Breeding better beans: how understanding plant genetics can improve the appearance of beans

Beans are tasty, versatile and in high demand. However, many varieties darken after harvesting, making them undesirable to consumers which reduces profits for growers. At the **University of Guelph** in Canada, **Professor Peter Pauls** and his team in the **Bean Breeding Program** have discovered a gene that prevents post-harvest darkening. With this knowledge, they have bred non-darkening beans that are also more nutritious.

Professor Peter Pauls

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PROFILE

Fields of research
Plant breeding, plant genetics

Research project
Uncovering the genetic basis for post-harvest darkening to breed non-darkening beans

Funders
Ontario Ministry of Agriculture, Food and Agribusiness, Ontario Bean Growers, Natural Sciences and Engineering Research Council of Canada (NSERC), Hensall Co-op

Talk like a ...

plant breeder

Allele — a variation of a gene, e.g., in beans, the seed colour gene J has a darkening and non-darkening allele

Chromosome — a structure made of DNA and protein that is found in the nucleus of a cell

Crossbreed — to combine genetic material from two different plants to create offspring with desired traits from the parents

DNA sequencing — a genetic technique used to determine the order of nucleotides in DNA

Folate — a nutrient (also known as vitamin B9) found in plants

Gene — a segment of DNA that contains the instructions for expressing traits, e.g., in beans, multiple genes are responsible for seed colours

Linkage mapping study — a genetic technique to map the location of an organism's genes

Nucleotide — the molecular building blocks of DNA and RNA, composed of a nitrogenous base, a sugar molecule and a phosphate group

Polymorphism — a variation in a DNA sequence between two samples

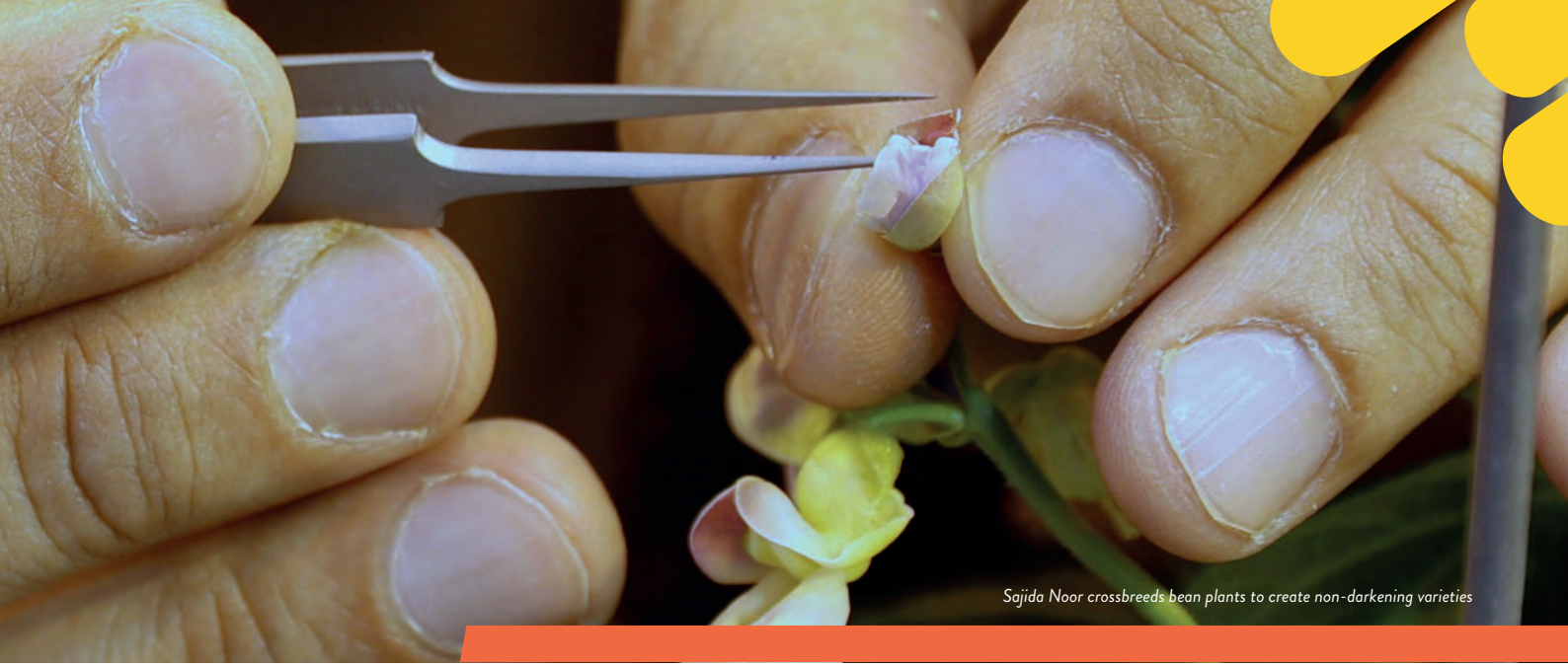
Recessive — a trait that will only be expressed if an organism inherits the recessive allele from both parents

