Our understanding of yellowing in wheat (so far…)

September 2016

Why do the trial?

Yellowing in wheat is often observed in the paddock and appears to be triggered and exacerbated by stress, such as unfavourable wet and cold conditions. We also see a different style of yellowing in what appear to be stress free favourable conditions such as a warm wet mild spring or summer conditions in the greenhouse. We know that this yellowing is not a disease and its severity is variety dependant and interacts with the environment. Adding nitrogen may reduce the yellowing a little but nitrogen deficiency is not the cause of the yellows.

Determining the cause of yellows in the paddock is made difficult for three reasons. Firstly, although yellows seems to be associated with cold, wet conditions, this is not always the case, and not in all varieties, therefore it is difficult to artificially induce for research purposes. Secondly, nutrition influences the severity of the yellows but the inherent differences in soil type and fertility between regions make it difficult to identify any specific cause. Leaf analysis of plants affected by yellows in earlier research did not identify consistent differences between affected and unaffected plants (AGT Factsheet "Yellowing in Wheat" 2013). Thirdly, the yellows manifests differently in different varieties. The combination of these factors makes a simple explanation very unlikely.

However, two observations provided leads for us to investigate further:

1. Chloride deficiency in durum wheat leads to symptoms similar to that seen in Wyalkatchem/Mace/Corack (Schwenke, Simpfendorfer & Collard 2015).
2. Field observations by breeders suggest that boron tolerance in wheat appears to be related to higher levels of yellowing.

What did we do?

The varieties

Varieties (11 bread wheat and two durum) were selected based on previous research, and field and glasshouse observations. The bread wheats were selected to represent the RAC875 (Gladius), Spear and Wyalkatchem families, with individuals selected from each family that are boron tolerant or intolerant (Table 1). We have confirmed boron tolerance in these lines using a molecular marker to detect the presence of the Bo1 boron tolerance gene.

RAC2040-BoIntol and RAC2040-BoTol are unreleased 'near isogenic lines', that is, they are derived from RAC2040 and are, to the best of our knowledge, identical except for the presence (RAC2040-BoTol) and absence (RAC2040-BoIntol) of the boron tolerance gene. These lines provided the initial connection between the boron tolerance gene and yellows when it was noticed that the yellows was quite obvious in RAC2040-BoTol, yet non-existent in RAC2040-BoIntol I when grown side-by-side. This observation led us to look at other varieties affected by the yellows and we found that they too were boron tolerant. RAC1537 and WAGT487 are unreleased lines that display very severe yellows in some environments. Like Scepter, RAC1537 is very closely related to Mace but in environments where the yellows occurs it is yellower than Mace, while Scepter is greener than Mace.

Table 1: Varieties used in the yellows trials, showing boron tolerance and family of origin.

Name	Boron Tolerance	Family	Chloride Experiment	Boron Experiment	Paddock Experiment
Axe	✗	RAC875	✓	✗	✓
Kord CL Plus	✓	RAC875	✓	✗	✓
Frame	✓	Spear	✓	✗	✓
Phantom	✓	Spear	✓	✗	✓
Wyalkatchem	✗	Wyalkatchem	✓	✓	✓
Mace	✓	Wyalkatchem	✓	✓	✓
RAC2040-BoIntol	✗	Wyalkatchem	✓	✓	✓
RAC2040-BoTol	✓	Wyalkatchem	✓	✓	✓
Scepter	✓	Wyalkatchem	✓	✓	✗
WAGT487	✓	Wyalkatchem	✓	✗	✗
RAC1537	✓	Wyalkatchem	✗	✓	✗
Hyperno	✗	Durum	✓	✗	✗
Jandaroi	✗	Durum	✓	✗	✗

Chloride hydroponics experiment

Twelve varieties (ten bread wheat and two durum) were grown in a greenhouse, using vermiculite filled 900ml pots in three replicates until harvest ready. The varieties were selected based on tendency to get yellows in the paddock and on a previous study that tested the effect of chloride on wheat (Schwenke, Simpfendorfer & Collard 2015). The vermiculite was washed using laboratory grade filtered water to remove any trace of chloride. Nutrient solutions were made using a commercial nutrient mix and laboratory grade filtered water to eliminate any chloride. There were two treatments: control and chloride. The commercial nutrient mix did not contain chloride so this was used as the control. The chloride treatment had chloride added to a concentration following the study by Schwenke, Simpfendorfer and Collard. Plants were scored for the yellows, heading date, biomass, seed number, seed size characteristics, flag leaf length, head length and tiller number.

