Could a sorghum from Ethiopia offer a pathway to food security in a drier world? **Wendy Pyper** reports.


Wendy Pyper

feeding the future

Australian grain growers face three major challenges this century, according to the Grains Research and Development Corporation: meeting quality requirements, increasing productivity and protecting and enhancing the environment.

But can these challenges be met in a world where 25% of the population is expected to experience severe water shortages by 2025, and food consumption in the next 50 years will be double that of the past 10 000 years?

Part of the answer may lie in the development of drought-resistant cereals such as sorghum. While sorghum is the fifth most important food crop in the world, behind wheat, rice, maize and potatoes, researchers anticipate its promotion up the ranks thanks to its remarkable ability to stay green and fill grain during drought.

This ability was vividly imprinted on the mind of Queensland Department of Primary Industries (QDPI) crop physiologist, Dr Andrew Borrell, when he visited India's International Crops Research Institute for the Semi Arid Tropics (ICRISAT) in 1995.

'I was standing in a field of sorghum during southern India's dry season,' he recalls. 'Massive cracks snaked through the clay soil and most of the sorghum lines were dead, yielding about one tonne per hectare.

'But one sorghum line from Ethiopia stood defiantly in the field with a strong green stem, three large green leaves in the upper canopy and a considerable panicle yielding close to three tonnes per hectare.

'I was amazed at the resilience of this line and determined to find out what drought-resistance mechanisms contributed to its remarkable survival.'

Since then, Borrell and his colleagues at the Hermitage Research Station in Warwick have unravelled many of the physiological mechanisms behind this drought resistant or 'stay-green' trait.

With the help of CSIRO Plant Industry molecular biologists, the search for the genes responsible for stay-green is continuing apace.

Elements of the physiology and genetic work are also being carried out by American collaborators at Texas Tech University, Texas A&M University and the University of Missouri.

As a result of this work, new drought-resistant sorghum varieties will be developed at Hermitage Research Station, using a combination of traditional plant breeding and modern molecular techniques. QDPI principal plant breeder, Dr Bob Henzell, says these new varieties will offer many benefits.

'Sorghum that provides higher yields in low soil moisture conditions would benefit producers through increased production, animal feed industries through increased reliability of supply, and Queensland's export position as a reliable supplier of sorghum to global markets,' he says.

'The international implications are even greater, as sorghum is a staple food for 400 million people in 30 countries. In many cases crops are grown under less than ideal conditions, and improving yield could have a significant effect on food supply.'

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Top: Dr Andrew Borrell and his colleagues at the Hermitage Research Station in Warwick have unravelled many of the physiological mechanisms behind the drought resistant trait contained in a sorghum line from Ethiopia.

Above: While sorghum is the fifth most important food crop in the world, behind wheat, rice, maize and potatoes, researchers anticipate its promotion up the ranks thanks to its remarkable ability to stay green and fill grain during drought.

Stay-green physiology

How does the stay-green trait work?

'Understanding the stay-green phenomenon is akin to piecing together a jigsaw puzzle of considerable complexity,' Borrell says.

'Some of the pieces describe the processes determining the onset and rate of leaf death.

'Others relate to transpiration (water use) and transpiration efficiency, and still others link leaf longevity and grain yield.

'Not surprisingly, nitrogen is a key piece of the puzzle.'

Borrell says the onset and rate of leaf death in sorghum can be viewed as the balance between nitrogen demand by the grain and nitrogen supply during grain filling. When water is limited during grain filling, the leaves of 'senescent' (drought susceptible) plants die progressively from the base up, as nitrogen is extracted from the photosynthetic pigments in the leaves to supply the grain.

While nitrogen can be extracted from the soil, studies have shown that under drought conditions, nitrogen remobilisation from vegetative tissues is particularly important for grain growth.

If water limitation continues, the stems eventually yellow and die as well.

'The plant literally self-destructs in an effort to fill its grain,' Borrell says.

In contrast, plants containing stay-green genes originating from sorghum lines of Ethiopia (B35) or Nigeria (KS19) have more nitrogen in their leaves than senescent plants.

Borrell's research has shown that under drought conditions this higher 'specific leaf nitrogen' delays the time and rate at which leaves die.

This means the plants stay green for longer and are therefore capable of producing more biomass (carbon) through photosynthesis.

Enhanced transpiration efficiency may also enable the plants to use water more efficiently to assimilate carbon.

Ultimately, grain yields increase, compared with senescent plants.

