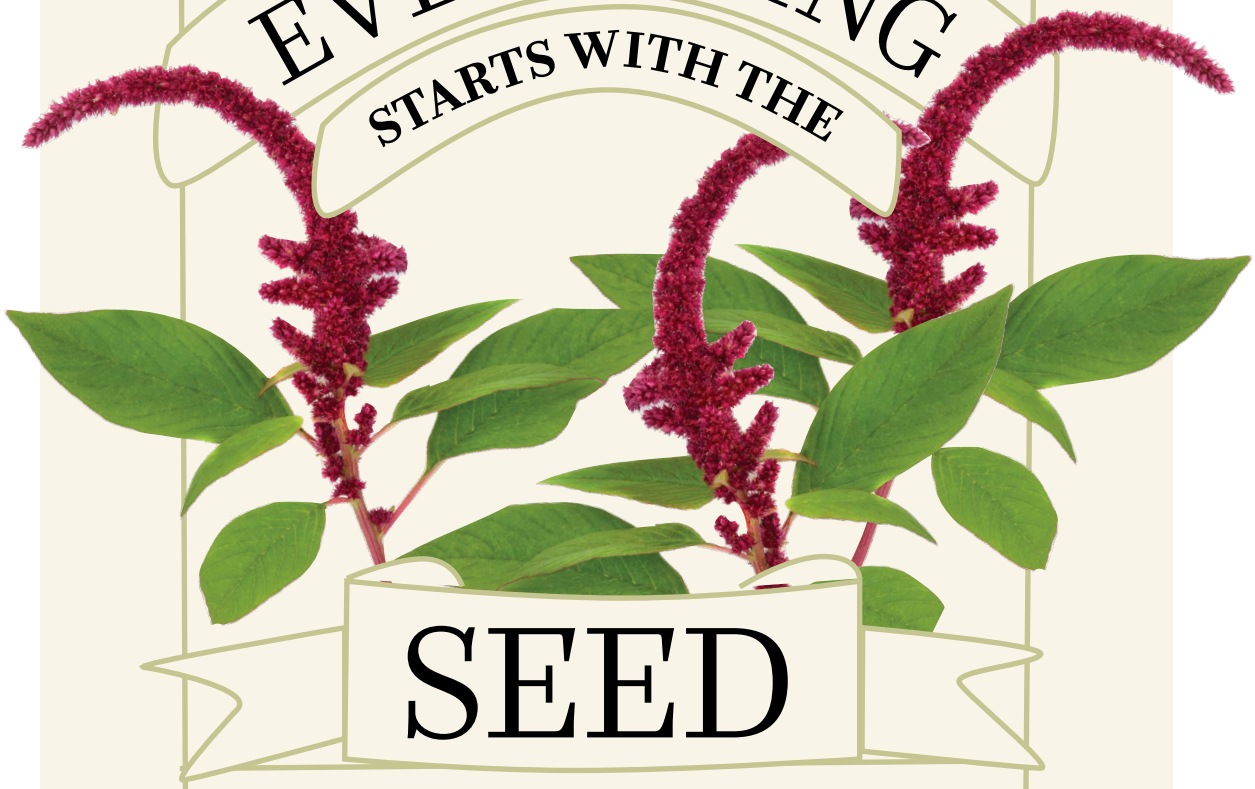
EVERYTHING STARTS WITH THE SEED



A global organisation working to rescue vegetable diversity neatly combines old and new techniques and technologies, reports **Natalie Parletta**.

AMARANTH (*AMARANTHUS* SPP.)

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When Sognigbé N'Danikou was a small boy, his grandmother cooked meals with yantoto, a wild green that grew on his mother's farm in Ouèssè, a small village in Benin, West Africa, about 250 kilometres north of the capital Porto-Novo. "At that time, I fell in love with this indigenous vegetable," he tells me, a warm smile transforming his serious demeanour.

Years later, N'Danikou attended university to study agriculture in Benin's seaside town, Cotonou. But he couldn't find his favourite green, which he likens to a type of lettuce but more nutritious. "I couldn't enjoy them anymore, and that is an indication of how traditional knowledge can be lost; this connection with my mother and the stories she told about these crops."