If you were to visit your nearest restaurant, you would almost certainly find beans on the menu, in one form or another. Found in chili con carne, in the popular form of baked beans, or as a fresh side vegetable, the humble bean is a staple ingredient in many meals. Indeed, the common bean (*Phaseolus vulgaris*) is the most important food legume crop grown in the world, eaten as immature pods (e.g., green beans) or as dried seeds (e.g., kidney, cranberry/borlotti and pinto beans).

"Beans are excellent sources of protein, fibre, minerals, vitamins and other nutrients, thus contributing to the health benefits associated with plant-based diets," says Professor Peter Pauls, who leads the Bean Breeding Program at the University of Guelph. "They are rich sources of folate and antioxidants, and eating beans has positive effects on gut health." Today, Canada is the main exporter of dry beans to the USA and Europe.

Why are non-darkening beans desirable?

Beans come in a huge range of colours. Some particularly attractive varieties, such as cranberry and pinto, have spotted patterns on a white background. However, these beans can darken during storage, making them look older. "Consumers associate age-related



Sajida Noor crossbreeds bean plants to create non-darkening varieties

darkening with a decrease in palatability and increased cooking time," says Peter. When Dr Mohammad Erfatpour was a PhD student in Peter's lab, he found that non-darkened pinto beans were preferred by a trained taste panel. They were perceived to be sweeter in taste, softer and smoother in texture, and to have shorter cooking times, making them more desirable for consumers. This means that if beans darken as they are dried before being sold, they have less market value, leading to reduced profits for growers. To address this challenge, Peter and his colleagues are breeding new varieties of non-darkening beans.

What causes the non-darkening trait?

After Lori Wright, a technician in the lab, identified the non-darkening trait in a bean variety called 'wit-rood', Mohammad crossbred this non-darkening variety with regular-darkening pinto beans. He then exposed the bean seeds from the resulting plants to ultraviolet (UV) light for 24 hours and measured the extent of seed coat darkening.

Mohammad demonstrated that non-darkening is a recessive trait, meaning that a bean plant will only have non-darkening seeds if it inherits the non-darkening allele from both parents. If it inherits the non-darkening allele from one parent but the regular-darkening allele from the other, then the resulting plant will produce seeds that undergo post-harvest darkening. "The non-darkening trait was previously shown to be associated with a seed coat colour gene called Joker (J)," says Peter. "It determines whether a bean will darken, as seeds from plants that have two recessive alleles of the gene do not darken at all." Mohammad then conducted a linkage mapping study to locate the gene responsible for non-darkening and discovered it on chromosome 10. He conducted DNA sequencing of 21 genes on chromosome 10 in the region that controls the non-darkening trait and identified a polymorphism in the MYB gene that controls the synthesis of plant pigments. The polymorphism in this gene consists of a single nucleotide deletion, in which one of the gene's nucleotides is missing. This polymorphism is believed to prevent flavonoid synthesis (the process that produces brown pigments in seed coats).

How can this knowledge be used to breed non-darkening beans?

