Salt tolerance of durum wheat

PROJECT DETAILS

PROJECT CODE: CSP298
PROJECT TITLE: SALT TOLERANCE OF DURUM WHEAT
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SUPERVISOR: RANA MUNNS
ORGANISATION: CSIRO PLANT INDUSTRY
CONTACT NAME: RANA MUNNS

Summary

The project aimed to make durum wheat as salt tolerant as bread wheat so as to give growers more profitable options when dealing with subsoil salinity which is widespread in southern Australia (30% of the wheat belt).

A trait for sodium (Na) exclusion was identified in an ancient durum landrace. The trait was crossed into four durum varieties and advanced breeding lines. The trait is controlled by two major genes and a robust molecular marker was found for one, which proved useful in breeding.

Field trials on saline soil in 2003 indicated a yield advantage of the sodium exclusion trait of 20%.

BC4 Tamaroi and BC2 Bellaroi\(^d\) lines are being evaluated in multiple saline and non-saline sites in 2004.

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Conclusions
1. Durum wheat production can be more profitable
The material produced in this project has the potential to significantly increase the production of durum wheat, and hence the profit margin for growers able to reach the protein levels needed for AD1 (13%) or AD2 (11.5%). In areas with subsoil salinity, the increase in yield is expected to be 20%.

Areas with rising water tables, i.e. suffering from ‘dryland salinity’, may not benefit from this material as the salt tolerant durum may not have sufficient tolerance to withstand the high salinity at the surface.

2. Durum wheat production can be more globally competitive
The germplasm and intellectual property (IP) developed in this project have been protected to make the first release of salt tolerant durum (in the world) available for Australian growers first, and to keep the durum industry competitive for Australian growers by not releasing material to other countries. There has been strong interest from plant breeders in USA and elsewhere to obtain the breeding lines. The seeds will be commercialised through Australian Grain Technologies (ACT) (Tamaroi lines) or New South Wales Department of Primary Industries (NSW DPI) (Bellaroi and related lines).

3. Subsoil salinity is more widespread than was thought five years ago
During the course of this project, the extent and magnitude of subsoil salinity became recognised, mainly due to Adelaide scientists who showed that ‘transient’ salinity was affecting the yield of durum wheat and other crops in South Australia (SA) and the Victorian (VIC) Mallee. More recently this has been recognised in western New South Wales (NSW) and Queensland (QLD). This is being confirmed by surveys conducted as part of the GRDC Subsoil Constraints Initiative (SIP08). As other constraints such as infertility, acidity or aluminium (Al) toxicity are being overcome, along with disease resistance, subsoil sodicity or salinity is showing up as a major constraint. That is, there is unused water remaining in the soil at harvest.

Growers in SA may benefit most from salt-tolerant durum wheat lines as subsoil salinity is so widespread (two thirds of the SA wheat belt, according to Rengasamy, 2002). Growers in the Victorian Mallee would also benefit, where good nitrogen management of soils by rotation with pulses produces high N crops but subsoil salinity restricts the growth of current durum varieties. Durum growers in northern NSW and QLD would benefit as there are significant areas of subsoil salinity. Very recently, the origin of shallow water tables on the Liverpool Plains has been shown to predate cropping (Young et al., AJEA 2004), so even there, cropping is acceptable, as long as it can use all the available water.

Recommendations
1. That the wide ranging usefulness of increasing crop salt tolerance be assessed. All Australian crops need salt tolerance. Increasing the salt tolerance of crops means that more of the available water would be used. This has two benefits; reducing any leakage to ground water and providing a higher yield.

2. That the extent of subsoil salinity in the Australian wheat belt be documented.
3. That interaction between relevant GRDC projects in Programs 1 and 4 (Winter Cereals and Sustainable Farming Systems) be encouraged and facilitated.

