Holistic Consideration of the Inheritance and Use of the Potential of On-Farm Selection Shown on the Example of Poma Culta Apple Breeding

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Abstract

Most of the traits to be improved on our crops are inherited quantitatively, i.e. they are linked to a multitude of genes which in turn interact with the prevailing environmental conditions. The resulting complexity has already been explored to some extent and in special cases causal relationships can be presented. Poma Culta's approach to achieving useful breeding results even without knowledge of the detailed relationships is to understand the complexity of the system holistically and to make the selection under the environmental conditions under which the cultivated plants will later grow. The most ideal way to do this is on-farm.

In order to counter the high heterozygosity of the apple as an obligatory cross-pollinator, line breeding is carried out. The aim is to genetically anchor characteristics such as plant health or fruit quality and thus obtain more useful offspring from a crossing.

Keywords: Apple breeding, on-farm selection, holistic view

Question

Can on-farm-breeding as a method contribute to improving the assortment of suitable varieties for organic fruit growing? Is it possible to obtain useful breeding results in the foreseeable future without detailed genetic testing?

Preface

Allow me to make a few brief prefaces to my remarks on the holistic view of breeding. The focus of this consideration is on the life processes that take place in our case between the apple tree and its environment with all its biotic and abiotic conditions. The history of this these interactions can be found in the genome. The DNA is the basis for the life processes, whether it is the cause or only condition for it, is a philosophical question.

In accordance with the holistic view, the breeding objective is formulated in such a way that the focus in the breeding process is not on solving individual problems, but on optimally adapting the plant to its environment and thus improving the quality of the fruit, optimising the yield and reducing the cultivation risk.

What is on-farm breeding?

As the name implies, this breeding takes place on farm, i.e. on a farm and under practical conditions. This means that selection takes place under conditions that are as comparable as possible to the situation in which the new varieties later have to prove themselves in apple production on practical farms.

Methodically, the focus is mainly on the selection of phenotypically detectable traits. The simple and efficient collection and processing of data is of great importance. Poma Culta works with a specially designed IT solution.

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The conditions on-farm in Hessigkofen 600 m.a.s.l:

- Climate: Location with annual precipitation of around 800 - 1000 mm. Outdoor conditions with the exception of the cultivation of seedlings in unheated polytunnel.

- Soil: The apple seedlings are planted directly from the growing tray into the open field. There is no pot culture even in later selection stages. The soil has the same parameters regarding soil life and nutrient availability as in later cultivation. Soil maintenance measures such as hoeing and mulching as well as organic fertilisation are carried out according to organic farm standards.

  Example 1: Uptake of micronutrients. The seedlings often show differences in the uptake of micronutrients. Especially in the first and second summers, more vigorous seedlings can show clear deficiency symptoms on the leaves. These convars probably have a less pronounced ability to obtain the required nutrients via symbiotic microorganisms. These observations are an important basis for selection.

- Disease and pest pressure of the site: Due to the climate, there is a high apple scab pressure in most years. Vf resistance has been broken for 6 years at the site at Hessigkofen. Due to weather conditions, the pressure for infections with powdery mildew, sooty blotch and *Marssonina coronaria* varies, but is usually sufficient for selection. As a result of the renunciation of direct plant protection measures in selection stage 1, there is a tendency towards increased disease pressure at the entire site.

  From selection stage 2, the plant protection strategy is as it could also be recommended for later cultivation. Poma Culta deliberately avoids the highly effective fungicides copper, net sulphur and lime sulphur and thus selects under much harsher conditions than are currently common in organic farming.

  Example 2: Various leaf diseases. In addition to the easily identifiable symptoms of apple scab and powdery mildew, there are various leaf lesions which are not always specifically pronounced and which are attributable to microorganisms (*Alternaria alternata*, *Marssonina coronaria* and others). Leaf health as a holistic trait is an important selection characteristic. No fungicides are used during the juvenile phase of the seedlings, which means that only convars with good growth and high leaf health progress.

