sciendo

PROCEEDINGS OF THE LATVIAN ACADEMY OF SCIENCES. Section B,
Vol. 76 (2022), No. 4 (739), pp. 424–431.

DOI: 10.2478/prolas-2022-0066

Orginal Paper

CURRENT ACHIEVEMENTS OF THE LATVIAN APPLE BREEDING PROGRAMME

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*The commercial apple growing industry in Latvia has a lack of climate adapted modern cultivars. The Latvian apple breeding programme is targeted at cultivars adapted to the cool climate of Baltic countries and Scandinavia, with fruit quality and storage suitable for commercial production. Since 1989, scab resistance (*Rvi6*,* Rvi5*) donors are included in crosses. Several cultivars already show commercial promise — 'Dace', 'Gita', 'Monta' (*Rvi6*) and the polygenic resistant 'Laila' and 'Pure Ametist'. However, in 2020, the Rvi6 resistance was overcome in Latvia. Donors of polygenic scab tolerance may prove a better alternative. The most successful donors have been 'Iedzēnu', 'Eksotika', 'Alesya', and 'Bohemia'. Marker assisted gene pyramiding was started, including markers linked to the resistance genes* Rvi5 *and* Rvi6*. Scab resistant cultivars 'Edite', 'Felicita', 'Ligita', and 'Paulis' show low susceptibility to* Neonectria ditissima *canker. To achieve high fruit quality and good storage, worldwide commercial cultivars are crossed with local adapted cultivars. Such crosses that have been registered include 'Inta', 'Lora', and 'Saulesmeita'. Recent crosses for quality include 'Honeycrisp', where H-1-07-36 and H-1-07-42 show most promise. Improved biochemical content and flesh structure is one of the main targets. An additional line of breeding is aimed at ornamental and cider apples. The scab resistant Nr.19-97-154 (Cidross) was selected for cider. The red leaf columnar apple 'Karlens' and the compact red-leaf crab 'Auce' have been registered.*

Keywords: Malus domestica*, disease resistance, fruit quality.*

INTRODUCTION

Apple growing in Latvia and aims of the breeding programme. Commercial apple growing in Latvia is on the rise, but the industry has some lack of climate adapted modern cultivars. Because of the specific climate, the variety list in orchards significantly differs from those grown in Western Europe and Scandinavia (Kaufmane *et al*., 2017). Among introduced cultivars, recently only 'Ligol' has been commercially successful, but its winter-hardiness is marginal in Latvia. The climate of Latvia is characterised by an active growth period (temperatures over 10 °C) of 135–150 days and an active temperature sum of 1700–2100 °C (Kļaviņš, 2016). Winter temperatures below –30 °C repeat every 5–10 years. The average annual air temperature is 6.4 °C, in February –3.7 °C, in July 17.4 °C, and annual precipitation is 692 mm. Apple breeding in Latvia is aimed for the Northern European apple growing region with specific demands, where cultivars must be selected for their winter-hardiness and length of vegetation period. Winter and spring temperature fluctuations as well as relatively abundant precipitation increase these problems. This poses a need of breeding cultivars locally.

Controlled apple breeding in Latvia started after 1945, by breeders A. Maizītis, R. Āboliņš, and R. Dumbravs at "Iedzēni" farm. The first crosses were carried out between climate-adapted landraces and traditionally grown cultivars. Later, scab resistance donors and introduced cultivars with high quality and compact growth were involved in crosses, and breeding was continued at the Institute of Horticulture.

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The current Latvian apple breeding programme is targeted at:

– cultivars adapted to the cool climate of Baltic countries and Scandinavia;

– fruit quality and storage suitable for commercial production;

– complex disease resistance;

– improved storage and biochemical content; and

– additional — ornamental and columnar apples, cider apples.

The aim of the paper is to present a summary of recent apple breeding work at Institute of Horticulture, Latvia (LatHort).

MATERIALS AND METHODS

Apple breeding at the Institute of Horticulture is carried out along the following lines.

Careful choice of parents for crosses. Characteristics and pedigree of cultivars are analysed, along with available genetic data. One of parents must be a winter-hardy cultivar. The crosses must combine winter-hardiness, disease resistance and fruit quality. Scab resistance gene pyramiding and creation of homozygous hybrids with the dominant allele for the resistance gene *Rvi6* has started. Known donors of resistance to fire blight (*Erwinia amylovora*) and *Alternaria mali* blotch are also included in crosses, as these diseases in the nearest future may become dangerous in Latvia.

Scope of hybridisation. Annually 6–10 crosses are done, obtaining 1000–5000 seeds.

Seedling evaluation in greenhouse (1st year). Seedling evaluation includes artificial infection with a mix of scab races, evaluation of mildew (natural infection), seedling vigour and general health, and tree habit, including columnar habit. After evaluation, 10% to 60% seedlings are planted out in the field.

Molecular markers for scab resistance genes. Gene specific markers for *Rvi6* and *Rvi5* (Cheng *et al*., 1998; Vejl *et al*., 2003, respectively) are used for crosses where parents are thought to carry these genes (Zelmene *et al*., 2022). For elite hybrids and parent cultivars, molecular screening has started also for other scab resistance gene markers. It must be stressed that, as the aim was practical breeding, marker analysis is done only for selected seedlings. For this reason, the final percentage of resistant hybrids does not reflect the whole population. The only exception was open pollinated seedlings of 'Enterprise'.