Today, N'Danikou is a scientist focused on traditional vegetables conservation and utilisation as the African genebank manager for the World Vegetable Center – or WorldVeg, as it's affectionately known – based in Shanhua, Taiwan. Since 1973, this non-profit organisation has amassed the world's largest collection of vegetable germplasm – live seeds or other viable plant parts – and their genetic profiles, which are stored in Taiwan and Tanzania.

The centre collaborates with public and private research institutes to collect, conserve and identify important traits of vegetable germplasm. They aim to help increase farmers'

Sognigbé N'Danikou
African genebank manager for the World Vegetable Center

> "I couldn't enjoy [yantoto] anymore, and that is an indication of how traditional knowledge can be lost."

The gourd luffa (above) and the vegetable hummingbird (right) are among the diverse plants studied by WorldVeg in Taiwan (below).

CLOCKWISE FROM LEFT: WORLD VEGETABLE CENTER X2; XIJUAN JITTINARKSOMPONG; MANSOREH MOTAMEDI / GETTY IMAGES.

productivity and livelihoods, alleviate poverty and malnutrition in developing countries and mitigate the environmental and health impacts of pesticides and synthetic fertilisers.

"We say everything starts with the seed," says Gabriel Rugalema, WorldVeg's regional director for operations in eastern and southern Africa (who introduced himself to me with his perpetual, cheeky grin as "Gabriel the archangel").

Diverse and inclusive

I visit WorldVeg in November 2023 for their 50th anniversary celebrations. As our airport bus pulls into the hub of the centre's sprawling 216 hectares, an oasis formerly covered by sugar cane, a wiry man in a business suit is pedalling furiously across the campus on a pushbike.

"There's Marco!" says my companion, Cathy Reade from Australia's Crawford Fund – a not-for-profit focused on food security. Marco Wopereis, an agronomist, is the centre's director general. A couple of days later at a public open day, I see him boogying down in jeans and a WorldVeg t-shirt in an African dancing demonstration; in the days before, on stages elaborately decorated with vegetables, he hosts scientific talks and government officials for the celebrations, kicked off by guttural, tribal drumming that feels like it erupts from the Earth.

In my room is an invitation to join board members and scientists for dinner, hosted by Wopereis and his energetic wife, Myra. Their house is a short walk from our accommodation, in a mini village of red-roofed houses set among trees with large branches that form a welcoming green canopy. Wopereis later told me they'd planted another 9,000 trees on the campus a couple of years ago. I notice the landscaping is like a botanical garden, with multitudes of familiar and exotic edible plants growing in between the lawns, trees and buildings, all tagged with their common and scientific names.

Gabriel Rugalema, WorldVeg's regional director for operations in eastern and southern Africa

At the dinner, tables decorate the Wopereis's lawn with a banquet created from an array of – you guessed it – vegetables. Myra introduces the food enthusiastically, highlighting an exotic dish made from a white edible Asian flower (*Sesbania grandiflora*). Other delicacies include grilled eggplant, grilled squash and red pesto with pasta. After the feast, Wopereis gives a carefully prepared speech in which he mentions everyone there, from dignitaries to people who helped with preparations, and even me. I came to realise that this inclusivity is a central thread in

the tapestry of the organisation's extensive networks.

Scientists travelled from all over the world to attend the celebrations, including Africa, India, Thailand, Germany, Japan, the Philippines, Korea, America, Britain and Australia. The accents wafting around, which also include French, Austrian and Dutch, reflect the diversity at the core of their united vision.

"If you lack diversity, you lack options," says Roland Schafleitner, who leads the centre's biotechnology/molecular breeding group and the Vegetable Diversity and Improvement Flagship. "And when something happens, you lose even more options until you have nothing left. So, vegetable diversity is crucial."

