Adaptation capabilities of apple trees in the Southern Baikal region

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Abstract. The harsh climatic conditions of Siberia, and in particular of the Southern Baikal region, make special requirements for the selection of apple varieties. These are a high frost resistance in the middle of winter, insensitivity to temperature changes at the end of winter, a short growing season and the ability to quickly hardening in autumn. The aim of the work was to study the adaptive capabilities of different apple varieties in the conditions of the Southern Baikal region. In this work was reflected the analysis of climatic conditions in the research region and conducted microclimatic zoning of the territory for gardening. To achieve this goal, the methods of field observation, artificial modeling of climatic factors and statistical analysis were used. Based on 11 features, the "model" of the variety for the area of research was substantiated. Comparison of 30 varieties of apple trees with a "model" of the variety allowed identifying varieties of interest for commercial cultivation of apple trees in the Southern Baikal region.

1. Introduction
The lack of cold endurance is the main limiting factor for the cultivation of fruit crops in many regions of the world. Damage by low temperature causes serious economic losses. Southern regions of Siberia are among the most severe climatic indicators for conducting industrial gardening. For comparison, in Canada, large losses of unstable fruit trees occur once or twice every 5 – 10 years depending on the type of fruit and the location of the gardens. Fruit tree injuries are associated with low autumn or winter temperatures that can put trees or fruit buds to death, or with late spring frosts during flowering [1, 2, 3, 4, 5]. On average, very cold winters, when the temperature in southern Finland falls below -30°C, happen once in 10 years. In these conditions, parts of woody perennials that do not have snow cover are damaged. Damage to the root system is also likely if the snow cover during severe cold periods is small [6, 7, 8, 9]. Climatic indicators of the Siberian region are more severe. Temperature -30°C and lower is the norm not only for the middle of winter. Such frosts often occur in November-December. In most years of research the snow cover settled in early December and is not always sufficient for a full plants wintering. Temperature changes in February-March, which can reach up to 25°C or more (daytime temperatures up to + 8°C, night temperatures to -30°C) are especially disastrous. Winter damaging factors are aggravated by unfavorable conditions of the growing season: short frost-free period and insufficient sum of positive temperatures, lack of a full period of quenching and a sharp transition from autumn to winter. Under these conditions, the number of crops grown is
very limited. Therefore, in addition to assessing the climatic conditions of the growing region, careful selection of varieties that are the least sensitive to the peculiarities of these conditions is necessary. The study of these factors inevitably takes a long time, but it has an important final result [10].

Apple tree is one of the few fruit trees that can be grown in Siberia for the commercial use. This is evidenced by a 150-year history of Siberian gardening and works of Siberian garden scientists. This is also due to the great species and variety diversity, high biological and ecological plasticity of apple trees. Long-term cultivation of cultivated apple (Malus domestica Borkh.) is possible only in the presence of formation of a prostrate tree culture. But even in this case the number of varieties is small. Full wintering and harvesting is possible only for apple trees of those varieties whose winter hardiness is at the level or slightly below the level of Antonovka. Other varieties die either in the first winter or within 3-4 next years [11]. Involvement of Siberian crabapple into the selection allowed Siberian gardeners to obtain a large number of varieties suitable for growing under the uneasy climatic conditions of Siberia [12]. Siberian crabapple (Malus baccata (L.) Borkh.) is also the main rootstock for Siberian apple varieties.

2. Materials and methods

2.1. Study area
Collection studies were carried out in Irkutsk on the basis of the Siberian Institute of Plant Physiology and Biochemistry of the SB RAS and in the Irkutsk district of the Irkutsk region on farms sites. The composition of collection sites included 30 varieties of apple-reennets and small-fruited semi-cultures. The number of apple trees of one variety in the collection sites varied from 2 to 4. The placement of trees in the collection sites was random.

Artificial freezing was carried out in a low-temperature Binder MKT-240 chamber of the Phytotron Experimental Station with a temperature range from -70 to + 180 °C. The time of freezing was 24 hours. The experiments were carried out in triplicate biological replication. The material for research was the annual branches of selected apple tree genotypes. The material was stored before the experiments at a temperature of -10 °C. Variety studies were carried out according to the Program and the method of selection of fruit, berry and nut-bearing crops [13]. The degree of damage to the tissues of the cut branches was determined by the baking of the tissue on longitudinal and transverse sections on a 5-point scale: 0 - no damage; 5 - the tissue died.

