OVER 100 YEARS OF PLANT BREEDING

Looking for the best genes

In the early 20th century, Wageningen wheat varieties were popular for their high yields. Today's plant breeders aim at making crops less dependent on pesticides or more resistant to climate change. The approach is also increasingly customized thanks to robots and DNA techniques.

TEXT MARION DE BOO

'Look, this is quinoa,' says plant breeder Gerard van der Linden of Wageningen University & Research. 'The quinoa research is the most important breeding programme we're running at the moment: most European growers are using Wageningen varieties.' In the greenhouses north of Wageningen, there is a colourful collection of bushy quinoa plants, some of them green, others purplish-red. 'We are mean to them – we are giving them saltwater,' says Van der Linden. 'Rice would have died here long ago, but these plants are staying fairly healthy at salt concentrations approaching that of seawater. Only they are a bit smaller than usual.'

Quinoa is at home on the hot dry highland plateaus of the Andes. The crop even grows around Lake Titicaca, whose banks are white with piles of salt crystals. 'In the course of evolution, this crop has adapted remarkably to salt, drought and strong sun,' explains Van der Linden. 'Other crops sorely need those characteristics now, as an adaptation to climate change. In countries such as Bangladesh and Vietnam, for instance, the rivers are lower in the dry season, so that seawater penetrates the delta and the salt front moves inland. The irrigation water from the river gets saltier and saltier too, seriously affecting the rice harvest.'

SALT TRANSPORT

Van der Linde's research group, Abiotic Stress, is working out quinoa's particular physiological characteristics with a view to building these into other crops. 'We have gradually formed an idea of the main genes involved, in things like salt transport and storage for instance.'

Quinoa also makes smart use of its stomata, as revealed by infrared cameras flown over the crop on drones. Drought-resistant plants close their stomata in time to limit evaporation. In order to monitor the position of the stomata even better, work is now being done on a trial installation with robots in which the camera readings are analysed automatically.

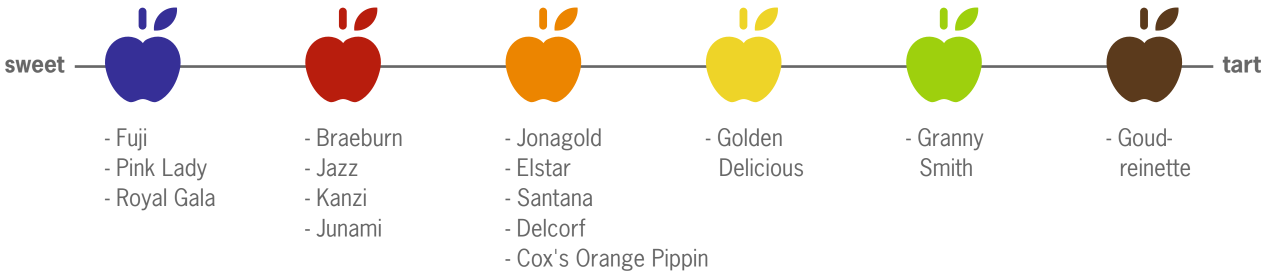
The quinoa research fits into a long tradition. Plant breeding has always been a Wageningen subject area. The Institute for Plant Breeding was founded in 1912, which makes it six years older than the university itself. 'Two highly successful wheat varieties, Wilhelmina wheat and Juliana wheat, were bred in the early 20th century, and that was ground-breaking,' says professor of Plant Breeding Richard Visser. Thanks to the new varieties, wheat yields went up from about 2000 to 2700 kilos per hectare between 1900 and 1920. 'Because of that, the farmers' resistance to the academics from Wageningen melted away.'

From around 1930 to 1950, two thirds of the area planted with wheat in north-west Europe was planted with Wageningen varieties. Nowadays, up to 12,000 kilos of wheat per hectare are harvested.

TRACKING DOWN CHARACTERISTICS

The aim of plant breeding is to develop new varieties by selecting and cross-breeding plants with suitable characteristics. >

From: *Pomologia:* a Dutch book by Johann Hermann Knoop, with illustrated descriptions of apples and pears.



Nowadays the consumer can choose from a rapidly expanding range of apple varieties.

Plant-breeding programmes that used to go on for 50 years are completed within five years nowadays

In the past, this was a matter of time-consuming selection by hand of the plants with the best characteristics for cross-breeding. After cross-breeding the seed was sown in order to find the best breeding results among the descendants. Nowadays, the search for desirable characteristics involves a lot of technology. In April 2018, the green light was given for the construction of a new research centre which will include greenhouses with robot-driven cameras and sensors for measuring the differences in plants' characteristics under a range of different conditions. Wageningen is working with Utrecht University in this Plant Eco-phenotyping Centre (NPEC), a 22 million-euro project. Van der Linden: 'Using phenotyping you can select a group of offspring with a desirable characteristic very precisely, and then you can look for the underlying genetic characteristics within that group. Those genes can be tracked down ever more quickly and cheaply.'

The sequencing of genomes enables plant breeders to focus their work more precisely. As early as 1983, Wageningen scientists sketched a gene map of Arabidopsis thaliana, the model plant of the plant sciences, and in 2000 its complete genome was sequenced. In 2011, Wageningen plant breeders and other research groups around the world published the complete genome of the potato. The genome of the tomato followed in 2012. Since then the breeding of these and other crops with sequenced genomes has moved up a gear. Programmes that used to take 50 years can now be completed within five years.

