCING SUGARS CONCENTRATION IN PLUM SHOOTS IN POLLI, ESTONIA IN WINTER OF 2011–2012

Rootstocks	Parameter, mg·g^{-1}				
	dry matter in January	dry matter in March	reducing sugars in January	reducing sugars in March	flowering , scores 1–5
Ackermann	505	483	47.4	34.1	4.3
St. Julien INRA2	506	481	44.2	31.2	2.5
Brompton seedlings	526	499	46.3	34.2	4.3
Myrobalan	506	499	44.9	33.1	3.1
GF 8/1	506	499	44.8	32.2	2.1
G 5/22	536	489	42.6	33.2	1.7
St. Julien d'Orleans	508	493	42.2	36.5	4.3
Brompton cuttings	493	485	45.3	31.6	3.8
St. Julien Noir	509	506	49.4	27.0	2.8
St. Julien Wädenswill	512	517	44.5	37.6	4.1
Wangenheims Zwetsche	506	501	41.5	37.4	2.5
St. Julien A	481	497	47.9	24.6	4.0
Pixy	517	508	47.9	35.6	4.1
Hamyra	519	502	49.7	39.6	4.0
P. cerasifera	504	502	49.4	31.2	3.8
GF 655/2	524	492	43.8	28.2	4.0
$LSD_{0.05}$	24.1	NS	NS	5.79	1.7

Table 4

FLOWERING INTENSITY, DRY MATTER AND REDUCING SUGARS CONCENTRATION IN PLUM SHOOTS IN POLLI, ESTONIA IN WINTER OF 2012–2013

Rootstocks	Parameter, mg·g^{-1}				
	dry matter in January	dry matter in March	reducing sugars in January	reducing sugars in March	flowering, scores 1–5
Ackermann	512	514	37.5	43.2	2.0
St. Julien INRA2	520	540	36.4	19.2	0.0
Brompton seedlings	551	530	31.0	50.9	2.8
Myrobalan	587	493	40.1	47.7	2.1
GF 8/1	499	521	26.6	41.6	1.1
G 5/22	521	524	25.5	44.6	3.3
St. Julien d'Orleans	512	527	42.9	44.5	2.4
Brompton cuttings	509	530	29.1	49.5	1.8
St. Julien Noir	506	529	29.6	48.6	2.0
St. Julien Wädenswill	530	520	39.8	51.6	2.1
Wangenheims Zwetsche	521	527	42.2	47.8	1.6
Pixy	519	510	28.1	30.2	3.5
Hamyra	520	517	39.9	55.5	0.5
P. cerasifera	510	518	44.7	51.1	0.5
GF 655/2	509	518	46.8	45.4	3.0
$LSD_{0.05}$	NS	NS	8.59	5.46	1.12

A significant correlation (r_{yx} = 0.18, n = 16 in January and r_{yx} = 0.28, n = 16 in March) between the amount of reducing sugars in the annual shoots and flowering intensity was not found in Pūre for trees grafted on different rootstocks

(Table 1). There was a tendency for trees that had less differences in concentration of reducing sugars between January and March to have higher flowering intensity. In the winter of 2011–2012, a stable concentration of reducing sugars and higher flowering intensity was recorded for trees grafted on 'St. Julien INRA 2', 'St. Julien Wädenswill' and GF 655/2. This can be explained by different concentration of reducing sugars in the vegetative and generative buds; as shoots with more generative buds and higher concentration of reducing sugars (Moing *et al.*, 1994) have a higher concentration of sugar. As cultivar 'Kubanskaya Kometa' develops a lot of generative buds on the annual shoots, the estimated sugar concentration in the wooden part of shoots may be over- or under-estimated by the contribution of the sugar concentration in buds growing on the shoots.

In winter of 2012–2013, the highest amount of reducing sugars in Pūre was detected in the shoots of trees grafted on 'Brompton' cuttings, which had the lowest flowering intensity (Table 4). This contradicts the previous hypothesis, but confirms that factors other the amount of reducing sugars affect the flowering intensity, e.g., rootstock/cultivar compatibility.

Higher differences in the amounts of reducing sugars were observed between January and March in Polli during both winters, which can be explained by the lower temperature during winter in Polli compared to Pūre.

One of the most stable rootstock/graft combinations in the trials was using GF655/2 as rootstock, where dry matter concentration was between 491–525 mg·g^{-1}', reducing sugar concentration was 37.5–49.2 mg·g^{-1}, and the flowering intensity score was between 2.5 and 4.

DISCUSSION

The highest dry matter concentration in Pūre was occurred at the end of January, when the air temperature had dropped to –22.5 °C. According to literature, the amount of associated water increases and free water decreases with decreasing air temperature, and more winter hardy cultivars have a higher amount of associated water and lower dry matter concentration (Galasheva and Krasova, 2013).