Having identified the gene associated with post-harvest darkening, the team needed a way to screen future plants for this gene. PhD student Sajida Noor developed a molecular marker based on the polymorphism in the MYB gene. "This marker can be used to rapidly screen DNA samples from bean breeding populations to determine if individuals are carrying the recessive allele of the gene that leads to the non-darkening trait," explains Peter. "This is a critical tool for screening plant material to identify suitable breeding lines." Once the team has identified plants that contain the non-darkening allele, they can crossbreed them to produce offspring that are non-darkening.

Sajida is now taking this a step further and crossbreeding beans with the non-darkening allele with other bean varieties that have better growing characteristics. This means she can combine the desired traits of non-darkening seed coat and superior growth into one variety of bean.

What success has the team had?

Two of the non-darkening pinto bean varieties that Peter and his team have developed have now been commercialised, meaning that the variety has been registered with the Canadian Food Inspection Agency and licensed for sale by private agricultural companies. One of their non-darkening cranberry beans is also currently in the process of registration. "We have made many crosses with non-darkening breeding lines, and the trait will be advanced in the new varieties as they emerge from the breeding pipeline," says Peter.

Another interesting, unintentional benefit of the non-darkening beans was discovered through collaboration with Dr Raymond Glahn and co-workers in the US Department of Agriculture. "They found that our non-darkening cranberry beans have five times more bioavailable iron (iron that can be used by the body) than regular-darkening cranberry beans," explains Peter. This means that, although improving nutritional value was not a key aim when developing non-darkening beans, it transpires that they are in fact more nutritious.

By breeding beans with traits that are desirable to consumers, Peter and his team are supporting bean growers in Canada and around the world.

Non-darkening cranberry beans developed by Peter and his team

About *the Bean Breeding Program*

The University of Guelph's Bean Breeding Program is developing new bean varieties with a wide range of different characteristics, supported by genetic studies to examine the genes associated with these traits. This includes varieties which are resistant to specific diseases, as plant diseases cost the Canadian bean industry $25 million per year. Many farmers add nitrogen fertiliser to their fields to promote plant growth, but this causes environmental problems, so the team is breeding bean varieties with improved nitrogen fixation, meaning the beans can convert atmospheric nitrogen into a form that enriches the soil. And the team is breeding beans with nutritional benefits, such as high folate levels, as folate deficiency in pregnant women is linked to spine and brain defects in unborn babies.

Each year, the Bean Breeding Program makes more than 200 crosses between selected parents, and the offspring are tested to identify lines with improved yield and other desired traits. Superior breeding lines will then begin the registration process to become commercially recognised bean varieties. The whole process, from the original crossbreeding to the point at which consumers will eat the new bean variety, typically takes more than 10 years. The Bean Breeding Program has commercialised numerous bean varieties that have beneficial traits and which are now being grown and eaten around the world.

Developing new bean varieties is a team effort. The crossbreeding and field work is managed by technician Lyndsay Schram, who is supported by technicians Shania Van Herk and Alexander Schaefer and assisted by undergraduate students Anna Collins and Abrienna Mills, and graduate student volunteer Sajal Ahlawat. During the summer, additional undergraduate and high school students help in the field, planting and sorting beans. Dr Yarmilla Reinprecht, Dr Mohammad Erfatpour, Sajida Noor, Mylene Corzo Lopez, Ujomonigho Omoregie, Maryam Vazin and Holly Gallo all conduct research projects to understand bean genetics. And Dr Mohsen Yoosefzadeh Najafabadi, who specialises in bean breeding and computational biology, will replace Peter upon his retirement.

Pathway from school to *plant breeding*

At school, study biology, chemistry, physics, environmental science, mathematics and computer science, as agricultural studies will incorporate all these disciplines. Language skills (both written and oral) will also be useful.

"If you are interested in plant breeding, you are most likely interested in practical applications of knowledge and would feel at home in agriculture programmes," advises Peter.

At college or university, pursue a degree in plant breeding, agricultural studies, crop science, plant biology or plant genetics.