Boron hydroponics experiment

Six varieties were grown in a greenhouse, using vermiculite in 900ml pots in 3 replicates until harvest ready. These varieties were a subset of those in the chloride trial, based on boron tolerance and the tendency to express the yellows under favourable conditions in the field or greenhouse. Nutrient solutions were made using rainwater to eliminate any boron, and the same commercial nutrient mix, including chloride that was used in the chloride trial. Three treatments were used: a control and two higher rates of boron. The nutrient mix contains the correct amount of boron for healthy plant growth so this was used as the control. The other two treatments had boron added based on previous research into boron toxicity in wheat. All plants were scored for yellows, boron toxicity effects, tiller number, grain number and heading date. The difference between physiological yellows and boron toxicity was evident (Figures 1 and 2).

Figure 1 shows the physiological yellows. This is seen as pale blotches on the lower leaves. The effect of boron toxicity is seen as leaf tipping, extending down the leaf as the symptoms become more severe (figure 2).

Figure 1: Physiological yellows.

Figure 2: Boron toxicity effect

Paddock experiment

Eight varieties were grown in three replicates at three sites (Roseworthy, Rudall and Kaniva), for two years. Four pairs of varieties were selected, the pairs were selected from the same family but differed for their expression of the yellows. Twelve treatments were used: control, boron, zinc, copper, potassium, sulphur, nitrogen, nitrogen plus zinc, trace elements at two rates, Jockey Stayer seed treatment and Jockey Stayer seed treatment plus nitrogen and trace elements. The trials were scored for yellows during the growing season, harvested and yield and seed size characteristics recorded.

What happened?

Chloride hydroponics experiment

The no chloride (control) treatment produced little or no yellows in the varieties that do not have the boron tolerance gene whereas the boron tolerant varieties all developed the yellows. Adding chloride to the nutrient mix reduced the effect of the yellows in most of the boron tolerant varieties but increased yellows in many of the intolerant varieties (Figure 3). Any score of one or lower was deemed not affected by the yellows.