Evaluation in field for 3–5 fruit yields or more. A standard 0–9 scale is used where 0 – none, 9 – maximum degree. For apple scab, the VINQUEST scale (Patocchi *et al*., 2009) is applied. Evaluation is started in the 2nd year. The evaluated characteristics are: tree health and winter damages; scab (*Venturia inaequalis*), mildew (*Podosphaera leucotricha*), canker (*Neonectria ditissima*), and leaf blotch (*Phyllosticta solitaria*) infection; tree habit and yield; time of beginning of flowering and fruit ripening, fruit appearance and taste. A longer period of evaluation is needed to estimate winter-hardiness and sensitivity to spring frosts.

Fruit quality. For selected hybrids, fruit samples are collected (15–30 fruits). Fruit appearance and flavour are evaluated by the breeder. Biochemical analyses are done on ten mature fruits for soluble solids (°Brix), total acid (%) and total phenolics content (mg·100 g^{-1}), and fruit firmness (kg·cm^{-2}). Soluble solids content is measured by a refractometer (LVS EN 12143:2001). For determination of acidity, titration with 0.1 N NaOH till pH 8.1 is used on a 20 g of fruit sample blended with 100 ml distilled water, expressing total titratable acids as malic acid equivalents (% malic acid 100 g^{-1}). Flesh firmness is determined by a structure analyser TMS-PRO, using a 10 mm diameter head with penetration depth 6 mm, speed of measuring and penetration 600 mm·min^{-1}. Total phenolic (TP) content is determined by the photometric method using Folin-Ciocalteau reagent (Singleton *et al*., 1999). The total phenol content is expressed as gallic acid equivalents (mg GAE·100 g^{-1} FW).

Storage is evaluated at 3 °C (months), checking fruit damages every two weeks from September to April.

Evaluation of elite seedlings. The best seedlings are selected as elites and propagated on dwarfing rootstocks B.9 or B.396, and 6–9 trees are planted in a randomised trial, using a commercial cultivar as a control. Additional to the above described characteristics, productivity (kg per tree), average fruit mass (g) and % of non-standard fruits are determined. Eating quality is evaluated by a 10-person non-professional taste panel, and includes fruit appearance, flavour, sweetness, acidity, aroma, firmness, crispness and juiciness. By agreement with growers, observations at farms are performed for variety candidates, including 3–5 trees. After at least 4–5 fruit yields, the best variety candidates are handed in for cultivar registration.

RESULTS

Breeding for scab resistance. Breeding for *Rvi6* (Vf) resistance. Since 1989, *Rvi6* scab resistance donors have been included in crosses. Several resistant cultivars registered since 2009 are gaining commercial success in Latvia — 'Dace', 'Gita', and 'Monta'. In 1999, a first scab outbreak was observed on the resistant cultivar 'Freedom' at the Institute of Horticulture (LatHort) (Fig. 1), but it did not spread further to other resistant cultivars and was not observed in the following years there. Yet, in 2020 there was no doubt that the *Rvi6* scab resistance has been overcome in Latvia for the cultivars 'Dace', 'Gita', and in 2021 also 'Monta'. Cultivar 'Edite' at present shows a defence reaction — chlorotic and necrotic spots; it may possess other resistance genes (communications by Olga Sokolova). The



Fig. 1. Apple scab (*Venturia inaequalis*) infection on scab resistant cultivar 'Freedom' at Dobele, Latvia, 1999.

scab infection so far is limited to four farms, but they are located in different regions of the country.

Breeding for polygenic scab resistance. Donors of polygenic scab tolerance have been included in the Latvian breeding programme from the beginning.

The most resultative donors with polygenic resistance in Latvia have been:

'Iedzēnu' (Sīpoliņš × Adamsapfel; Latvia) — donor of scab and canker tolerance, late ripening; fruits large and firm, but susceptible to bitter pit, and tree training is difficult. Used in 20 crosses until 1994 by R. Āboliņš, A. Maizītis, and R. Dumbravs at "Iedzēni" farm. It is a parent of the cultivars 'Monta' (*Rvi6*), 'Daina', 'Laila', 'Eksotika', 'Pure Ametist' and others, and 2nd generation parent of scab resistant (*Rvi6*) 'Dace', 'Roberts', 'Edite', and 'Paulis'. These cultivars and several 2nd generation hybrids have been recently used in further crosses.

'Alesya' (Belorusskoe Malinovoe /Antonovka × Lawfam/ × Bananovoe /Babushkino × Winter Banana/; Belarus) — donor of scab and canker tolerance, winter-hardiness; fruits have very attractive shape and colour, but not always good flavour. About 30% of hybrids in all crosses are scab tolerant, with damage in the field not exceeding 2 points (Table 1). The highest amount of such tolerant seedlings was found in a cross with HL-141 (Starkrimson × James Grieve) from Czehia, Holovousy.