2.2. Siberian varieties, origin and classification
Hybrids obtained from the crossing of Siberian crabapple and domestic apple trees can be divided into three main groups: rennets, small-fruited semi-cultures, large-fruited semi-cultures.

The main Siberian centers for breeding apple trees are the Research Institute of Horticulture of Siberia (Barnaul, Gorno-Altaisk), Experimental breeding stations in Yekaterinburg, Krasnoyarsk and Buryatia, Botanical Gardens of Novosibirsk and Tomsk. Varieties were created for the specific climatic conditions of each territory. In the Siberian region, primarily in its southern parts, there is a wide diversity of climatic conditions, which necessitates zonal gardening systems, often with their targeted and even pointlike performance. Precisely the direction of gardening in Siberia can provide a real increase in the steadiness of fruiting and the economic stability of the industry [14].

In this regard, the purpose of this work was to study the adaptive opportunities of different apple varieties in the conditions of the Southern Baikal region.

2.3. Climate conditions of the research area
This research was carried out in the southern part of the Irkutsk region, which is called the Southern Baikal region. The climate of this territory is sharply continental, unstable, with significant differences in the years of research. The average minimum temperatures of the cold period (November-March) for the years of examination (2004-2016) ranged from -10°C to -26°C. On the average there were 8 days per year with a minimum air temperature -30°C and lower. The total precipitation averaged 459 mm
per year. The average decadal snow cover depth (cm), calculated from observations data on a protected area (on a fixed staff) for November-March was from 4 (November) to 29 (March) cm. Over the years of research (2004-2016), the average depth of freezing from the largest during the winter was 129 cm. The maximum value was noted in 2010 with the depth of 150 cm. The minimum value was noted in 2016 with the depth of 111 cm. The minimum soil temperature at the depth of 20 cm for winter periods of 2004-2016 was -15.2°C (December, 2014).

The duration of the growing season in Irkutsk is 116-127 days. The average sum of positive temperatures (above +10°C) over the years of research was 1984° with their minimum value of 1765° and their maximum value of 2251°. Autumn lasts about a month and is characterized by sharp daily temperature fluctuations and early frosts.

2.4. Statistical analysis
To identify varieties that are statistically different from the control sample, we used the Mann-Whitney criterion and the Wald-Wolfowitz test. Statistical data processing was carried out using the program Statistica12. In the work was used also analysis of variance.

3. Results and discussion

3.1. Microclimatic zoning
The general characteristics of the climate of the Southern Baikal region also include microclimatic zoning of the territory. We have identified five zones for horticulture.

Zone 1. Conditions unfavorable for horticulture. Lower parts of the relief, hollows that do not have air drainage.

Zone 2. Satisfactory conditions. Lowered but protected from the wind relief or areas with the mitigating effect of water bodies.

Zone 3. Good conditions. The main horticultural zone, the so-called average conditions.

Zone 4. Favorable conditions. Elevated relief forms, south-western and south-eastern slopes, most often protected by forest. Northern slopes providing air drainage can also refer to this zone.

Zone 5. Especially favorable zone. The middle part of the slopes facing south and west, where wind protection is combined with the accumulation of heat due to structures or features of the relief.

The division into zones is not geographic, since several microclimate zones can often be observed on the same territory. First of all, differences between zones are expressed in the duration of the frost-free period: the time of the end of spring frosts and the onset of autumn ones.

3.2. Phenology of apple trees in the Southern Baikal region
The cold hardiness of plants is a complex phenomenon and depends on the temperature, duration of the day and the condition of the plant, such as ripeness, water content, nutritional stage, physiological age and dormancy [15]. One of the indicators of acclimatization of species is their phenological rhythms. Plants adaptation to certain environmental conditions can be assessed by the passage of phenological phases, features and completeness of the passage of plants through the cycles of seasonal and ontogenetic development. Phenological investigations are one of the most accessible and effective methods for studying the degree of plant adaptation [16, 17, 18].

Our observations showed that the passage of the phenological phases of all apple varieties under the study from bud blossoming to fruit ripening was within the frost-free period. Leaves blossoming, depending on the year of observations and apple variety, occurred on May, 14-28. Beginning of flowering was observed in the beginning of June (June, 2-10), mass flowering was observed on June, 5-14 and by June, 14-17 flowering ended with fruit setting. In the last decade (21-30) of August, the ripening of summer apple varieties began. Before September, 10-12, late and autumn varieties finished ripening. Until September, 20-22, a harvest of late-autumn and winter apple varieties was carried out. The leaf fall stopped in late October or early November. The passage of all the phenological phases was the same for all the apple varieties. The time of buds blossoming, flowering and fruit setting
coincident both with European varieties and Siberian varieties. Differences were observed at the last stages of vegetation. Varieties originating from Malus baccata (L.) Borkh quickly passed the stage of hardening. This was well determined by the rate of shoot growth termination and the passage of leaf fall. Often the leaves did not completely fly from the Malus domestica Borkh. trees.