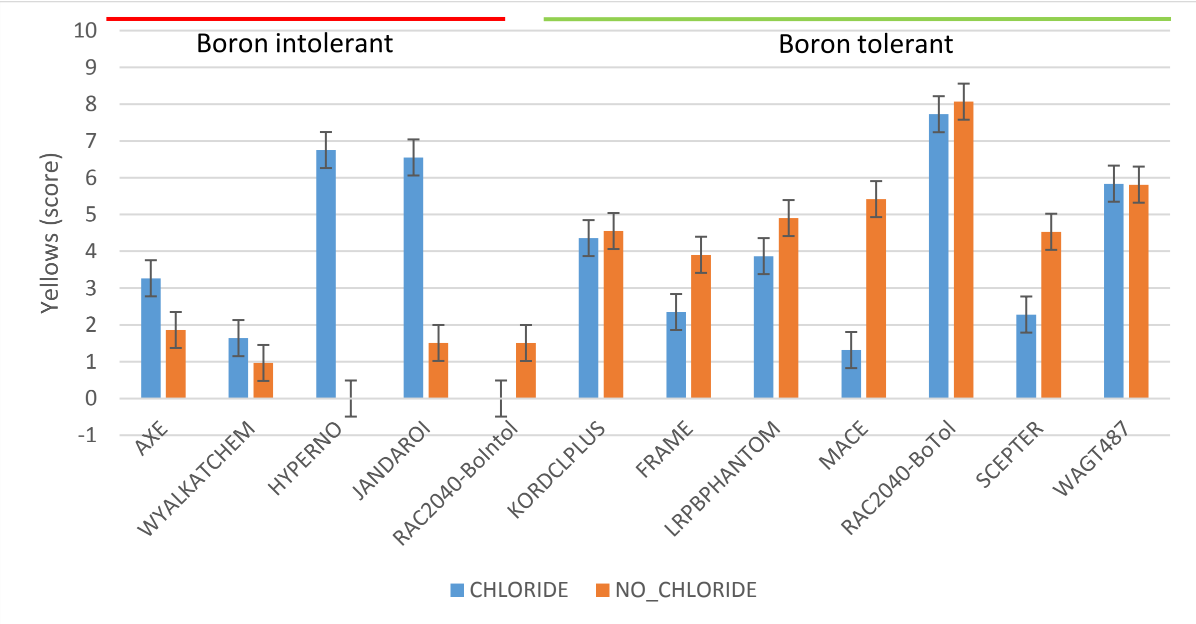

Figure 3: Yellows scores of selected wheat varieties in a hydroponic glasshouse experiment measuring the effect of chloride (0 = green, 9 = 100% yellow). Treatments were either a standard nutrient mix or the standard mix plus 2mM chloride.

Boron hydroponics experiment

Yellows were not observed in Wyalkatchem (boron intolerant) whereas Mace (boron tolerant) was slightly affected when grown without boron (Figure 6). The yellows in Mace reduced as the boron concentration increased. Both Scepter and RAC1537 are boron tolerant. RAC1537, like Scepter, is closely related to Mace but is strongly affected by the yellows. RAC1537 showed a similar response to boron concentration as Mace, but on a greater scale, while Scepter consistently showed less yellows than Mace. RAC2040-BoIntol (the boron intolerant selection of RAC2040) was very similar to Wyalkatchem in response but RAC2040-BoTol (the boron tolerant selection) was the most severely affected variety in this trial (Figures 4 and 5). As was the case with all boron tolerant varieties in this trial, the yellows reduced as the boron concentration increased (Figure 6).

Figure 4: RAC2040-BoIntol in control solution showing no evidence of yellows.

Figure 5: RAC2040-BoTol on control solution showing severe yellows.