4. That a crop or plant physiologist working with salt tolerant material, or plant breeder, be invited to participate in annual meetings of relevant Southern Farming Systems (SFS) projects and initiatives, particularly of SIP08.

**Outcomes**

Lack of salt tolerance limits durum production in Australia, particularly in south-eastern Australia where subsoil salinity is widespread. The expected 20% increase in yield in saline soil from the new salt tolerant durum lines produced in this project will make growers more competitive in the global grain market and have the following outcomes.

The most advanced lines, BC4 lines in Tamaroi background, are being evaluated this year on nine ‘non-saline’ sites in South Australia, Victoria and New South Wales by ACT in their commercial breeding program, and by University of Adelaide (UA) on three saline sites in SA. BC2 lines in four different backgrounds are being evaluated by NSW DPI on two saline sites in northern NSW.

**Economic outcome**

**Benefit to the durum industry**

Durum production in Australia is expected to reach 1,000,000 tonnes in the next few years, an average yield of 3.3t/ha from 300,000ha. At least one quarter of this will be from soils with subsoil salinity to various degrees. If the new salt-tolerant durum increases yield in these soils by 20%, then national production could increase by 50,000 tonnes, i.e. by 5%. The area under durum production may also increase, therefore increasing national production by another 5%. A total of 10% increase in yield will bring an extra $18 million at the current price of $180 a tonne.

Expansion of the durum industry in different regions will also provide more stability in national production as losses due to drought, frost, flooding or late season rains are usually regional.

**Benefit to the grower**

Durum growers in areas affected by subsoil salinity will benefit directly by the 20% increase in yield. Even in areas that only currently produce 2t/ha, the increased return would be $72 per ha at current prices.

This current research has shown that durum wheat is now as salt tolerant as bread wheat. This enables a grower to switch from bread wheat to durum wheat with no extra inputs, as long as soil acidity or crown rot are not restricting production. If growers can produce Prime Hard at 13% protein or Australian Hard (AH1) at 11.5%, then they could produce AD1 (13%) or AD2 (11.5%) with no extra inputs. For a three tonne crop, if the input costs are $250 per ha, and the extra return for durum as against bread wheat is $30 per ha (e.g. $180 per tonne for durum wheat versus $150 for bread wheat), then the extra return is $90 per hectare and the grower can increase his profit margin by 50%.

In addition, there is the flow on effect of durum wheat to the domestic pasta industry, where milling and pasta production derive additional benefits.

**Environmental outcome**

Increased salt tolerance of durum wheat means that more of the available water will be used. This has two benefits, reducing any leakage below the root zone and providing a higher yield in soils with moderate salinity.

**Social outcome**

Regional development will receive a flow on effect from farms remaining viable despite salinity.

**Achievements/Benefits**

**The problem being addressed**

Lack of salt tolerance limits durum production in Australia, particularly in south-eastern Australia where subsoil salinity is widespread. In South Australia and Victoria, two thirds of the agricultural areas have saline subsoils, and in New South Wales and Queensland, probably one third of the soils have sodic or saline subsoils, commonly both. As other constraints such as nutrient deficiencies and disease resistance are being overcome, subsoil sodicity and/or salinity is showing up as a major constraint. One indication of this, in the 250-450mm rainfall belt, is unused water remaining in the soil at harvest. Roots may
not penetrate below 60-80mm where there is often a sodic layer.

Project aim
The project aimed to increase the salt tolerance of durum wheat, as its sensitivity to sodic or saline soils is limiting its production, particularly in SA. The basic aim was to make durum wheat as salt tolerant as bread wheat to give growers more profitable options when dealing with saline soils.

Background
Bread wheat is more salt tolerant than durum wheat because of genes for sodium exclusion located on the D genome, which allow roots to discriminate against sodium in favour of potassium. It was speculated that similar discrimination exists in the A or B genomes of durum wheat or its close tetraploid relatives that has not been captured during the evolution of durum wheat. A large number of tetraploid lines in the Australian wheat collection were screened and a source of discrimination was found in an ancient durum landrace, which has been named the trait for sodium exclusion. Sodium is excluded by roots, in favour of potassium. The introduction of this trait into modern varieties has the potential to make them as salt tolerant as bread wheat.