'Eksotika' (Iedzēnu × Slava Peremozhtsam /White Transparent × McIntosh/; Latvia) — donor of scab and canker tolerance, intense fruit over-colour. It is a parent of the scab resistant (*Rvi6*) cultivars 'Dace' and 'Roberts'.

'Bohemia' (clone of 'Rubin'; Czechia) — also a donor of quality; tree training is difficult, and winter hardiness in Latvia is mediocre. The cross 'Eksotika' × 'Bohemia' has given five variety candidates.

Using *Rvi5* (Vm) donors in breeding. *Rvi5* scab resistance donors have been included in crosses since 1991.

The first *Rvi5* donor used in our breeding programme was:

SR 0523 (cross of *M. x atrosanguinea* 804, Red Melba, Wolf River; Sweden) — also donor of fruit colour, uniformity and shape; fruits have short storage. Crosses of this hybrid were made in 1991 by R. Dumbravs, and have given the variety candidate H-1-92-59 'Valentino' (scab tolerant, but without *Rvi5*) and breeding donor D-1-92-32.

The following *Rvi5* donors were used for gene pyramiding in crosses with *Rvi6* donors:

'Pervinka' (Antonovka Krasnobochka × SR0523; Russia) — also donor of compact growth and productivity, fruit uniformity; fruits are flat and mature early.

D-1-92-32 (SR0523 × /Lobo × 'Iedzēnu/; Latvia) — also donor of compact growth, productivity, flavour, colour, and uniformity; fruits are subject to storage scald.

Resistance gene pyramiding. Marker assisted gene pyramiding was started in 2009 (Table 2), including cultivars and hybrids 'Pervinka' (Russia), D-1-92-32 (Latvia) thought to carry the *Rvi5* resistance, 'Enterprise', 'Dayton', 'Scarlett O'Hara' and Latvian cultivars 'Dace', 'Ligita', 'Edite' car-

Table 1. Crosses with cultivar 'Alesya'

Cross combination	Seedlings in green-house, number	Planted out, number	Planted out, %	Field tolerant to scab, %	Variety candidates, number
Alesya × D-1-92-32 *Rvi5*	393	39	9.9	30.8	1
Alesya × Daina	152	68	44.7	26.5	2
HL-141 × Alesya	563	192	34.1	37.0	2
Alesya × Honeycrisp	140	120	85.7	33.3	3

Table 2. Crosses combining scab resistance genes *Rvi6* and *Rvi5*

Cross combination	Seedlings in green-house, number	Planted out, %	Evaluated with markers, number	*Rvi5* + *Rvi6*, %	*Rvi5*, %	*Rvi6*, %	Variety candidates, number
Dayton *Rvi6* × Pervinka *Rvi5*	550	31.0	137	15.3	40.1	19.7	2
Scarlett O`Hara *Rvi6* × D-1-92-32 *Rvi5*	850	23.4	85	43.5	32.9	14.1	4
Pervinka *Rvi5* × William's Pride *Rvi6*	184	26.6	49	12.2	18.4	12.2	1

Table 3. Crosses for obtaining homozygous *Rvi6* scab resistance (both parents are *Rvi6* resistant)

Cross combination	Seedlings in greenhouse, number	Planted out in field, %	Evaluated with markers, number	*Rvi6/Rvi6* homozygous, %	*Rvi6Rvi6* heterozygous,%	Variety candidates, number
Enterprise open pollination	163	39.3	162*	18.5	33.3	1 (*Rvi6*)
Kandil Orlovsky × Florina	516	43.4	117**	23.1	55.6	1 (*Rvi6*)
Kurnakovskoe × Rewena	961	33.9	131**	55.0	24.4	1 (*Rvi6*)

*Marker analysis done for all seedlings

**Marker analysis done only for selected seedlings

rying *Rvi6*. Three progenies were analysed with SSR markers at the institute (Zelmene *et al*., 2022). Other scab resistance genes found in these combinations were *Rvi11*, *Rvi12*, and *Rvi15* (Lejniece, 2018). Search for other resistance scab genes has recently started in other cross combinations and in the genetic resources (GR) collection of the Institute.

Some hybrids from the cross 'Scarlett O'Hara' × D-1-92-32 already show promise: **VM-2-85** (*Rvi5*) — late, firm, and very juicy; **VM-2-93** (*Rvi6*) — very late, sweet, crisp, and aromatic; **VM-2-111** (*Rvi5Rvi6*) — midseason and very sweet; **VM-2-148** (*Rvi5Rvi6*) — late, tree and fruits resemble 'Ligol'. Most hybrids in this combination have bright red colour and uniform fruits.

Creating homozygous *Rvi6* donors. In 2008, open pollinated seedlings of 'Enterprise' were obtained, for which screening with molecular markers showed presence of homozygous *Rvi6/Rvi6* seedlings (Table 3).

In 2009, eight cross combinations were performed between two parents carrying the dominant *Rvi6* allele, with the aim to obtain *Rvi6/Rvi6* homozygous seedlings, giving 100% resistant progeny in the next cross generation. The two largest populations from 2009 also were analysed with molecular markers — 'Kandil Orlovsky' × 'Florina' and 'Kurnakovskoe' × 'Rewena' (Lejniece, 2018), and homozygous seedlings were detected. However, these cross combinations produced very few elite hybrids, and their homozygous progeny could be used only as donors. Especially cultivar 'Kurnakovskoe', which was chosen for its high winter-hardiness, produced mostly seedlings with low-quality fruits, often astringent.