3.3. Study of the cold hardiness of apple trees

The increase of cold hardiness is one of the main goals in numerous apple planting projects around the world [3]. There are two ways to assess the cold resistance of a variety. One can rely on a natural selection after the most severe winter, or a field method. But this method has one significant drawback – its duration. Therefore, along with the field assessment of the resistance, it is possible to determine the cold resistance potential of apple species and varieties using the laboratory method of frost penetration by modeling the damaging factors.

13 varieties of apple trees of Buryatiya, Krasnoyarsk, Novosibirsk and folk selection which showed high winter hardiness afield were used in the research. For the contrast of the tests, a North American apple Melba and a tall Siberian crabapple (control) were taken into the research. The experiments were related to the testing of selected varieties for winter hardness components: 1 – resistance of the variety to early winter frost (-35°C); 2 – maximum frost resistance in the quenched state (-50°C); 3 – the ability to maintain high resistance to frost during the thaw period (+5°C; -25°C); 4 – the ability to restore frost resistance when re-quenched after thaws (+5°C; -25°C; -35°C) [10].

According to the test results, all studied varieties had no damage to cambium, wood and bark for 1 component of winter hardiness. Such varieties as Lada, Krasnaya Grozd’ and Melba had serious damage after -50 °C; the rest of the damage was reversible. All the studied varieties retained high frost resistance during the thaw period. During the re-quenching after thaws, significant wood damage was observed only in Melba cultivar; the other varieties showed high resistance within this component of winter hardness.

Such experiments give an estimate of the cold strength stock of a variety, but they do not give a complete picture of the resistance of the variety to a set of damaging factors of the cold season. These factors also include resistance to winter dry hot wind and sunburns. The speed of the autumn acclimation and spring deacclimation is different for different varieties; these parameters also determine the quality of apple trees wintering. The completeness of winter damage recovery is determined by the quality of the growing season after the wintering: the length of the frost-free period, the sum of positive temperatures, the amount of precipitation or watering, the level of nutrition of the fruit tree, the correctness of the sanitary procedures. The ripening period of fruits is of great importance [4]. To confirm this thesis for the conditions of the Southern Baikal region, we compared the varieties of small-fruited semi-cultured apple cultivars, which differ according to the period of fruit ripening: 4 summer varieties, 5 autumn and 3 winter ones. As a result of long-term observations of the field resistance of these varieties, it was found that the varieties of winter ripening season are worst adapted to the climate conditions of the Southern Baikal region. Their life and fruiting are limited to 7 and 4 years, respectively. Lack of time for the complete recovery after severe winters leads to the fact that cold damage accumulates and leads to the death of trees of these varieties. Frequent damage to reproductive buds reduces the yield of these varieties that makes their cultivation unprofitable.

Another factor affecting winter hardiness is the crop load. Trees that bear fruit every year are more demanding for the length of the growing season. It was noted that the lack of fruits in the previous year was important for increasing the cold endurance of apple buds [19]. High yields in unfavorable years very often led to the death of the tree in the conditions of the Southern Baikal region. Therefore, the more marked the periodicity of fruiting in a variety, the higher its winter hardness. This property is most pronounced in Malus baccata (L.) Borkh., in apple-rennets and in a part of small-fruited semi-cultured apples. But this property as well as insufficient size and mediocre fruit taste are not acceptable for the commercial use of the variety. Therefore, it is important to determine varieties that bear fruits moderately, but do it every year. And if it is impossible to combine high winter hardiness
and large-fruit in one variety, preference is given to high winter hardiness and high taste qualities of fruits.

3.4. “Model” of the variety

Choosing a variety that best suits the researcher's ideas about the ideal variety or “model” of the variety for a specific region with specific climatic conditions is the ultimate goal of any variety-study. We have developed and substantiated a “model” of the apple cultivar for the Southern Baikal region. For comparison, 30 apple varieties studied and a “model” of apple variety were described according to 11 main features: winter hardiness, reducibility, fruit year, scab sustainability, periodicity of fruiting, crop yield, fruit weight (g), fruit slough, fruits taste (score), strength of tree growth, maximum shelf life.