This project (CSP298) was initiated to introduce this trait into durum varieties and to find a molecular marker to accelerate the breeding process.

Project results
Genetic analysis showed that the trait is determined by two major and interacting genes. It has a very high heritability (realised heritability of 0.9).

Proof of concept that the sodium (Na) exclusion trait improves salt tolerance was shown in glasshouse studies. Durum genotypes with the trait had a yield advantage (20%) over those without the trait at moderate salinity (75mM NaCl). However, there was no yield advantage at high salinity (150mM NaCl), where other traits for salinity tolerance are necessary.

A molecular marker for sodium exclusion in durum wheat was developed and verified. From a cross between durum landrace line 149 (very low Na) and durum Tamaroi (high Na), a quantitative trait locus (QTL) was mapped on chromosome 2A (LOD score of 7.5) for the phenotype of low Na accumulation in the leaf blade, and a public domain microsatellite (Xwmg312) was identified closely linked to this trait. It accounts for 38% of the phenotype variation. The name ‘NaX1’ is proposed for this locus. It probably accounts for one of the major genes.

The linkage was verified in four other populations with unrelated genetic background. The Xgwm312 marker is being used in the backcrossing program and can reliably identify plants with extremely low Na.

The low Na trait from line 149 was backcrossed into three durum varieties (Wollaroi, Tamaroi, Bellaroi) and one advanced breeding line (960273), with recurrent selection at each F2. Thirty BC4F3 families were selected for advancing as breeding lines. The lowest Na individuals containing the Xgwm312 marker were selected in the F2 progeny, to ensure that the original trait carried by two genes was retained. Low Na selected families have leaf Na concentrations of 170 mol/g dry weight (DW) or less; high Na selected families close to their parents being 670 mol/g DW for Wollaroi, 895 mol/g DW for Tamaroi, 1278 mol/g DW for Bellaroi and 1245 mol/g DW for breeding line 960273.

Recurrent parent number of lines - status of advanced breeding material (BC4F4 or F5)
(low/high Na):
Tamaroi 28/25 Undergoing field evaluation at 12 sites (SA, VIC, NSW, Canberra). This includes nine sites for commercial consideration by AGT.
Wollaroi - Discontinued as Wollaroi superseded by Bellaroi.
Bellaroi 20/10 Bulking up in Canberra.
BL 960273 21/9 Bulking and field evaluation in Canberra. These are being fast-tracked through summer nurseries in Canberra.

As well, 32 BC2F5 families in four recurrent parents, Tamaroi, Bellaroi, Wollaroi and advanced breeding line 960273 are being tested on two saline sites in northern NSW by Ray Hare (NSW DPI). These comprise low sodium and high sodium contrasting lines in each background, selected at the BC2F2 stage.
Field trials of derived material (BC3 crosses of line 149 into the boron-tolerant durum, Kalka\(^6\)) on saline soil in SA in 2003 (run by Tony Rathjen and David Cooper) showed a yield advantage of 20%. These BC3 lines have only one gene from line 149 (verified by using Xwmg312).

More extensive field trials this year in SA indicate that the yield advantage could be even more than 20%, especially in areas with higher subsoil salinity. This would make it as tolerant as bread wheat, perhaps more so. The yield data for the 2004 field trials are not yet in.

Grain Na analysis showed that, although the Na content of grain is very low compared to shoots and roots, it reflects both the soil salinity level and the genotypic differences in the Na exclusion trait.

**Physiological mechanisms**

Studies on mechanisms for sodium exclusion in line 149 showed that it differed from Tamaroi in two control points for Na accumulation in the leaf blade: (1) low rates of net loading of the xylem going to the shoot and (2) high retention of Na in the leaf sheath. These add together to give very low rates of accumulation in the leaf blade.