'In some experiments, stay-green plants produced 47% more biomass after flowering than their senescent counterparts,' Borrell says.

'Grain yield also increased by 0.35 mg per hectare for every day that onset of leaf death was delayed beyond 76 days after emergence.'

Field trials have also shown that stay-green plants take up more nitrogen from the soil than senescent plants under drought conditions.

This is likely to be due to the continued availability of carbon from photosynthesis for root growth.

As a result, even in conditions of low soil nitrogen (40 kg N / ha compared with 300 kg N / ha) grain yield was enhanced in drought conditions.

Commercialising stay-green

How do scientists get these beneficial stay-green characteristics into commercial sorghum crops adapted to Australian conditions?

For the past 20 years, Henzell, and more recently his QDPI colleague, Dr David Jordan, have bred drought resistant sorghum by crossing plants containing the B35 or KS19 source of stay-green with plants containing other useful traits, such as midge-resistance and high grain yield.

The traditional breeding method involves testing the progeny of these crosses for desired traits, such as the ability to stay green under water stress.

Progeny expressing such favourable 'phenotypes' are then 'intercrossed' to produce another set of progeny for further phenotypic testing.

'It's a slow process, but we've developed germplasm with high levels of midge resistance combined with moderate levels of stay-green and high grain yield. This material is now benefiting grain-growers in Australia,' Henzell says.

Thanks to genetic technology, however, a much faster and more targeted method of producing plants with even higher levels of stay-green is now available to breeders.

Genetic markers

The method comes courtesy of research by Dr Lynne McIntyre of CSIRO Plant Industry, and QDPI scientists Dr Yuezhi Tao and Dr David Jordan (both formerly of CSIRO Plant Industry).

For the past 10 years, the trio has been developing a genetic map from a population of plants containing the B35 source of stay-green.


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QDPI principal plant breeder Dr Bob Henzell has developed commercial sorghum lines with high levels of midge resistance combined with moderate levels of stay-green and high grain yield.

The map consists of hundreds of flags or 'molecular markers' that help researchers identify each of sorghum's 10 chromosomes, and specific regions on each chromosome.

Importantly, some of the markers are closely associated with five gene regions or quantitative trait loci (QTL) thought to be responsible for the stay-green trait.

How many genes each QTL contains is anyone's guess, but as the genetic gap between the QTLs and markers continues to narrow, the molecular biologists' chances of pin-pointing them will increase.

Henzell and Jordan can now use the molecular markers associated with stay-green to test the progeny of their breeding program.

They do this by taking a small tissue sample from the progeny of different crosses, extracting the DNA, and looking for the presence of the relevant markers in that DNA. The technique has a number of advantages over the traditional selection methods.

'A number of genes control the stay-green phenotype, and have different functions' Jordan says.

'Rather than selecting on phenotype, which is the expression of all these genes, we can use the molecular markers to identify plants containing particular QTLs that have favourable effects, such as high levels of stay-green and good grain yield.'

United States association

To speed up the identification of the stay-green genes and their function, Borrell and Jordan are collaborating with scientists from Texas Tech University, Texas A&M University and the University of Missouri.

'Australia has strengths in plant breeding and physiology, so we can develop different stay-green populations and determine gene function through physiological experiments,' Borrell says.

'The Americans, on the other hand, have excellent biotechnology facilities for fine mapping and map-based gene cloning.'

Borrell is conducting physiological tests on several genetically similar sorghum lines developed by the Americans, with and without the key genomic regions for stay-green.

QDPI molecular biologist and plant breeder Dr David Jordan and his colleagues are helping to develop commercial lines of drought-resistant sorghum and identify the genes responsible for stay-green.

By measuring traits such as rate of leaf appearance, leaf growth and death, leaf greenness, water uptake from soil, transpiration efficiency and photosynthesis, he will link phenotype and genotype.

'We will be growing these lines in the field – sometimes under a rain-out shelter to simulate drought conditions – to determine the function of each of these chromosomal regions,' he says.

'We may discover genes associated with increased water use efficiency, reduced rate of leaf death, higher leaf nitrogen status, or increased nitrogen uptake under drought conditions. All these traits will be measured against a senescent line for comparison. We'll then send the results back to the US researchers so that they can identify candidate genes.'

Borrell and Jordan will also send the American scientists ribonucleic acid (RNA) samples from plants showing promising characteristics in the field.