DROUGHT, HEAT AND DISEASES

According to Visser, plant breeding is both an art and a science. To conquer the market, new varieties need to be better able to withstand diseases, drought, heat and salt, and to give better yields. Yields are going up by an average of 1.5 percent every year. Varieties are also under development that can fix nitrogen from the soil, that don't cause allergic reactions among consumers, and last but not least, that taste better.

'For years, Wageningen breeders marketed new varieties themselves,' says Visser. 'Since the 1960s, the business world has taken over this role. To avoid undesirable competition, Wageningen started concentrating on crops that were not yet being bred commercially, such as quinoa, hemp, flax, marigolds, elephant grass, strawberries, apples and pears. The big commercial successes were the Elsanta strawberry and the Elstar apple. We also give growers a lot of plant material in a 'semi-finished' state for them to continue cross-breeding. Potatoes, for example, that have been cross-bred with related wild species with resistance genes, as well as tomato and lettuce material. Resistant varieties are crucial. Take lettuce, for instance. In the shops it all looks the same but there are new varieties every year because the resistance to disease of the older varieties has been overcome after a year. If there is a random mutation in one in a million fungal spores, and you've got hundreds of billions of spores flying around your greenhouse, in no time you'll have thousands of mutant fungi attacking your crop.'

LOOKING FOR VARIATION

Since the 1940s, breeders have been looking for new plant characteristics by inducing mutations in the genetic material using radiation or chemicals. This kind of mutation breeding led in the US to the seedless grapefruit, for instance, a mutant that would not last long in nature but is very popular with consumers. A disadvantage of mutation breeding is that the mutations that occur are totally random. At the end of the 1990s, molecular-biological techniques were developed for changing DNA in a targeted fashion, thus speeding up breeding programmes considerably. For potatoes, for example, which have four sets of chromosomes, complicating cross-breeding, and for strawberries, which have eight sets. And for apples, which only start flowering after five or six years and can therefore only be cross-bred then. So in traditional cross-breeding it can take 50 years to cross an apple five times. With a special gene construct for early flowering, in the laboratory the apple plant now produces a mini apple within a few months, and this can be used for testing for resistance genes. In the final phase of the research the gene construct for early flowering is then outcrossed by classical methods.

FENDING OFF PATHOGENS

Exciting new territory is being explored by Yuling Bai in her research on Susceptibility genes, or S genes, as a new source of resistance to pathogens such as fungi and viruses. 'Some pathogens make active use of certain plant genes to penetrate the plant,' she explains in her office, which is full of bouquets as she has just been appointed personal professor of Plant Breeding. 'If you switch off that kind of S gene, infection doesn't recur.'

A subsequent research question is then whether the plant can do without that gene. Bai solves this by making some small changes in the gene instead of switching off the entire gene. A change might be made to part of the promoter, for example, which is what the pathogen uses to switch on the gene. 'Then the pathogen doesn't stand a chance. Removing just one or two base pairs can suffice to fend off a fungus or a virus.'

What is remarkable is that a number of these S genes are ubiquitous in the plant kingdom. But only some plants suffer if their S genes are switched off. It is no problem to switch off a particular S gene in the tomato to make it resistant to fungi, while the same intervention in the same gene in barley hampers growth.

A new technique, CRISPR-Cas, makes it possible to change DNA very subtly. Wageningen microbiologist John van der Oost received a Spinoza grant of 2.5 million euros in September for his contribution towards making this technique usable in practice. With CRISPR-Cas, plant breeders can change a characteristic more precisely than ever, using protein scissors (Cas9). This can modify one or more genes at a particular location in the DNA. That way, breeders in the laboratory can equip an existing variety with a new characteristic within a few months. Meanwhile, after years of debate the European Court ruled in July 2018 that varieties obtained this way are to be designated genetically modified organisms (GMOs) and may therefore only be marketed after extensive safety research.

SWITCHING ON AND OFF

'In the search for desirable characteristics, our methods of measuring are becoming more and more refined,' says Van der Linden. 'And we can map the DNA faster and cheaper all the time, getting more and more information out of it. We can characterize genes and study their functions by switching them on and off using molecular techniques, and thus identify their specific contribution to the yield of the crop. In quinoa, for example, in which many different genes determine the harvest between them.' Breeders can then cross-breed using the plants with the right genes. 'We can also build them in to new varieties, or into other crops. Once we know which tricks quinoa uses for its drought and salt resistance, and how the damage is minimalized, we can also start designing drought-resistant rice or wheat varieties.'

According to Richard Visser, designer varieties are just around the corner. 'You can figure out in advance what the best combinations are, and which parent plants you should pick, and how big your population needs to be to have enough chance of selecting the right offspring, instead of indiscriminately screening 100,000 offspring. If the fieldwork becomes cheaper to do, plant breeders will be able to serve all kinds of smaller, local niche markets and micro-environments as well. We are getting more of a grip on genetically complex characteristics such as yield stability and drought tolerance. We shall soon be getting the same yields with less water and pesticides. That is interesting from the food security angle as well.' ■

www.wur.eu/plantbreeding

DUTCH PLANT-BREEDING COMPANIES ON THE WORLD MARKET

Plant breeding is big business. One kilo of tomato seed is worth more than a kilo of gold. The production of horticultural seeds, seed potatoes and flower bulbs brings 2.4 billion euros into the Dutch economy every year. 40 percent of all the horticultural seeds and 60 percent of all the seed potatoes on the world market come from the 350 or so Dutch plant-breeding companies. These companies employ 11,000 people, with branches in more than 100 countries. This commercial success is due to intensive collaboration between educational and research institutions and the business world. On average, 14 cents out of every euro earned goes towards research and development.

PHOTO ALAMY