"Connect with university plant researchers and breeding programmes while you're in high school, since many hire students for field and lab work during the cropping season," says Peter. For example, you can contact Peter if you want to find out more or get involved: **www.plant.uoguelph.ca/ppauls**

Explore careers in *plant breeding*

Many students who have graduated from the University of Guelph's plant breeding programme have gone on to lead their own plant breeding programmes or seed companies, developing new varieties of crops such as peppers, watermelons, chickpeas and flax. Others conduct research for agricultural companies or deal with regulation in public institutions, such as the Canadian Food Inspection Agency.

Organisations such as Seeds Canada (**www.seeds-canada.ca**), the Canadian Seed Growers Association (**www.seedgrowers.ca/seed-growers**), AgScape (**www.agscape.ca**) and the National Association of Plant Breeders (**www.plantbreeding.org/students/education-resources/careers**) provide information about plant breeding as well as educational and careers resources.

The Bean Improvement Cooperation provides articles, information about research techniques, job listings and more: **www.bic.uprm.edu**

Meet *Peter*

In high school, I was interested in biology and chemistry. Out of school, I enjoyed hiking, canoeing and working with kids as a camp counsellor.

I started plant breeding when a colleague who I was collaborating with, who was the bean breeder in our department, moved to another university. We were co-advising students working on molecular studies in beans, and to keep the programme going I offered to supervise it for the department. Shortly after that, I got my certification as a plant breeder and I've been involved in bean breeding ever since, with a short time also spent breeding wheat.

The interesting aspect of plant breeding is that it puts your ideas to the test in practical ways. Once we've developed a new variety with a novel trait, like disease resistance or non-darkening seeds, it is either acceptable to farmers and the food industry, or not.

I enjoy the collaborative nature of working in the field of plant genetics and bean breeding. To understand bean traits at the molecular level, I have worked with a wide range of people, including agronomists (to characterise large breeding populations in field trials), plant biochemists (to analyse bean compositions), molecular biologists (to identify gene structures), food scientists (to study bean cooking characteristics and palatability), nutritionists (to examine the impacts of beans on gut health and obesity), remote sensing specialists (to collect and analyse drone measurements of field plots) and economists and companies (to determine the market potential of different varieties).

In my free time, I enjoy being outdoors, gardening, hiking, canoeing and photography.

Peter's *top tip*

Don't be afraid of trying something new. There are so many areas that turn out to be helpful in any career.

Meet *Sajida*

As a curious and eager teenager, I was highly observant and had a strong passion for science, especially biology, chemistry and mathematics. This drove me to seek answers to my questions, constantly exploring gaps in knowledge and striving to bridge them through inquiry and discovery.

I have always been deeply concerned about food insecurity and the challenges of feeding a growing global population. My desire to understand the complexities of the food system led me to shape my educational path towards improving crop productivity and developing new crop varieties based on consumer needs.

I worked in a tissue culture lab for a research project during my undergraduate degree, which was a turning point in my journey towards the field of biotechnology. This experience inspired me to pursue a master's degree and PhD in plant breeding and genetics, as I realised that understanding food insecurity requires studying plants at the genetic level and that modern biotechnology can revolutionise agriculture.

My work as a bean breeding PhD student involves growing bean seeds in the greenhouse and crossbreeding different varieties. I then take the plant material from the greenhouse to the laboratory for genetic studies, such as DNA extraction, and I analyse the resulting data and interpret my findings.

Agricultural studies is a wonderful blend of science and art, allowing me to enjoy every moment of learning while experiencing the beauty of nature and discovering real-world insights firsthand. Learning becomes enjoyable when it is driven by reasoning and curiosity. I truly enjoy my work when I realise that my research is meaningful and has the potential to make a real impact.

I love cranberry beans, which are beautiful in appearance and delicious in taste. Farmers and consumers both demand these beans because of their appearance, shape, yield and taste. My favourite way to cook them is in bean soup, which is simple, tasty and quick to make. I add spices like paprika, chilli flakes and oregano to the boiled beans, along with kale and pasta.

In my free time, I enjoy reading historical books, gardening, jogging, swimming, and spending quality time playing with my daughter.