The amount of RNA in a plant cell changes depending on whether a particular gene is 'upregulated' or 'downregulated'. Genes whose expression varies in times of drought are likely to be associated with stay-green in some way.

Using 'micro-array' analysis to examine the RNA, Texas A&M University will be able to determine which genes have increased or decreased activity under drought conditions, controlling the coordinated cascade of biochemical reactions that produce the overall stay-green phenotype.

A blue future

As a result of this research, scientists will know the identity and function of the different genes involved in stay-green, while sorghum breeders will have the tools to develop a new generation of crops adapted to our increasingly dry continent.

Ultimately, the team hopes to transfer the stay-green genes to grain crops less well adapted to dry environments, or to identify similar drought resistant mechanisms in those crops.

For example, rice is grown with quantities of water that are unlikely to be available as urbanisation and industry increase their demands for water.

Borrell contemplates a world in which stay-green rice varieties (genetic solution) might be grown on raised beds (agronomic solution) in rotation with water-efficient legumes (management solution), halving total water use.

'The 1960s and 70s were dominated by the "Green Revolution", when semi-dwarf varieties of wheat and rice were grown with high water and nitrogen inputs to produce record yields of grain,' he says.

'The early 21st century needs to be dominated by a "Blue Revolution" in which genetic, agronomic and management solutions are integrated to ensure food security in the face of global water shortages.'

More about sorghum

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Abstract: Drought-resistant cereals such as sorghum are being developed to feed growing human populations in a drier world. Using sorghum lines from Ethiopia and Nigeria with high resistance to water stress, plant breeders have developed 'stay-green' plants containing other useful traits, such as midge-resistance and high grain yield. Stay-green lines are being genetically mapped and molecular markers identified. Australian and US scientists are working to identify genes associated with water use efficiency, reduced leaf death, higher leaf nitrogen status, or increased nitrogen uptake under drought conditions. Genes whose expression varies in times of drought are thought likely to be associated with the stay-green trait. The research will reveal the identity and function of the different genes involved in stay-green, offering sorghum breeders the tools to develop a new generation of crops adapted to dry growing conditions.

Keywords: sorghum, drought resistance, plant genetics, stay-green genes.

Rice research yields cereal benefits

THE sequencing of the rice genome, completed last year by the International Rice Genome Sequencing Project (IRGSP), will help researchers pinpoint the genes that govern drought tolerance, not just in rice, but in other key crops.

Because the genomes of all major grain crops are highly collinear, with shared genes appearing in similar positions on different genomes, locating a gene for drought tolerance in rice tells wheat researchers, for example, where to look for the equivalent gene in wheat.

Ronald P Cantrell, director general of the Philippines-based International Rice Research Institute (IRRI), says he is confident that one day this will lead to improved drought tolerance in Australian cereals, especially rice and wheat.

'Rice is seen by researchers as a model crop, from which we can learn a lot that can be applied to other cereals,' Cantrell says. 'And the good news is that this is a time of unprecedented growth in our knowledge about rice.'

In December, Japan's National Institute of Agrobiological Sciences (NIAS), the leader of the IRGSP, launched a five-year collaboration with IRRI to unlock the secrets of rice gene functionality, with particular attention to tolerance for stresses such as drought.

The partnership combines the expertise of NIAS as a world leader in rice genomics research, IRRI's four decades of experience in rice biology and breeding, and the vast store of genetic resources held in trust in the International Rice Genebank at IRRI.

Genomics research also promises to accelerate a proposed revolution in rice farming in water-short environments. IRRI is developing so-called 'aerobic rice' for growing in unflooded fields, as wheat is, to cut water losses from percolation, seepage and evaporation. Low-yielding aerobic upland rice varieties already exist for subsistence agriculture in mountainous areas.

The IRRI project aims to develop a package of input-responsive aerobic varieties and agronomic techniques so farmers in irrigated lowlands can maintain high productivity while using much less than the 3000–5000 litres of freshwater currently needed to grow one kilogram of rice. This would preserve world food security while freeing water resources for industrial development and conservation.

'Important aspects of this research are being funded by Australian taxpayers, so we are committed to sharing the benefits with Australian farmers through our collaborative partners in Australia such as the Australian Centre for International Agricultural Research, Yanco Agricultural Institute and the CSIRO,' Cantrell says.

For more information, visit the websites of the Consultative Group on International Agricultural Research (www.cgiar.org) or Future Harvest (www.futureharvest.org). Future Harvest is a non-profit organisation that supports food and environmental research.