Spreading the risk

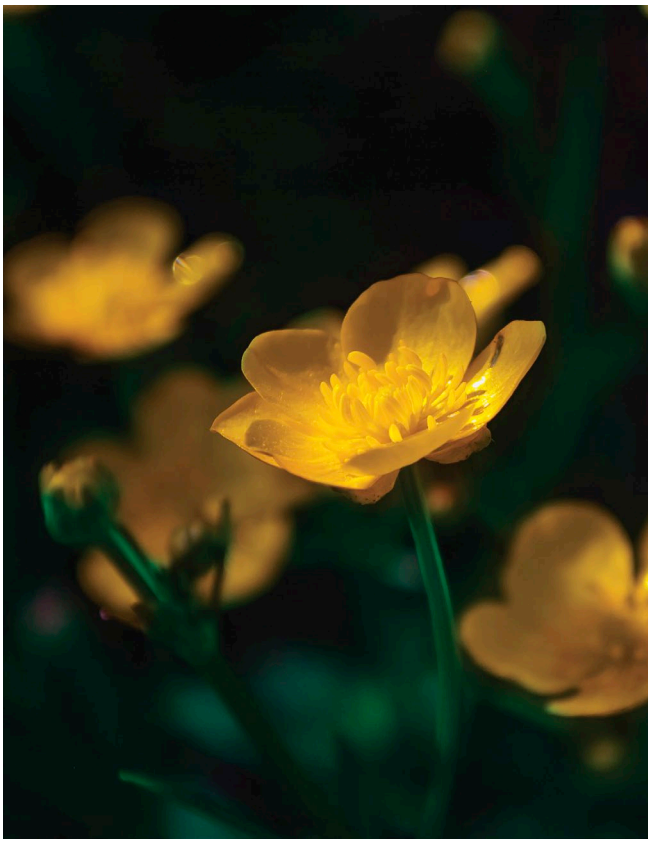
One of the many benefits of diversification is that if a crop fails, you're not putting all your tomatoes in one basket, as it were; it can be supplemented by high value vegetable crops such as mungbeans (*Vigna radiata*) or amaranth (*Amaranthus* spp.) to help spread the risk.

Yet, as food systems become more centralised and people's tastes become more uniform, we are at risk of losing this diversity. "We eat tomato, cucumber, some beans and carrots, maybe eggplant and broccoli," says Delphine Larrousse, regional manager for East and Southeast Asia, in her animated French accent. "But about 1,100 vegetable species are recognised worldwide – there is a massive disconnect."

Importantly, diversity doesn't just apply to different types of vegetables – it's also a critical feature within species. With fewer genes in the pool, hybrid vigour is diminished, leaving plants weak and vulnerable. Diversity helps breeders develop improved varieties of vegetable species that are resistant to stresses such as pests, diseases, drought, floods and heat, and that can produce more nutritious crops with higher yields, longer shelf life, shorter harvesting times and desirable traits such as taste, size and colour.

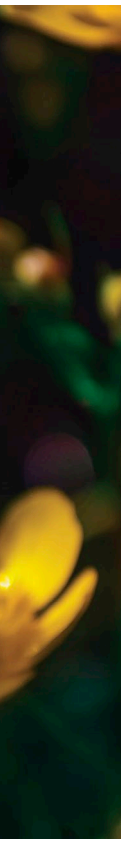
Bitter gourd (*Momordica charantia*), for instance, is a highly nutritious type of squash that feeds at least a billion people in Asia, and the annual seed market is valued at $26.4 million. However, hybrid crossing of elite lines to fill niche markets has diluted its genetic diversity, as confirmed via molecular analysis. That has made it vulnerable to biotic (living) and abiotic (non-living) stresses, and impacted long-term yield. WorldVeg scientists are now actively introducing diversity to breed new, improved lines and rescue the market.

Marco Wopereis, the centre's director general



Right: Ethiopian mustard (*Brassica carinata*). Below: mung bean (*Vigna radiata*). Opposite: soybean (*Glycine max*).

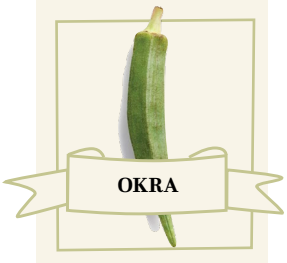
CLOCKWISE FROM LEFT: ENY PURWANTI, SIRICHAI_ASAWALAPSAKUL, IRINA BLINOVA / GETTY IMAGES.