All crosses with the cultivar 'William's Pride', crosses 'Edite' × 'Reanda' and 'Florina' × 'Kurnakovskoe', as well as reciprocal crosses of cultivars 'Enterprise' and 'Dace' produced too few seedlings for statistical analysis. However, the reciprocal crosses of 'Enterprise' and 'Dace' gave two variety candidates.

Canker tolerance. Canker (*Neonectria ditissima)* tolerance is another acute problem in Latvia. However, so far only long-term field trials in affected areas can show reliable results, as the climate here facilitates bark micro-cracking and winter injury increases the damage for some cultivars, while other cultivars are more resistant to temperature fluctuations. The damage may start in the tree nursery and accumulates during years.

Table 4. Tree health and canker damages of new Latvian apple cultivars at two locations (5-year average, points 0–9)

Cultivar	Tree health, Dobele	Tree health, Pūre	Canker injury, Dobele	Canker injury, Pūre
Dace *(Rvi6)*	8.4	2.3*	0.08	2.83
Edite *(Rvi6)*	8.8	6.8	0	1.18
Felicita *(Rvi6)*	8.3	7.0	0	0
Gita *(Rvi6)*	9.0	7.0	0.07	0.33
Inta	8.4	8.5	0.40	0
Laila	9.0	8.2	0	0.26
Ligita *(Rvi6)*	8.4	7.9	0	0.04
Lora	9.0	6.9	0	0
Monta *(Rvi6)*	8.1	7.8	0.10	0.06
Paulis *(Rvi6)*	8.8	7.4	0	0
Pure Ametist	8.7	8.1	0	0
Saulesmeita	8.6	7.0	0	0
Ligol (control)	8.4	3.4	0.7	1.60

Canker damage was observed in the field at two locations — Dobele (more continental) and Pūre (more maritime). No damage at those locations was observed for 'Lora', 'Pure Ametist', and 'Saulesmeita' (Table 4). Among the scab resistant cultivars, 'Felicita', 'Ligita', and 'Paulis' so far have shown no or low susceptibility to *Neonectria ditissima* canker. 'Edite' had no damage at Dobele, but significant damage at another location Pūre because of winter injury (lower winter-hardiness). The most canker-susceptible cultivar in the maritime climate was 'Dace'.

Breeding for quality. In Latvia, the market has some lack of firm, tasty long-storage apples that easy to grow. For fruit quality and extended storage, worldwide known commercial cultivars are crossed with local adapted cultivars. Most of these cultivars are seriously lacking winter-hardiness and disease resistance, and there is a danger of losing genetic diversity. However, their involvement so far has been the only way to drastically improve quality. Registered cultivars from such crosses are 'Inta', 'Lora', and 'Saulesmeita'.

Recent crosses for quality include 'Honeycrisp'. From these crosses, several hybrids already show promise (Table 5). Cultivar 'Bohemia' also has proved itself as a quality donor in crosses with 'Eksotika'.

Improved biochemical content and flesh structure is one of the main breeding targets. It includes: °Brix > 13 (desir-

Table 5. Crosses of cultivar 'Honeycrisp'

Cross combination	Seedlings in green-house, number	Planted out in field, number	Planted out in field, %	Resistant to scab (*Rvi6*), %	Field tolerant to scab, %	Variety candidates, number
Alesya × Honeycrisp	140	120	85.7	-	33.3	3
Edite × Honeycrisp	148	96	64.9	29.2	11.5	1
Ligita × Honeycrisp	384	248	64.6	21.0	10.8	4
(Alkmene × Bogatyr) × Honeycrisp	113	70	61.9	-	30.0	0

ably > 15), balanced sugar-acid content, increased polyphenol content (100 to 180 mg·100 g^{-1} for dessert apples), firmness 5 kg·cm^{-2} (desirably 7–8), crispness and juiciness.

Among the registered cultivars, 'Monta' and 'Felicita' have the best set of quality characteristics. Among variety candidates, H-3-07-164 (Ligita × Honeycrisp) with 'Golden Delicious' type fruits, shows very good quality — firmness 8.2 kg cm^{-2}, 16.1°Brix, acids 0.8%, and polyphenols 174.8 mg·100 g^{-1}.

Hybrids are selected also for their suitability for juice and cider production (Krasnova *et al*., 2013). Their suitability is tested in cooperation with Latvian cider and wine makers. The best large-fruited hybrids in this group are DI-93-4-14 or 'Dobeles Sidrābols' (Liberty × /Iedzēnu × Starkrimson/) – 12.8–13.8 °Brix, acids 1.1%, and polyphenols 175.1 mg·100 g^{-1}, and Nr. 19-97-154 'Cidross' (Remo o.p.) — 16.1°Brix, acids 1.2% and polyphenols 439.7 mg·100 g^{-1}, among redleaf crabapple hybrids, the cross 'Top Millionaire' × D-1-94-2 (Arbat × Forele) gave most elites: 'Dūdars' (*Co*) — 18.4 °Brix, acids 1.3%, and polyphenols 184.5 mg·100 g^{-1}; 'Rūdis' —17.9 °Brix, acids 1.5% and polyphenols 222.6 mg·100 g^{-1}; 'Sliņķis' (*Co*) — 17.9 °Brix, acids 0.34% and polyphenols 141.9 mg·100 g^{-1}; and hybrid H-17-05-1 — 18.3 °Brix, acids 0.4% and polyphenols 56.4 mg·100 g^{-1}.