- Parental choice: Also the parent trees used for the crosses usually grow under the conditions of the farm. This means that the decisions for the choice of crossing partners are also based on location-relevant observations.

Classical crossbreeding as a standard method

In order to achieve breeding goals, strategies are required that promise success in the foreseeable future with a rational approach. It has to be differentiated whether an improvement of monogenic or polygenic conditional traits is in the foreground. This is decisive for the choice of the method. If, for example, the goal is to additionally equip a Gala with individual resistance genes, but to leave its other traits unchanged, genetic engineering methods are now available that can be used to modify specific sequences on the genome. A great deal of work is being done in this direction around the world today. In my opinion, classical crossbreeding is still a promising approach when it comes to improving traits that are quantitatively inherited.

Jules Janick, the well-known American apple breeder, writes in his textbook in the Apple Breeding chapter: "*Fruit size, shape, and productivity are under polygenic control, which*

means that when two cultivars are intercrossed there will be a wide and continuous range of expression of all these characters in the seedlings. The range of variation is related to the expression of the characters in the parents and the progeny mean is always related to the parental mean" (Janick *et al*.,1996).

One can still extend the examples mentioned by Jules Janick. Most of the traits of the apple that are important for us are of a quantitative nature. Just think of the aroma, the texture or the shelf life. But growth traits, vitality and resistance to disease also depend on a variety of genes. The fact that there are also monogenic relationships, such as dwarfism, columnar forms etc., does not contradict this.

Quantitatively inherited traits cannot be improved abruptly, but only gradually over several generations. It should be noted that traits that are already at a high level, such as fruit size, are retained.

The success of a crossing depends to a large extent on the skillful selection of the parents. Their positive as well as their suboptimal characteristics must be known, especially their interaction with the location. Ideally, cross-breeding partners should be used from whom the highest possible number of valid progeny can be expected. This requires experience that can be gained from the documentation of the selection process over the years.

One difficulty that should not be underestimated is the heterozygosity of the apple caused by obligatory cross-pollination. The degree of heterozygosity could be gradually reduced by means of targeted line breeding, as it is known from animal breeding, in order to anchor characteristics such as plant health or fruit quality genetically more firmly and thus obtain more useful progeny from a crossing. Breeders generally have great respect for negative inbreeding effects. But varieties like Topaz, Rubens or Mairac show, that crossing half siblings has led to successful varieties.

Example for illustration

Convar PoC_3988 comes from the offspring of a cross between the variety Braeburn (favoured fruit quality) and Rewena (progenitor of robustness). In the first step the plant health could be improved significantly. Only the spots known from Rewena (Elsinoe) still occur. The flesh firmness is very good and therefore also the shelf life. The aroma and sugar content proved to be insufficient.

In the following years PoC_3988 was crossed with high quality varieties (Topaz, Rajka, Otava and others). In these offspring convars with good or improved tolerance characteristics were found. Further progress has been made with regard to fruit quality. They are now in the range of older standard varieties. In order to meet the quality requirements of a future top variety, further crossings are necessary.

Status of breeding and prospects

Over the past 20 years, the breeding of Poma Culta has been successively expanded and has reached a professional level in recent years. The good cooperation with the Agroscope Research Station (Wädenswil) on the one hand and the FiBL Research Institute for Organic Agriculture (Frick) on the other makes it possible to supplement on-farm breeding in the scientific and laboratory fields.