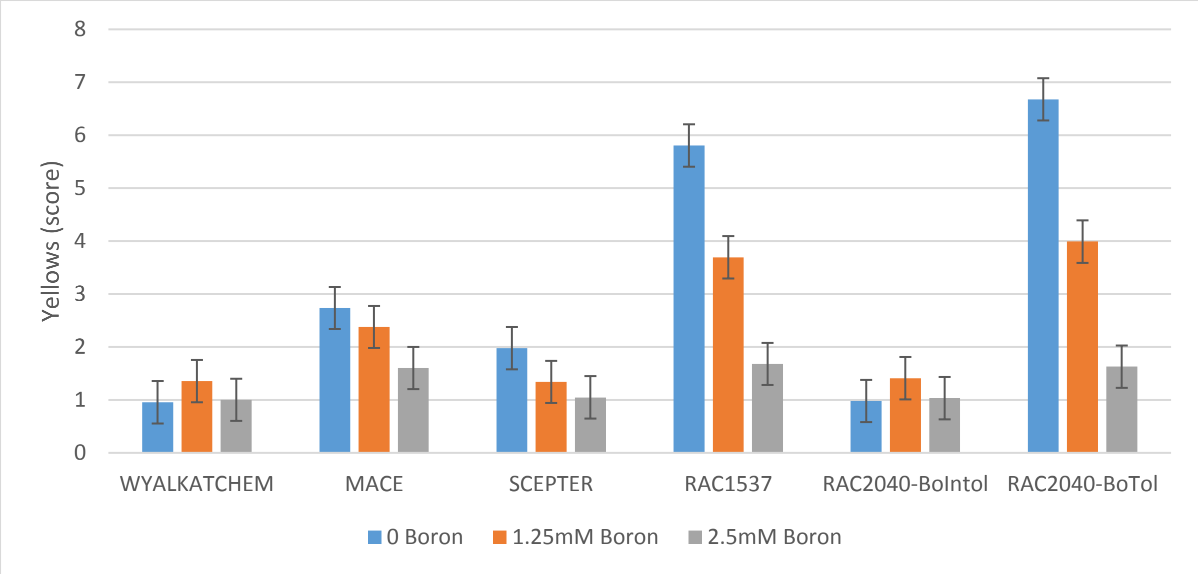

Figure 6: Yellows scores of selected wheat varieties in a hydroponic glasshouse experiment (0 = green, 9 = 100% yellow). Treatments were either a standard nutrient mix or the standard mix plus 1.25mM or 2.5mM boron.

Paddock experiment

The yellows trial was specifically designed to investigate the yellows in southern Australia. Environments and varieties that frequently experience the yellows were selected and treatments that were hypothesised to influence the yellows from previous research or anecdotal evidence were tested. In 2015 the yellows were evident in the trials at Rudall (severe), Roseworthy (moderate) and Kaniva (moderate). The effect of different treatments was highly significant at all three locations. Treatments that included nitrogen had lower yellows scores which confirms that increasing nitrogen can reduce the visual effect of yellows (Figure 7). Beyond this, the field experiments did not help determine the true cause of the yellowing.

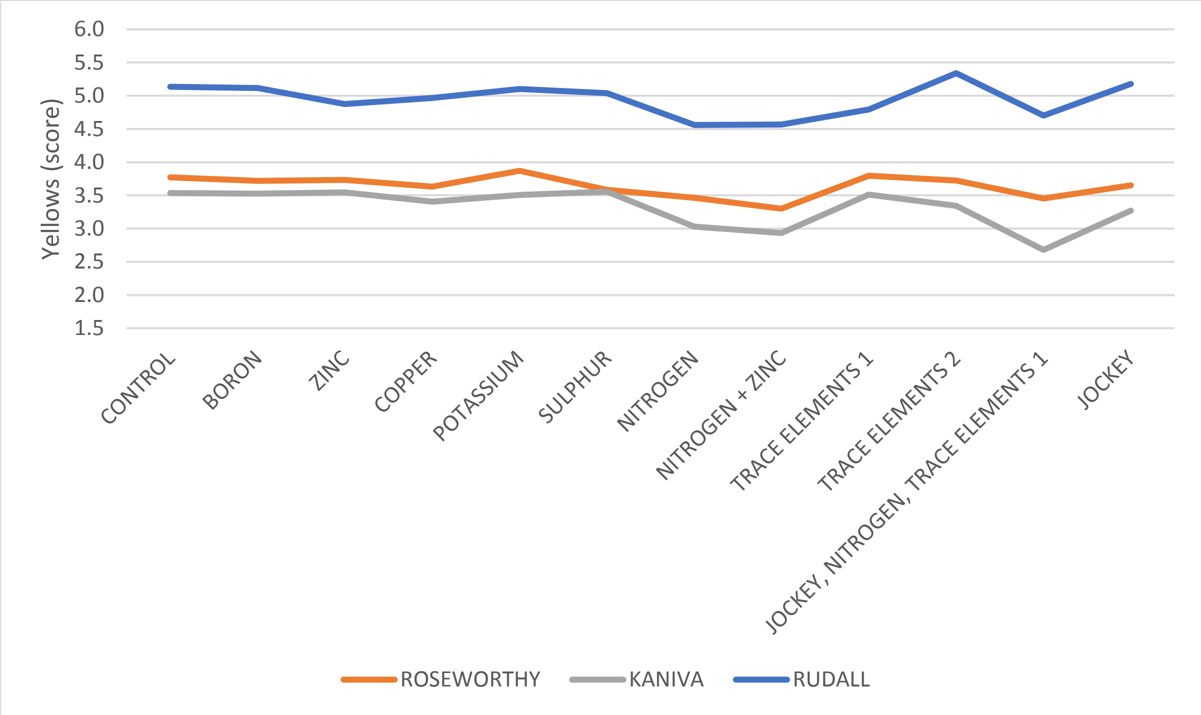

Figure 7: Effect of treatment on the yellows paddock trials at Rudall, Roseworthy and Kaniva, 2015 (0 = green, 9 = 100% yellow).