Commercially promising cultivars. Several cultivars registered since 2009 already show commercial promise. However, their *Rvi6* scab resistance has been lost at some locations in Latvia:

'**Dace'** *Rvi6* (BM41497 × Eksotika) — midseason, holds very well on tree, storage 3–4 months. Large pink fruits with very good flavour. Early annual yields, easy tree training, and no need of fruit thinning. Rated as the best at farms, but more suitable for integrated growing than organic orchards, as often damaged by codling moth and fruit rot, and may suffer from mildew. In climate with fluctuating winter temperatures, it is susceptible to canker.

'Gita' *Rvi6* (Liberty × Melba) — midseason, storage 2–3 months. Large bicolour fruits with good to very good flavour. Vigorous tree, early and high annual yields, little need of fruit thinning. May need two pickings. Best results were obtained in southern Latvia. Suitable both for integrated and organic crop production.

'Monta' *Rvi6* (Iedzēnu × Liberty) — late ripening, very good storage. Bright red, medium size, firm fruits with good flavour. High total polyphenols — 170 mg·100 g^{-1}. Vigorous tree with some tendency to bare wood, production is good, and tends to become biennial. Winter-hardiness medium, best results in warmer areas. Suitable both for integrated and organic crop production.

Less planted, but promising are cultivars with polygenic scab tolerance (Pure HRC), which are suitable for integrated production:

'Laila' (Lawfam × Iedzēnu) — late ripening, storage 4–5 months. Dark red, uniform fruits with good to very good flavour. Easy tree training, with medium, but annual yields, little need for fruit thinning. Tolerant to diseases.

'Pure Ametist' (Iedzēnu × Idared) — late ripening, storage 5–6 months. Firm (7–8 kg cm^{-2}) fruits with pink overcolour, good original flavour. Easy tree training, with medium, but annual yields, little need for fruit thinning. Tolerant to scab and canker.

Newest cultivars (2018–2020) for commercial use are:

'Felicita' *Rvi6* (BM41497 × Forele) — midseason to late, storage 4–6 months. Fruits medium size, with dark red overcolour, smooth, flavour good to very good, and harmonic. High sugar content (to 16.8 °Brix) is balanced by acids to 1.56% (sugar-acid proportion 10.8). Tree very productive, with high winter-hardiness, tolerant to canker. Fruits harvested too late may suffer from lenticel spot. Suitable for cooler regions. Promising for organic growing.

'Inta' (Yellowspur open pollination (o.p.)) — midseason, storage three months or longer. Medium to large fruits, bright red overcolour, flavour very good with dominance of sweetness, flesh crisp, juicy. Rather high total polyphenol content — 93 to 141 mg·100 g^{-1}. Tree productive, easy to train. Relatively good tolerance to diseases. Fruits hold well on tree and have a long harvest window. Promising for integrated crop production.

'Lora' (Lodel × Rubin Kazakh cv.) — harvest medium to late, storage six months or longer. Fruits medium size, bright red, uniform, flavour good to very good. Total polyphenols 117.7 mg·100 g^{-1}. Tree compact, highly productive. Scab tolerance high, but canker possible in some areas. Some drawback is a tendency to overbearing. Promising for integrated and organic crop production.

Newest cultivars for home gardens (2018)

'Paulis' *Rvi6* (Arona × Liberty) — midseason, dark red, sweet smallish fruits; high disease resistance (scab, mildew, canker), compact tree, and annual yields.

'Lienite' *Rvi6* (Remo o.p.) — early, excellent taste, pink striped smallish fruits; and small tree.

'Saulesmeita' (Redchief o.p.) — early, very large and tasty yellow fruits; very productive, and medium scab tolerant.

Redleaf crabs (2018–2020)

'Auce' (Top Millionaire × D-1-92-2) — compact crab, highly productive, ornamental and for processing. Good disease tolerance. Fruits dark red, 40–45 g, contain 15.2 °Brix, 1.04% acids, and 78.5 mg·100 g^{-1} polyphenols. Juice has very attractive colour and good flavour.

'Karlens' *Co* (Top Millionaire x D-1-92-2) — columnar crab, tree without branches. Flowering late, flowers large and purple. Good disease tolerance. Ornamental use only.

Best variety candidates

D-1-92-59 'Valentino' (SR0523 × /Lobo × Iedzēnu/) — late ripening, storage 5–6 months. Fruits medium to large, smooth, uniform, bright red on yellow, excellent eating quality and good shelf life. Contains 140.8 mg·100 g^{-1} polyphenols. Tree easy to train, medium to good production, tolerant to diseases. May be sold for Valentine's day.