> “We eat tomato, cucumber, beans and carrots ... but about 1,100 vegetable species are recognised worldwide.”

Diversity also safeguards against future challenges. “The issue is that you don’t know yet what kind of traits you need in five years from now,” says genebank manager Maarten van Zonneveld in his softly spoken Dutch accent, “and the other issue is that you don’t know which variety has the traits you want.”

In recognition of this, the genebank’s collection includes 8,000 different accessions of mungbeans alone – 10,000, including its wild relatives. (The UN’s Food and Agriculture Organization defines an accession as “a distinct, uniquely identifiable sample of seeds representing a cultivar, breeding line or a population, which is maintained in storage for conservation and use”.) There are more than 12,000 soybean (*Glycine max*) accessions, 8,000 tomatoes (*Solanum lycopersicum*) and 6,000 chilli peppers (*Capsicum annuum*). Ethiopian eggplant (*Solanum aethiopicum*) seeds have topped 4,000, “but there are so many more varieties,” says van Zonneveld.



Roland Schafleitner, leader of the centre’s biotechnology/ molecular breeding group

It’s hard for most of us to imagine thousands of different types of chilli, eggplant or tomato. But vegetable species consist of a wide range of varieties with “an astonishing diversity of forms, tastes and colours, adapted to myriad environments and pests and diseases,” according to van Zonneveld. “This is what we conserve in our genebank.”

Other lines include amaranth, okra (*Abelmoschus esculentus*), jute mallow (*Corchorus olitorius*), cowpea (*Vigna unguiculata*), Ethiopian mustard (*Brassica carinata*) and bitter gourd. Van Zonneveld worries that they only have about 4,400 accessions of cucurbits (pumpkins, squash and gourds). “The luffa [*Luffa* spp.], all these cucurbits, let’s collect them before they get lost.” His personal dream is for the vegetable collection across global genebanks to grow from around 200,000 to 300,000 accessions by 2030. “It’s just a number, no, but something to aim for.”

Van Zonneveld’s favourite seed rescue was a student’s rediscovery of an endangered cowpea and mungbean relative named *Vigna keraudrenii*, endemic to Madagascar. It was initially found in 11 spots among the island’s rich biodiversity in the 1990s and described by botanists David du Puy and Jean-Noël Labat. The student visited all 11 sites in 2022 and found only one remaining plant, which is not stored in any

FROM TOP: FLAVIO BENEDITO CONCEIÇÃO, SCIENCE PHOTO LIBRARY / GETTY IMAGES.

genebank. So WorldVeg partners put a little fence around it – but it was recently lost in a fire. "Fortunately, they got some seeds and are now producing seedlings for seed multiplication," says van Zonneveld. "It is species rescue in live action."

Veggies in the bank

As head of genetic resources, van Zonneveld strives to ensure the genebank operates professionally in accordance with the international Genebank Standards for Plant Genetic Resources for Food and Agriculture. These voluntary standards include maintaining high-quality, viable seeds, formalised procedures for characterising germplasm and backup storage in other genebanks. WorldVeg also partners with Genesys, an online resource for finding germplasm accessions stored in genebanks globally.

Maarten van Zonneveld, genebank manager

> "We are not interested in conserving tomato. We are interested in conserving 8,000 varieties of tomato."

Currently, the WorldVeg genebanks store more than 65,000 seed accessions, which includes germplasm of more than 370 species from 155 countries. Twelve thousand of those are indigenous vegetables. However, vegetables still only comprise an estimated 5–10% of germplasm saved in public genebanks – a travesty given this food group's vital importance for providing life-essential nutrients and gut-healthy fibre.

Reade and I visit the genebank during the anniversary celebrations. Before entering, we take off our shoes and don slippers provided at the door to prevent pathogens entering the facility. The refrigerated storage rooms are a shivering contrast to the warm humid air outside. In a room containing rows and rows of carefully numbered vaults, our guide dips into one of many neatly stacked boxes and shows us a seed packet, with its unique identification number, year of registration and a QR code.