All information was transformed into linear combinations using the principal component method and subjected to the cluster analysis to identify varieties similar in the complex of 11 counted characteristics to the “model” of the variety. As a clustering algorithm, a hierarchical method was chosen. The varieties Ural'skoe nalinnoe, Katyusha, Rajskoe, Zhivinka were the closest to the “model” of the variety (figure 1).

Figure 1. Grouping of apple varieties according to the complex of 11 basic features.

4. Conclusion

Our studies, as well as the works of other authors, show that the study of the cold resistance of apple trees should be complex and be linked to a specific region of cultivation. Despite the instability of the climatic conditions of the Southern Baikal region, the selection of varieties and agro technical techniques makes it possible to minimize the influence of these conditions and opens the possibility of growing an apple tree in the Southern Baikal region for commercial use. Apple trees with a small fruit size are uncompetitive in the market of fresh fruit consumption, but they can be claimed as raw materials for the processing industry [16].
Acknowledgments
The research was done using equipment of The Core Facilities Centers “Bioanalytics” and “Bioresources Center” at The Siberian Institute of Plant Physiology and Biochemistry SB RAS (Irkutsk, Russia).

References
[1] Baraer M, Madramootoo C A and Mehdi B B 2010 Evaluation of winter freeze damage risk to apple trees in global warming projections Transactions of the ASABE 53(5) 1387-97
[2] Coleman W K 1992 A proposed winter-injury classification for apple trees on the northern fringe of commercial production Can. J. Plant Sci 72 507-16
[3] Khanizadeh S, Brodeur C, Granger R and Buszard D 2000 Factor associated with winter injury to apple trees Proc. XXV Int. Horticultural Congress, part 4 “Culture Techniques with Special Emphasis on Environmental Implications”
[4] Palonen P and Buszard D 1997 Current state of cold hardiness research on fruit crops Can. J. Plant Sci 77(3) 399-420
[5] Kaukoranta T, Tahvonen R and Ylämäki A 2010 Climatic potential and risks for apple growing by 2040 Agricultural and Food Science 19(2) 144-59
[6] Hiirsalmi H and Säkö J 1991 Developing cold-tolerant fruit cultivars for Finland Hortscience 26(5) 504-7
[7] Lindén L 2001 Re-analyzing historical records of winter injury in Finnish apple orchards Can. J. Plant Sci 81(3) 479-85
[8] Lindén L, Palonen P and Seppänen M 1999 Cold hardness research on agricultural and horticultural crops in Finland Agricultural and Food Science in Finland 8 459-77
[9] Khanizadeh S, Groleau Y, Granger R, Cousineau J and Rousselle G 2000 New hardy apple selections from the Quebec apple breeding program Acta Horticulturae 2 719-22
[10] Sergeyeva K A 1971 Physiological and biochemical basis of winter hardiness of woody plants (Moscow, USSR: Nauka)
[11] Rachonen M A 2015 Biological features of varieties of apple trees in the prostrate form in the Southern Baikal region Bulletin of Russian Agricultural Science 4 21-2
[12] ARC 2005 Pomology. Siberian varieties of fruit and berry crops of the 20th century (Novosibirsk, Russia: Yupiter)
[13] ARC 1999 Program and methodology for the variety research of fruit, berry and nut-bearing crops eds E Sedov and S P Ogoltsova (Orel, Russia: All-Russian Research Institute of Fruit Crops Breeding)
[14] Khabarov S N 1999 Agroecosystems of gardens in the south of Western Siberia (Novosibirsk, Russia: RASKHN)
[15] Stushnoff, C. 1972. Breeding and selection methods for cold hardiness in deciduous fruit crops. HortScience. agris.fao.org
[16] Losev A P 1979 The weather and apple harvest (Sankt-Petersburg, USSR: Gidrometeoizdat)
[17] Smirnova M Yu 1997 Cultures of some coniferous exotic plants in the experimental forestry Forest Journal 1-2 48-53
[18] Tatarintsev A S 1960 Selection and sorting of fruit and berry crops (Moscow, USSR: Sel'khozgiz)
[19] Khanizadeh S, Buszard D and Zarkadas C G 1992 Effect of crop load on hardiness, protein and amino acids content of apple flower buds at the wintering stage and the beginning of growth J. Plant Nutr 15 2441-55
[20] Gusakova G S and Rachenco M A 2016 Prospects of industrial use of winter-hardy apple varieties of the Southern Baikal region Bulletin of Russian Agricultural Science 5 52-6