Recent results indicate that the mechanism of high retention of Na in the leaf sheath is linked to the Xgwm312 marker and the Na1 locus. Also that this trait is lacking in bread wheat, so this opens an opportunity to increase the salt tolerance of bread wheat. The mechanism of xylem loading is controlled by a second locus which has been named Na2, but as yet does not have a molecular marker.

**Other traits for salt tolerance in tetraploid wheat**

Tetraploid germplasm was screened for other traits that might confer tolerance of higher levels of salinity, such as tolerance of high internal Na levels, high shoot vigour, or high root vigour. Genetic variation was found, crosses made, and lines are being propagated by single seed descent. Crosses between five tetraploid lines with apparently high tolerance of high leaf Na concentrations were made with two durum varieties (Wollaroi and Tamaroi) and are progressed through single seed descent from F2 to F3. This material will be assessed in the new durum project CSP00058.

**Other research**

1. **Extending the salt tolerance trait into other adapted varieties**

   Traits for water use efficiency (WUE), early establishment and greater agronomic flexibility will be pyramided with the Na exclusion trait in the new project CSP00058 ‘Development and delivery of salt tolerance and water use efficiency (WUE) traits for durum with diversified genetic background’. This includes crosses into the boron-tolerant Kalka\(^6\) and into durum germplasm with diversified genetic background advanced by AUSGRAINZ for disease resistance and later maturity.

2. **Grain sodium as indicator of subsoil salinity**

   An unexpected result was that grain Na not only indicates the genotypic differences, but also the soil salinity and can be used retrospectively, in combination with check varieties to validate the genotype and also the amount of salt seen by roots. This has benefits over soil sampling because it is less laborious and integrates over time. This relationship is being tested this year. It could prove useful to agronomists assessing the degree and local variation in subsoil salinity.

3. **Salt tolerance of bread wheat**

   Results indicate that at least one of the two mechanisms present in the durum landrace line 149 is not present in bread wheat, and may enhance its tolerance especially at higher salinities or in the presence of waterlogging. Bread wheat has control of xylem loading in the roots, but does not have the trait of Na retention in the leaf sheaths. To enhance the Na exclusion capability of bread wheat, direct crosses have been made with several bread wheat varieties and seed is ready for testing. Direct crosses into several bread wheat varieties have been made and a new project CSP00059 has started which will test this. Crosses with Westonia, Janz, Carnamah, Yitpi\(^6\), Chara and Sunstate are at BC2F3 or BC3F3 stage.

   It is known that root control of Na uptake depends on a high rate of energy-consuming efflux, and it is suggested that bread wheat could benefit from having the mechanism of Na retention in the leaf sheaths (the Na1 locus, linked to Xgwm312). This would be particularly useful at high salinity or during periods of waterlogging and other conditions that impair root function such as soilborne pathogens.

4. **Potassium (K) deficient soils**
K deficiency is a major problem for wheat crops grown on sandy soils in Western Australia (Brennan et al., AJEA, 2004). Furthermore, K deficiency may be common in the leached soils in the higher rainfall zones of southern Australia. The Na excluding wheat lines also have enhanced K uptake, even in the absence of salinity. Thus the character may be beneficial in non-saline soils.

**Intellectual property summary**

A patent application covering the use of markers to introduce the Na exclusion trait from line 149 into durum wheat was filed by CSIRO Plant Industry (PI) in June 2004: 'Markers for salinity tolerance in wheat plants and the use thereof in breeding programs'. This was filed before the paper by Lindsay et al. (2004) listed below was submitted for publication.

All breeding lines were protected to allow full commercialisation benefits to Australian plant breeding companies. Germplasm was released to a limited number of people under Material Transfer Agreements (MTAs) for research purposes only.

**Additional information**

Key publications