H-1-07-36 'Inara' (Alesya × Honeycrisp) — medium to late, fruits bright red on yellow, subacid, crisp, and aromatic. Tree easy to train, productive, and tolerant to scab.

H-1-07-42 (Alesya × Honeycrisp) — medium to late, fruits uniform, bright red on yellow, subacid, very aromatic and juicy. Tree easy to train and productive. High tolerance to scab.

H-15-05-61 (Eksotika × Bohemia) — late ripening, fruits large, firm, dark red with conspicuous dots, excellent eating quality. Tree vigorous, medium productive, and disease tolerant.

H-12-05-14 'Asnate' (Ciepa × Greensleeves) *Co* — midseason, fruits large, bright red striped, and very good flavour. The columnar, vigorous, productive, disease tolerant and winter-hardy. Beautiful in flower.

Co-4-24 'Dina' *Rvi6* (/Arbat × Forele/ × Inese) *Co* — medium to late ripening, fruits bright red, sweet and juicy, contains 16.7 °Brix, 149.7 mg·100 g^{-1} polyphenols. Tree columnar, early and good annual yields, and disease tolerant.

Nr. 19-97-154 'Cidross' *Rvi6* (Remo o.p.) — late ripening, good storage, quality approved by wine makers. Fruits contain 16.1 °Brix, 1.2%, 439.7 mg·100 g^{-1} polyphenols. Tree easy to train, early and high yields, and tends to become biennial.

Variety candidates 'Valentino', 'Inara', H-1-07-42 and H-15-05-61 have perspective for integrated fruit production, 'Asnate' and 'Dina' for home gardens, 'Cidross' for organic juice and cider production.

DISCUSSION

Breeding for *Rvi6* scab resistance in Latvia has been successful. Several resistant cultivars are gaining commercial success in the country. 'Dace' has shown good results in trials also in Estonia, and 'Gita' in Russia (Univer and Univer, 2015; Krasova *et al*., 2020). However, *Rvi6* resistance recently has been overcome in Latvia, as it has been already observed in many countries (Patocchi *et al*., 2020). Donors of polygenic scab tolerance, may prove a more sustainable alternative. Some old cultivars have shown good scab tolerance determined by other genes, for example, 'Discovery', which is used in hybridisation also at LatHort (Höfer *et al*., 2021). In our breeding programme, cultivars 'Iedzēnu', 'Alesya', 'Eksotika', and 'Bohemia' also have produced many scab tolerant seedlings. Recent findings in other countries suggest that *Rvi5* may give more stable resistance (Patocchi *et al*., 2020), especially in combination with other known resistance genes or polygenic scab tolerance, like in cultivars from crosses with 'Antonovka' and its clone 'Antonovka Krasnobochka' (syn. 'Antonovka Kamenichka') obtained in Russia (Sedov *et al*., 1989; Sedov, 2014). Resistance gene pyramiding is considered the most promising solution by most breeders. Crosses combining *Rvi6* and *Rvi5* resistance genes have already produced good results at LatHort, but more genes should be involved. No scab races so far have overcome *Rvi11* and *Rvi15*, which gives a possibility to obtain more durable resistance than with *Rvi6* alone (Patocchi *et al*., 2020).

Breeding for complex resistance must consider also other apple diseases. Fire blight (*Erwinia amylovora*) is becoming an acute problem in Latvia. Although quarantine regulations limit research of this disease in Latvia, potentially resistant cultivars were included in crosses. The scab resistant 'Enterprise' is considered also as donor of fire blight resistance (Van de Weg *et al*., 2018), 'Dayton' — a donor of *Alternaria* blotch resistance (Li *et al*., 2019). Other fire blight resistance sources included in our breeding programme were *Rvi6* resistant cultivars 'Rewena' and 'Remo' (Sansavini *et al*., 2004). The latter has given a number of promising seedlings, suitable not only for juice (as 'Remo'), but also for dessert use.

Hybridisation for homozygous *Rvi6/Rvi6* resistance produced progeny useful only as donors. In each cross, cultivar with high winter-hardiness was used as one parent, which could have a negative influence on fruit quality, especially with cultivar 'Kurnakovskoe', which includes small-fruited cultivars and seedlings in its origin: 814 (F4 *M. floribunda*) × PA 29-1-1-63 (Yantar × /Samotsvet + Komunarka/) (Sedov *et al*., 1989).

Breeding for *Neonectria* canker tolerance demands long-term research in each specific climate. There is no single gene responsible for canker resistance; it may depend on location and individual phenology of genotypes (Weber and Børve, 2021). So far results in different locations of Latvia and other countries have been contradictory. Observations in Belgium (Ardennes) have showed canker tolerance for 'Edite' and 'Ligita', in Netherlands (Randwijk) — 'Felicita' (communications from testing institutions). Cultivar 'Lora' was very susceptible at Randwijk, while no canker injury was observed in Latvia.