The seeds stored in the genebank are 'orthodox' seeds that can be dried – up to 4–7% moisture content – and frozen; 'recalcitrant' seeds such as avocado can't or they would die. All are kept under 5°C for mid-term storage (for seed distribution in the WorldVeg genebank) and -18°C for long-term storage (for conservation), with relative humidity levels monitored at around 15%.

Even then, seeds differ in their storage longevity and germination requirements; viability is actively monitored over time. Crops such as cucurbits have relatively short lifespans and can only be kept in short-term storage for 10–20 years, or two to three times as long in long-term storage. Others such as mungbean might keep for 50–100 years in mid- to long-term storage. For germination, some crops such as bitter gourd need special heat treatment while others, such as pumpkin, don't need anything other than water to get started. Chutchamas (Chat) Kanchana-Udomkan, director of the Tropical Vegetable Research Center in Thailand which works closely with WorldVeg, specialises in papaya. She explains that before drying papaya seeds you need to remove the jelly-like coating because it contains chemicals that prevent germination.

Type, geno- and pheno-

Saving seeds and keeping them alive is just one consideration. To unlock the genebank's vast treasures, modern genotyping and phenotyping technologies are key. This essentially delivers the means to fast-track centuries-old agricultural practices of collecting seeds from high-performing plants and replanting them next season.

VEGETABLE? FRUIT? OR SOMETHING ELSE?

How do you define that astonishingly diverse, nutritious and colourful group of foods that we call vegetables? And which ones make the grade for preservation in genebanks?

Vegetables are generally defined as the edible part of a plant – the leaves (lettuce, spinach), stem (celery, asparagus), roots (carrot, parsnip), tubers (potato, yam) or flower heads (broccoli, cauliflower) – while fruits are formed from the ovary of a flowering plant and contain seeds. This is where it gets tricky; with this classification, squash, tomatoes, capsicum and eggplants are fruit. Conversely, sweet melons are classified as vegetables. Botanically, there's no clear-cut definition.

Instead, veggies are usually defined by their cultural and culinary uses, although this isn't straightforward either – for instance, papaya and mangoes can be eaten as vegetables while young, or as fruit when they become ripe, while mungbeans might be eaten as sprouts (vegetables) or as grains.

"Arriving at an indisputable, unassailable definition of vegetables is virtually impossible," write WorldVeg scientists Narinder Dhillon and Pepijn Schreinemachers. They tentatively suggest vegetables are "mostly herbaceous annual plants of which some portion is eaten, either cooked or raw, during the principal part of the meal to complement starchy food and other food items."

So which seeds are considered worth saving? WorldVeg collects seeds with social and economic importance. This might include global crops such as tomato, pepper and pumpkin, or vegetables popular with local markets and diets: jute mallow in west Africa, yardlong bean in Southeast Asia.

They also consider nutritional value, genetic relatedness to crops, and complementing other genebanks. But their focus is conserving intraspecific crop diversity.

"We are not interested in conserving tomato," says van Zonneveld. "We are interested in conserving 8,000 varieties of tomato because this offers a gene pool for tomato breeding." Each variety has been created by humans in different contexts, but many no longer exist in farmers' fields, he adds.

For added breeding diversity, WorldVeg also conserves wild crop relatives.

Above: okra (*Abelmoschus esculentus*). Left: bitter gourd (*Momordica charantia*).

Delphine Larrousse, regional manager, East and Southeast Asia

Genetic sequencing provides a window into traits embedded in the seed's DNA, and rapid advances have enabled the genes to be identified quickly and cheaply. "We can genotype anything," says Shanice Van Haeften, a PhD student researching mungbean crops in Australia, who did an internship at WorldVeg. But while the centre has a vast resource of genetic information, it needs data on the physiological traits expressed by a seed, such as yield, pest resistance or abiotic tolerance – a cumbersome task. "We have a phenotyping bottleneck," says Van Haeften. "We're struggling to get enough physiological information we need to be able to link it to our genetics."