Evaluation of flowering intensity of 'Kubanskaya Kometa' during the spring of 2012 did not show significant differences between rootstocks, since flowering was generally low on all rootstocks (Dēķena *et al.*, 2013).

Summarising the data obtained in Pūre for both winter periods, we did not observe that a higher concentration of reducing sugars in the annual shoots during the coldest period was associated with more intense flowering. The lack of correlation between the concentration of reducing sugars and bud winter hardiness has been observed also by others, but this does not indicate that sugars concentration has no effect on the winter hardiness of buds, as it is only one of the factors influencing the tree resistance in the stress conditions (Tyurina *et al.*, 2000).

The higher concentration of reducing sugars in samples of trees grafted on the rootstocks was observed in January 2012. It decreased in March in both winters, in both locations. However, in 2013 in Polli the concentration of reducing sugars in March increased. This can be explained by the lower air temperature in the March, which promotes increase of concentration of sugars in the trees (Ashworth *et al.*, 1993; Tyurina *et al.*, 2000).

CONCLUSIONS

The differences in dry matter concentration in plum shoots varied among rootstocks, years and growing locations. In Pūre, Latvia, the largest differences in dry matter concentration were observed for trees grafted on 'St. Julien INRA2' (in 2011–2012) and 'Brompton' cuttings (in 2012–2013) but in Polli, Estonia for trees grafted on G5/22 (in 2011–2012) and 'Myrobalan' (in 2012–2013).

Rootstocks with lower variation of reducing sugars concentration during winter had a tendency for higher flowering intensity. The most stable reducing sugars concentration and the highest flowering intensity was observed for rootstocks 'St. Julien INRA 2', 'St. Julien Wädenswill' and GF 655/2.

A higher concentration of reducing sugars in annual shoots of plums during the coldest period was not significantly associated with more intense flowering.

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Received 28 January 2019
Accepted in the final form 8 April 2019

PLŪMJU POTCELMU IETEKME UZ ZIEDĒŠANAS INTENSITĀTI ATKARĪBĀ NO SAUSNAS UN REDUCĒJOŠO CUKURU SATURA VIENGADĪGOS DZINUMOS

Baltijas reģionā ir aktuāls jautājums par potcelmu ietekmi uz plūmju (*Prunus* × *rossica* Erem.) ziedpumpuru ziemcietību. Potcelmu izvēle ir svarīgs priekšnoteikums intensīvu un ražīgu plūmju dārzu izveidošanā. Ziedpumpuru izsalšana ir viens no nozīmīgākajiem kauleņkoku ziemas bojājumiem. Pētījuma mērķis bija salīdzināt sausnas un reducējošo cukuru satura izmaiņas plūmju viengadīgajos dzinumos ziemošanas periodā un to ietekmi uz ziedpumpuru ziemošanu. Reducējošo cukuru dinamika viengadīgajos dzinumos ziemošanas periodā tika pētīta divas sezonas, divās audzēšanas vietās. Izmēģinājums ierīkots 2001. gadā Latvijā un Igaunijā. Šķirne 'Kubanskaja Kometa' (*Prunus* × *rossica* Erem.) potēta uz astoņiem veģetatīvi vairotiem potcelmiem: 'St. Julien A', 'Brompton', 'Ackermann', 'Pixy',`GF8/1`, 'G5/22', 'GF655/2', 'Hamyra' un astoņiem ģeneratīvi vairotiem potcelmiem: 'St. Julien INRA2','St. Juliend`Orleans', 'St. Julien Noir', 'Brompton', 'Wangenheims Zwetsche', 'St. Julien Wädenswill', 'Myrobalan' un *Prunus cerasifera* var. *divaricata*. Paraugi ievākti divas reizes ziemas periodā — janvāra un marta beigās. Sausnas saturs noteikts mg·g^{-1}, reducējošo cukuru daudzums (mg·g^{-1}) noteikts izmantojot Fēlinga šķīdumu. Koku ziedēšanas intensitāte vērtēta ballēs (1–5), kur 1 = ziedu nav, 5 = koki zied maksimāli. Novērotas sausnas satura atšķirības starp potcelmiem, gadiem un audzēšanas vietām. Lielākās sausnas satura svārstības Pūrē bija kokiem, potētiem uz "St. Julien INRA2" (2011./2012. g. ziemošanas periodā) un 'Brompton'veģetatīvi vairotiem (2012./2013. g.), bet Polli, kokiem potētiem uz 'G5/22 (2011./2012. g.) un 'Myrobalan' (2012./2013. g.). Viena no stabilākajām potcelmu-šķirnes kombinācijām pētījumā bija koki uz potcelma 'GF655/2', kur sausnas saturs svārstījās no 491 līdz 525 mg·g^{-1} un reducējošo cukuru daudzums 37,5–49,2 mg·g^{-1}, ziedēšanas intensitāte starp 2,5 un 4.