More than a decade has passed since Sansavini *et al*. (2004) made their summary about apple breeding for quality, yet the main targets remain the same — to create an apple meeting the demands of both the consumer and market, attractive, tasty, juicy, and crisp, with good storage potential, and also taking in account regional differences of consumer acceptance. Use of 'Honeycrisp' as a breeding parent has produced the best results. This cultivar not only has very crisp fruits, but also possesses high winter-hardiness possibly inherited from 'Borovinka' (syn. 'Duchess of Oldenburg'), which appears in its corrected pedigree (Howard *et al*., 2017). However, there is a risk of gene erosion in future, as many breeding programmes worldwide at present use this cultivar. This makes necessary the involvement of other, less used sources of fruit quality, found in genetic resources collections.

ACKNOWLEDGEMENTS

The research was supported by the Ministry of Agriculture, project No. 10 9.1-11/21/1225-e, "Evaluation of fruit crop breeding material for introduction of integrated and organic crop production technologies".

REFERENCES

Cheng, F. S., Weeden, N. F., Brown, S. K., Aldwinckle, H. S., Gardiner, S. E., Bus, W. G. (1998). Development of a DNA marker for *Vm*, a gene conferring resistance to apple scab. *Genome*, **41** (2), 208–214. https://doi.org/10.1139/g98-020

Höfer, M., Flachowsky, H., Schröpfer, S., Peil, A. (2021). Evaluation of scab and mildew resistance in the gene bank collection of apples in Dresden-Pillnitz. *Plants,* **10**, 1227. https://doi.org/10.3390/plants10061227

Howard, N. P., Weg, E. van de, Bedford, D. S., Peace, C. P, Vanderzande, S., Clark, M. D., Teh, S. L., Cai, L., Luby, J. J. (2017). Elucidation of the 'Honeycrisp' pedigree through haplotype analysis with a multi-family integrated SNP linkage map and a large apple (*Malus* × *domestica*) pedigree-connected SNP data set. *Horticult. Res.,* **4**, 17003. DOI: 10.1038/hortres.2017.3

Kaufmane, E., Skrīvele, M., Ikase, L. (2017). Fruit growing in Latvia — industry and science. *Proc. Latvian Acad. Sci., Section B*, **71** (3), 237–247.

Kļaviņš, M. (2016). *Klimats un ilgtspējīga attīstība* [Climate and Sustainable Development]. LU akadēmiskais apgāds, Rīga. 383 pp. (in Latvian).

Krasnova, I., Segliņa, D., Ikase, L., Gornas, P. (2013). Sidra ražošanai piemērotu šķirņu ābolu ķīmiskā sastāva izvērtējums [Biochemical evaluation of apple cultivars suitable for cider production]. *Vietējo resursu (zemes dzīļu, meža, pārtikas un transporta) ilgtspējīga izmantošana – jauni produkti un tehnoloģijas (NatRes). VPP 2010-2013: Rakstu krājums* [Sustainable Use of Local Resources (Depths of Earth, Forest, Food, and Transport) – New Products and Technologies (NatRes). VPP 2010-2013: Collection of articles]. Latvijas Valsts koksnes ķīmijas institūts, Rīga, 212.–216. lpp. (in Latvian).

Krasova, N., Ikase, L., Dēķena, Dz. (2020). Evaluation of the main biological and production traits of Latvian apple cultivars in the conditions of Central Russia. *Agron. Res.,* **18** (S4), 2727–2742. https://doi.org/10.15159/AR.20.222

Lejniece, K. K. (2018). Ābeļu (*Malus* × *domestica* (L.) Borkh.) izturības pret kraupi (*Venturia inaequalis* (Cooke) Wint.) iedzimtība hibrīdajā selekcijas materiālā, veicot gēnu piramidēšanu [Heredity of apple resistance to scab in hybrid breeding material, using gene pyramiding]. University of Latvia, Master Thesis. 74 pp. https://dspace.lu.lv/dspace/handle/7/39631 (accessed 20.08.2022) (in Latvian).

Li, Y., Hu, X.-L., Trigiano R. N., Aldwinckle, H., Cheng, Z.-M. (2019). Evaluation of 110 apple cultivars for resistance to alternaria blotch caused by *Alternaria alternata* apple pathotype. *HortScience,* **54** (8), 1268–1274. https://doi.org/10.21273/HORTSCI13841-18

Patocchi, A., Frei, A., Frey, J. E., Kellerhals, M. (2009). Towards improvement of marker assisted selection of apple scab resistant cultivars: *Venturia inaequalis* virulence surveys and standardization of molecular marker alleles associated with resistance genes. *Mol. Breed.,* **24,** 337. https://doi.org/10.1007/s11032-009-9295-6

Patocchi, A., Wehrli, A., Dubuis, P. H., Auwerkerken, A., Leida, C., Cipriani, G., Passey, T., Staples, M., Didelot, F., Philion, V., *et al.* (2020). Ten years of VINQUEST: first insight for breeding new apple cultivars with durable apple scab resistance**.** *Plant Disease,* **104**, 2074–2081. https://doi.org/10.1094/PDIS-11-19-2473-SR

Sansavini, S., Donati, F., Costa, F., Tartarini, S. (2004). Advances in apple breeding for enhanced fruit quality and resistance to biotic stresses: New varieties for the European market. *J. Fruit Ornam. Plant Res.,* **12**, 13–52.