To help pull the stopper out of the bottleneck, Van Haeften has been experimenting with UAVs (unmanned aerial vehicles, or drones) with specialised sensors to capture data more quickly at a large scale and across the seasons. Manually, it took her more than nine months to collect data on mungbean biomass – how much light a plant can absorb for production and yield – by harvesting 60 plots, dissecting the leaves and stems and weighing and drying them. Her drone

CLOCKWISE FROM LEFT: JIANDE WU, ONLY_FABRIZIO, JORDAN LYE / GETTY IMAGES. TATYANA SIDYUKOVA / ADOBE STOCK.

captured the same data, using images derived from different reflective wavelengths, in 25 minutes across 800 plots.

WorldVeg has access to even more advanced phenotyping technology: an automated laser scanner that moves over a field and captures 3D models of the plants under any conditions, generating data that enables diverse traits to be measured. This remarkable piece of kit is made by the Dutch biotech company Phenospex.

"It scans the plants in the field every day, three times a day, and shoots light on the plant," explains Derek Barchenger, a US pepper breeding specialist. "[It] then measures the wavelengths of light that are returned so we can figure out how healthy a plant is, how much biomass it has, how big it is, how quickly it's growing – without ever entering the field."

With this system, large numbers of plants can be monitored and then challenged to find the superstars. "I can see how this plant is feeling in this environment in real time," says WorldVeg's Schafleitner. "I can grow it in a hot and humid summer, I can flood it, I can put other stresses on it, whatever, and then select the plants with the most interesting responses." By doing this, his team has generated improved crops such as flood-tolerant okra and peppers tolerant to heat stress.

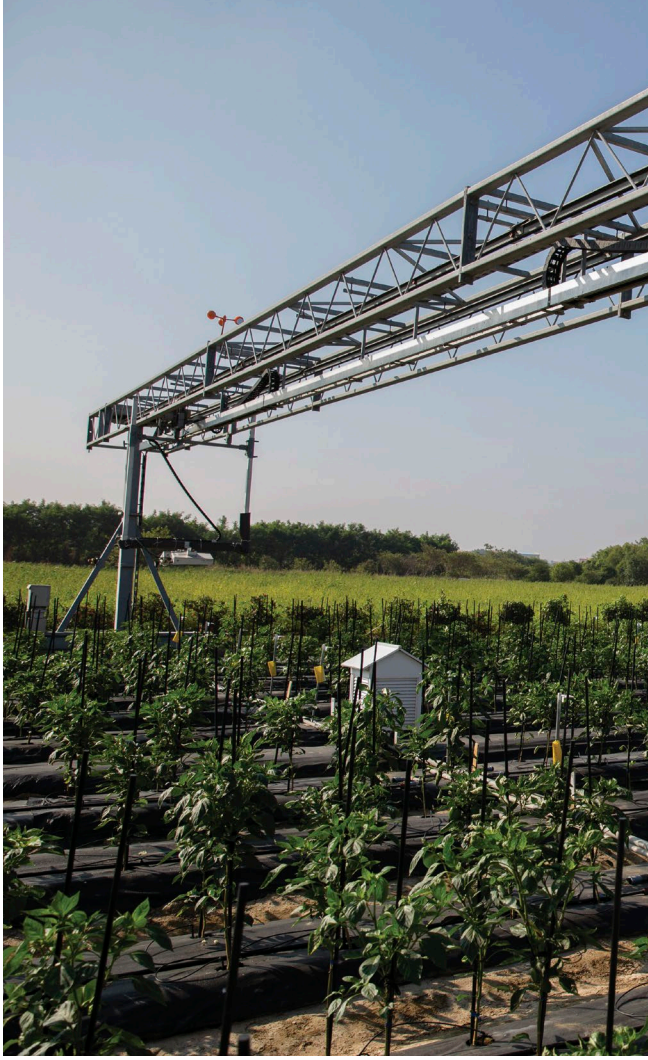
It's impossible to overstate the significance of this. Attributes such as heat tolerance derive from a combination of traits, not just one. For the peppers, researchers combined 75 different traits ranging from plant height, biomass and pollen variability to leaf area, angle, colour and yield, measured during the entire plant life cycle to select heat tolerant plants.