Table 1: Examples for crossings and change in characteristics

Convar	Parents	Year of Cross	Crispi-ness	Aroma	Gloeo-sp.	Elsinoe-Spots	Scab, resist. breaking	Mars.	Sooty Blotch
1. Generation									
Braeburn			++	+++			--	-	---
Rewena			--	--		--	++	-	--
PoC_3988	**Braeburn x Rewena**	**2001**	**++**	--	**+++**	--	**++**	**++**	**+**
2. Generation	**Example 1**								
Otava			+	+++	-		--	---	---
PoC_3988	Braeburn x Rewena	2001	++	--	+++	--	++	++	+
PoC_0700	**Otava x PoC_3988**	**2011**	+	**++**	**++**	**+**	**++**	**++**	**++**
2. Generation	**Example 2**								
Rajka			+/-	++	+		+/-	---	+/-
PoC_3988	Braeburn x Rewena	2001	++	--	+++	--	++	++	+
PoC_0321	**PoC_3988 x Rajka**	**2011**	**++**	**++**	**++**	**+++**	+	**++**	**++**
2. Generation	**Example 3**								
Topaz			+	+++	--	-	-	--	--
PoC_3988	Braeburn x Rewena	2001	++	--	+++	--	++	++	+
PoC-1329	**PoC_3988 x Topaz**	**2008**	**+++**	+	**+++**	**+**	**+**	**++**	**+++**
Rating:	+++	best rating		---	worst rating				

Currently there are about 20 valuable breeding numbers with partly very good fruit and resistance characteristics, which are used for further crossbreeding. At six locations in various important fruit-growing areas in Europe, trial cultivation is carried out for the internal preliminary clarification of the variety suitability. Eight convars undergo official variety testing at various state stations. First preliminary clarifications with the trade for the introduction of Poma Culta varieties are underway.

Reference

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Crowd breeding of Danish apple cultivars

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Abstract

At the University of Copenhagen a gene bank of app. 800 apple cultivars is situated. In order to breed new, robust apple cultivars, we invited volunteers to participate in a "Crowd-breeding project" in 2013. The 136 people sowed out 10.000 open pollinated apple seeds from the 54 most robust and tasty cultivars of Danish origin from the gene bank. In 2019 we visited the 45 growers, who had succeeded in growing trees. 1422 trees got screened, and 54 % was rated very robust towards the diseases scab, mildew, cancer and Elsinoe fruit and leaf spot. 11 % got discharged due to diseases. Only 5 % of the trees got fruits in 2019. 39 % of the 33 tested fruits had a good or very good taste. The trees will be evaluated again in 2020 and a final selection will be made in 2023.

Keywords: Apple, Breeding, Participatory, Robust, Cultivar

Introduction

"The Pometum", the national fruit gene bank in Denmark, is hosting app. 800 apple cultivars. The gene bank collection is a part of NordGen. The apple cultivars represent all the different kinds of apple cultivars which have been cultivated in Denmark in gardens and orchards through history. App. 350 of the cultivars are of Danish origin.

In 2013 we posed the question: "Why should only Kazakhstan have apple-forests, why not apple-forests in Denmark?" That initiated the project "Apple oasis" aiming to spread the genes from the gene bank, increase biodiversity and apple plantings in the landscape and to develop new robust apple cultivars with a local history.

Apple breeding requires a lot of work, space and time, and has never been a national task in Denmark. To succeed in breeding apples at a low budget, we therefore invited volunteers for help. That's why we call it "Crowd breeding".

Material and Methods

We distributed 10.000 apple seeds in 2013. The seeds were sown out by 136 engaged volunteer gardeners and farmers from all parts of Denmark.