Sedov, E. N., Zhdanov, V. V., Sedova, Z. A., Sedisheva, G. A., Serova, Z. M., Trunova, V. A., Krasova, N. G. (1989). *Apple Breeding.* [Седов, Е. Н., Жданов, В. В., Седова, З. А., Седышева, Г. А., Серова, З. М., Трунова, В. А., Красова, Н. Г. *Селекция яблони*]. Agropromizdat, Moscow. 256 pp. (in Russian).

Sedov, E. N. (2014). Apple breeding programs and methods, their development and improvement. *Russ. J. Genet. Appl. Res.,* **4,** 43–51. https://doi.org/10.1134/S2079059714010092

Singleton, V. L., Orthofer, R., Lamuela-Raventos, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin–Ciocalteu reagent. Packer, L. (Ed.). In: *Methods in Enzymology. Oxidant and Antioxidant (Part A).* Vol. 299. Academic Press, San Diego, CA, pp.152–178.

Univer, T., Univer, N. (2015). The results of comparison trial of apple scab resistant cultivars in Estonia. Nordic view to sustainable rural development. In: *Proceedings of the 25th NJF Congress,* 16-18 June 2015, Rīga, Latvia. Rīga, pp.70–74.

Van de Weg, E., Di Guardo, M., Jänsch, M., Socquet-Juglard, D., Costa, F., I., Broggini, G. A. L., Kellerhals, M., Troggio, M., Laurens, F., Charles-Eric Durel, C.-E., Patocchi, A. (2018). Epistatic fire blight resistance QTL alleles in the apple cultivar 'Enterprise' and selection X-6398 discovered and characterized through pedigree-informed analysis. *Mol. Breeding,* **38,** 5. https://doi.org/10.1007/s11032-017-0755-0

Vejl, P., Skupinovį, S., Blažek, J., Sedlįk, P., Bardovį, M., Drahošovį, H., Milec Z. (2003). PCR markers of apple resistance to scab (*Venturia inaequalis* CKE.) controlled by *Vf* gene in Czech apple breeding. *Plant Soil Environ*., **49** (9), 427–432.

Weber, R. W. S., Børve, J. (2021). Infection biology as the basis of integrated control of apple canker (*Neonectria ditissima*) in Northern Europe. *CABI Agric. Biosci.,* **2,** 5–16. https://doi.org/10.1186/s43170-021-00024-z

Zelmene, K., Karklina, K., Ikase, L., Lacis, G. (2022). Inheritance of apple (Malus × domestica (L.) Borkh) resistance against apple scab (Venturia inaequalis (Cooke) Wint.) in hybrid breeding material obtained by gene pyramiding. *Horticulturae*, **8**, 772. https://doi.org/10.3390/horticulturae8090772

Received 24 August 2021
Accepted in the final form 14 July 2022

JAUNĀKIE SASNIEGUMI LATVIJAS ĀBEĻU SELEKCIJAS PROGRAMMĀ

Komerciālai ābeļu audzēšanai Latvijā trūkst klimatam piemērotu, modernu šķirņu. Latvijas ābeļu selekcijas programmas mērķis ir iegūt šķirnes, kas adaptētas vēsajam Baltijas un Skandināvijas valstu klimatam, ar komerciālai audzēšanai piemērotu augļu kvalitāti un uzglabāšanas spējām. Kopš 1989. gada krustojumos iekļauti kraupja rezistences (*Rvi6, Rvi5*) donori. Vairākas šķirnes var atzīt par komerciāli perspektīvām — 'Dace', 'Gita', 'Monta' (*Rvi6*) un poligēni rezistentās 'Laila', 'Pure Ametist'. Taču 2020. gadā *Rvi6* rezistence Latvijā tika pārvarēta. Poligēnas kraupja rezistences donori var izrādīties labāka alternatīva. No šādiem donoriem rezultatīvākie bijuši 'Iedzēnu', 'Eksotika', 'Alesya', 'Bohemia'. Uzsākta gēnu piramidēšana ar marķieru palīdzību, iesaistot gēnus *Rvi5, Rvi6*. Kraupja izturīgās šķirnes 'Edite', 'Felicita', 'Ligita', 'Paulis' uzrāda mazu uzņēmību pret vēzi *Neonectria ditissima*. Augļu kvalitātes un glabāšanās uzlabošanai pasaules komercšķirnes tiek krustotas ar vietējām, adaptētām šķirnēm. Reģistrētas šķirnes no šiem krustojumiem ir 'Inta', 'Lora', 'Saulesmeita'. Nesenie krustojumi iekļauj kvalitātes donoru 'Honeycrisp', no tiem perpektīvākie hibrīdi ir H-1-07-36 un H-1-07-42. Viens no galvenajiem mērķiem ir bioķīmiskā sastāva un mīkstuma struktūras uzlabošana. Papildus selekcijas virziens ir dekoratīvās un sidra ābeles. Kraupja izturīgais hibrīds Nr. 19-97-154 (Cidross) ir perspektīvs sidra ieguvei. Reģistrētas sarkanlapu kolonnābeles šķirne 'Karlens' un kompakta sarkanlapu krebu šķirne 'Auce'.