"You can imagine, without a machine like [the] Phenospex [one], we would rely on only a few traits for selection and probably miss important features," Schafleitner explains. Collecting 75 traits from plants in the field would require 400 people to work 24/7, he adds. "Now, measuring plant parameters is automatised and we just need a few gardeners to take care of the plants and harvest the product at the end."

The sheer amount of information gathered is mind-boggling, with millions of data points. But artificial intelligence and machine learning have unlocked new ways to combine genotypic and phenotypic data to process multitudes of traits simultaneously and provide a more complete picture of how plants respond to stresses. This

Chutchamas (Chat) Kanchana-Udomkan, director of the Tropical Vegetable Research Center in Thailand

Shanice Van Haeften, PhD student, intern at WorldVeg



CLOCKWISE FROM LEFT: NIKOX2 / ADOBESTOCK; WORLDVEGETABLE CENTER X3; LIGHTFIELD STUDIOS / ADOBESTOCK.

THE FATHER OF GENEBANKS

You can't talk about genebanks without talking about the Russian scientist Nikolai Ivanovich Vavilov. "He is a pioneer of collecting vegetables, of crop diversity ... [and] founded, in my opinion, the best collection of crops, which is still in place in St Petersburg; it's huge," says WorldVeg's Roland Schafleitner.

Vavilov, a geneticist and plant breeder, was born in 1887. Dedicated to eliminating hunger and famine, he travelled the world on more than 100 expeditions searching for wild relatives of cultivated crops, proposing that crossing them would make their offspring more resilient.

***Russia Today* called him "one of the most outstanding scientists of the 20th century". Recognising the need to store and conserve seeds, Vavilov's collection grew to 250,000 specimens: the world's first genebank. By 1934 he had founded more than 400 research institutes with 20,000 staff to run plant breeding programs and experiments.**

Politics became Vavilov's nemesis as his approach to genetic breeding lost favour. After Stalin replaced Lenin in 1924, a different concept of genetics proposed by plant breeder Trofim Lysenko took hold (and was later debunked).

Accused of sabotaging Soviet agriculture and being an English spy, Vavilov was imprisoned. He died, ironically of starvation, in 1943.

Phenospex technology (left) is the next-gen of WorldVeg, which has just turned 50 (Myra Wopereis is pictured at the celebrations below).

> "If we had not shared germplasm in our history, potato would only be eaten around Lake Titicaca."

improves the accuracy of selecting better performing individuals to enhance the gene pool and help breeders select their desired plants.

For the global good

Ultimately, the goal is to share seeds. "The genebank is not a museum," says Schafleitner. "If we had not shared germplasm in our history, potato would only be eaten around Lake Titicaca and in Europe you would starve."

WorldVeg has shared more than 700,000 seed samples with researchers and breeders in more than 200 countries, and in 2022 was the largest contributor to the Svalbard Global Seed Vault, on the island of Spitsbergen in Norway. It also provides free seed kits to farmers.

An important advantage of WorldVeg seeds is that they are open pollinated rather than hybridised. "So you can use the next crop from the last crop, and it fits in with the farmers' culture of saving seeds," says Rugalema.

Derek Barchenger
US pepper breeding specialist

While open pollination is unrestricted and creates greater genetic variation, hybrids are controlled combinations of pure lines. They might produce improved plants but when their seeds are planted, they don't carry the original traits of the parents. So, you might get one line that is productive but not adapted to the environment, and vice versa. "It's like crossing a horse with a donkey," says Rugalema, "and then you get this stupid mule."

In Africa, N'Danikou distributes seed kits to farmers, focusing on traditional vegetables that are not commercially available, and he trains them to grow and save the seeds for replanting. To date, he estimates they have distributed more than half a million seeds across 10 countries in Africa alone.

His personal favourite, yantoto (*Launaea taraxacifolia*), also known as wild lettuce, is of course one of the traditional vegetables he is dedicated to keeping alive.

"In my position today, I try to revive some of those stories by going back to such communities, and encouraging them to preserve and share seeds with the genebank so we can conserve those treasures," he says.

NATALIE PARLETTA attended WorldVeg's 50th anniversary as part of a Food Security Journalism Award from the Crawford Fund, which she won for an article published in *Cosmos* Issue 82.