The seeds were selected from the 54 most robust and tasty old Danish cultivars, evaluated under unsprayed conditions. The selected mother cultivars are the following: Annas æble, Blangstedgård 157, Barritskov madæble, Bredsteds æble, Brøndæble, C.J.H. 7-27, C.J.Hansen 603, Dansk Rosenhæger, Degneæble, Dronning Louise, Edle Wendelborg, Elmelund, Fejøæble, Filippa, Filippa anka, Flaskehalser, Flintinge, Fynsk udvalg II, Grænseæble, Guldborg, Guldæble, Hans Mathiesen, Harreslev, Henrik Jensens æble, Herman, Hvidkilde voksæble, Hyltofte æble, Højbjerg kalvil, Ildrød Eilstrup, Kyholm reinette, Langeland hvid pigeon, Lise Legind, Lundbytorp, Lyngbyæble, Maren Nis, Marieæblet fra Hjortholm, Mikkel Peders æble, Nonnetit Bastard, Nørregaards æble, Ondrup Sommeræble, Ormslev æble, Oudrupgårds høstæble, Pigeon Maribo, Rasmus Hansen, Ringkloster Kammerjunker, Rødbyæble, Sildig Sandholt, Skarridsø æble, Spilmose, Spiseæble fra Vejle, Stjerneæble II fra Samsø, Søbjerg æble, Vallekilde,

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Vallekilde sommeræble and Yduns æble. The cultivars are described in the Pometum apple key. The mother cultivars were selected for their good taste and robustness towards apple scab, mildew and cancer. Many of the mother cultivars are offspring of the old cultivars Pigeonnet blanc d´hiver, Cox´s Orange, Nonnetit, Maglemer and Filippa. (Larsen et al 2017).
The seeds were open pollinated. The potential 800 father-cultivars include:

- International cultivars, known or commercially grown in Denmark during history
- Danish local cultivars
- Wild apples from Kazachstan
- Ornamental apples (crab-apples)
- Columnar apples
- Cider apples

Results

In 2019 we evaluated the initial outcome of the project. About 45 participants succeeded, now having app. 1700 new apple trees from seedlings. 18 participant lost all trees due to attacks by dear, voles, mice, dogs, hens or they had moved away. We never heard from 50 participants and we lost track of 37 participants in the period from 2013-2019.
121 trees were flowering in 2019, but due to spring frost only 71 got fruit. 30 of these turned out to be small crab apples and 41 were normal sized apples. The robustness of the new trees towards fungus diseases was screened as well as the fruit quality.
The screening shows, that we have obtained a high proportion of robust trees. 766 trees (54 %) had no or small attacks of both apple scab, mildew, cancer and Elsinoe spot. At the other end 171 trees (11%) were not thriving, mainly due to attack of fungus diseases.

Table 1: Percentage of new apple seedlings attacked by apple scab and/or apple mildew and/or cancer and/or Elsinoe leaf and fruit spot. Screening in 2019 at 30 Danish locations.

	% with no attack (1)	% with small attack (3)	% with middle attack (5)	% with severe attack (7)	% with total attack (9)	Number of trees evaluated
Apple scab on leaves (*Venturia inaequalis*)	74,9	17,4	5,2	2,5	0,1	1261
Apple Mildew (*Podosphaera leucotricha*)	75,3	16,1	4,4	1,7	2,5	1305
Apple Cancer (*Neonectria ditissima*)	96,4	1,7	1,2	0,6	0,2	1249
Elsinoe leaf and fruit spot (*Elsinöe pyri*)	35,4	30,9	19,7	7,7	6,3	1309

The distribution of the attack of different diseases in 2019 is shown in table 1. The main problem vas Elsinoe leaf and fruit spot (also known as Topaz spots), where 33% of the trees were suffering from a middle attack or more.
The diversity in fruit appearance and in tree growth is very large. 17 of the seedlings (5 ‰) have inherited an interesting columnar growth.
The evaluation of the taste of 33 new apple cultivars is shown in figure 1. 13 cultivars (39 %) of the new apples had a good or very good taste. The apples with a “very good” taste was shared and tasted by a group of 30 participants at a workshop, and everyone agreed on this high score in taste.

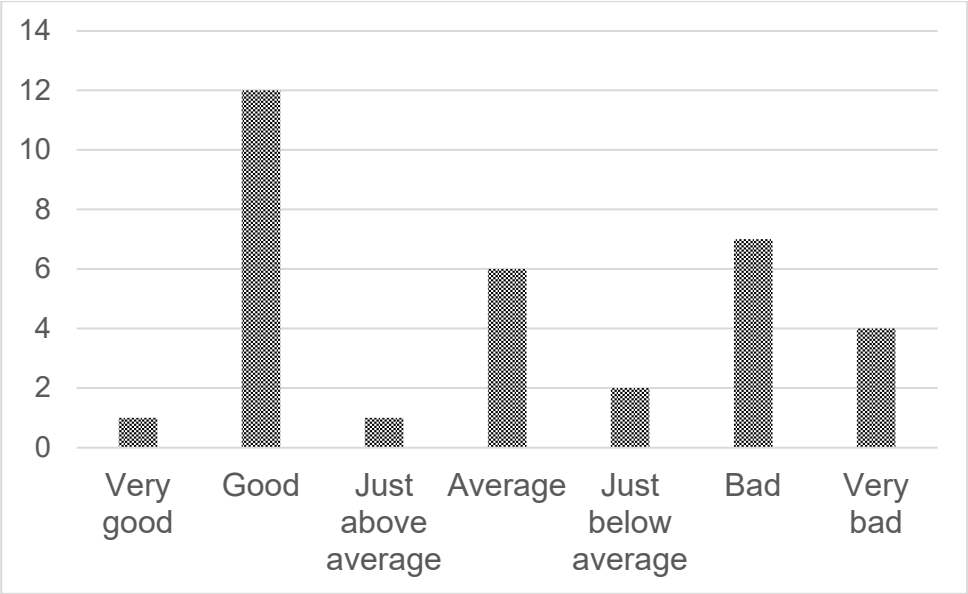

Figure 1: Number of apples with a certain taste.
Apples from 33 new seedlings, tasted fresh by 2-3 persons.

Discussion

We have chosen to work with open pollinated seeds to gain the highest possible diversity. Only very few places in the world are having 800 different potential apple fathers within the flight range of a bee. We wanted to explore this great potential of new combinations in this project. One drawback of this strategy is, that many seedlings apparently were fertilized by ornamental apple trees, and has inherited their very small fruit size. On the other hand, we have got some beautiful new ornamental apple cultivars from the project.

The growing conditions are very different within the group of Crowd-breeders. That was part of the idea, that the seedlings should struggle in different environments, and the most robust should survive. There was though quite a big loss due to attack by voles, and we might have lost valuable cultivars due to that. One of the growers lost 59 out of 60 trees to voles. The one tree surviving the attack turned out to have apples with a taste like a bitter-sweet cider apple, which might explain why the voles didn't eat it. But even with this drawback in natural selection we are optimistic, while the ratio of well-tasting cultivars until now is good.

The rather big proportion of cultivars with crab-apple size we expect to go down. We also expect the proportion of late cultivars to go up, while there is a correlation between short juvenile period and early maturity (Hanke et al 2007).

Future actions

We hope for more flowering trees in 2020 and no spring frost. We repeat the evaluation of trees and fruits in 2020. The best cultivars will then be grafted on both a weak and a strong rootstock and cultivated at The Pometum for a final evaluation in 2023. We hope and expect to obtain a selection of robust, tasty and diverse new Danish apple cultivars in 2024.

We do not expect, that our new cultivars will compete with the standard market cultivars. But we hope and expect to achieve several good cultivars for gardening and organic production. Our new cultivars are meant for the customers, who appreciate local origin and surprising apples that offer more than just being red, crisp, sweet and juicy.

Acknowledgements
Thanks to the 136 Danish gardeners and farmers, that voluntarily have offered their time to try the task of breeding new Danish apple cultivars. Especially thanks to the 45 of these, who had the patience, skills and luck to succeed in growing trees. Thanks also to the employees at the Pometum at The University of Copenhagen and to the funding bodies: Fonden for Økologisk Landbrug and Promilleafgiftsfonden for frugtavlen og gartneribruget.

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