What does this mean?

The glasshouse trials confirmed there is some nutritional component to the yellows. The absence of chloride produced much greater yellowing in the boron tolerant compared to the boron intolerant varieties (Figure 3). It was interesting that adding chloride increased the yellows in the durum varieties (which is inconsistent with the observations of Schwenke, Simpfendorfer and Collard) and the boron intolerant Axe and Wyalkatchem but not RAC2040-BoIntol. In general adding chloride reduced the yellows in the boron tolerant varieties; Frame, Phantom, Mace, Scepter, Kord CL Plus, RAC2040-BoTol and WAGT487. However, the responses of the different varieties to boron varied and some were not significantly different.

The boron tolerance gene clearly has some role in the occurrence of the yellows. When grown with no added boron, the boron tolerant varieties exhibited high levels of yellows, yet when grown with boron, the yellows did not occur. Conversely, the boron intolerant varieties (Wyalkatchem and RAC2040-BoIntol) showed little to no yellows regardless of the level of boron in the nutrient mix.

The effect of the boron tolerance gene was demonstrated most clearly by the RAC2040 lines. RAC2040-BoTol was the most severely affected by the yellows in the boron trial, and this effect reduced as boron concentration was increased. RAC2040-BoIntol was unaffected or very slightly affected by yellows regardless of the boron concentration. Why the boron gene contributes to the yellows is not yet clear. More in-depth research is required to solve this question. What we can assume is that a nutrient imbalance is a cause of the yellows, and this is exacerbated by the boron tolerance mechanism. Although adding nitrogen appears to reduce the visual effect, it is not the cause of the yellows itself. The yellow is often observed in very wet conditions, which also cause both nitrogen leaching and soil denitrification and this may explain the positive effect of adding nitrogen. Examining these results together with soil tests from each site has not suggested a particular nutritional cause.

Is there an effect on yield?

From a grower's perspective, this would be the most important question. Although yellows is not a disease, it can make the crop look unsightly but as growers are paid on grain yield, not appearance, protecting grain yield is the ultimate aim. In the field trials reported here, there was no statistically significant effect on yield nor any correlation between yellows score and yield. There was also no correlation between yellows score and tiller or seed number in the glasshouse trials. In earlier research by AGT, yellows and yield were measured at eight sites and at half of those sites there was an effect on yield. However, at three sites where yields were high, varieties with more yellows had lower yields, but at one site where drought was a factor, yield was higher in the varieties with yellows (for a more complete explanation please see AGT Factsheet "Yellowing in Wheat" 2013).

Comparing the effect of yellows on yield between varieties does not necessarily give an answer, due to the extensive genetic variation between varieties. Using near isogenic lines such as RAC2040-BoIntol and RAC2040-BoTol can give a better indication as there is very little genetic variation between these, except for the presence (RAC2040-BoTol) and absence (RAC2040-BoIntol) of the boron tolerance gene. Figure 8 shows the average yields and yellows scores of RAC2040-BoIntol and RAC2040-BoTol. Yellows scores were higher in RAC2040-BoTol than RAC2040-BoIntol at all sites and the yield of the boron intolerant line was also greater at Rudall (1t/ha) and Roseworthy (200kg /ha). It is interesting to note that at Kaniva, where there was a terminal drought, there was no difference in yield between the two lines despite yellows being significantly higher in the boron tolerant line RAC2040-BoTol, a result similar to that reported in the earlier AGT factsheet "Yellowing in Wheat". These results for the RAC2040 isogenic lines show that a yield penalty is associated with a severe case of the yellows. However, it is important to note that RAC2040-BoTol was discarded from the AGT breeding programme due to its severe yellowing and no commercial varieties are affected by yellows to the extent seen in RAC2040-BoTol.

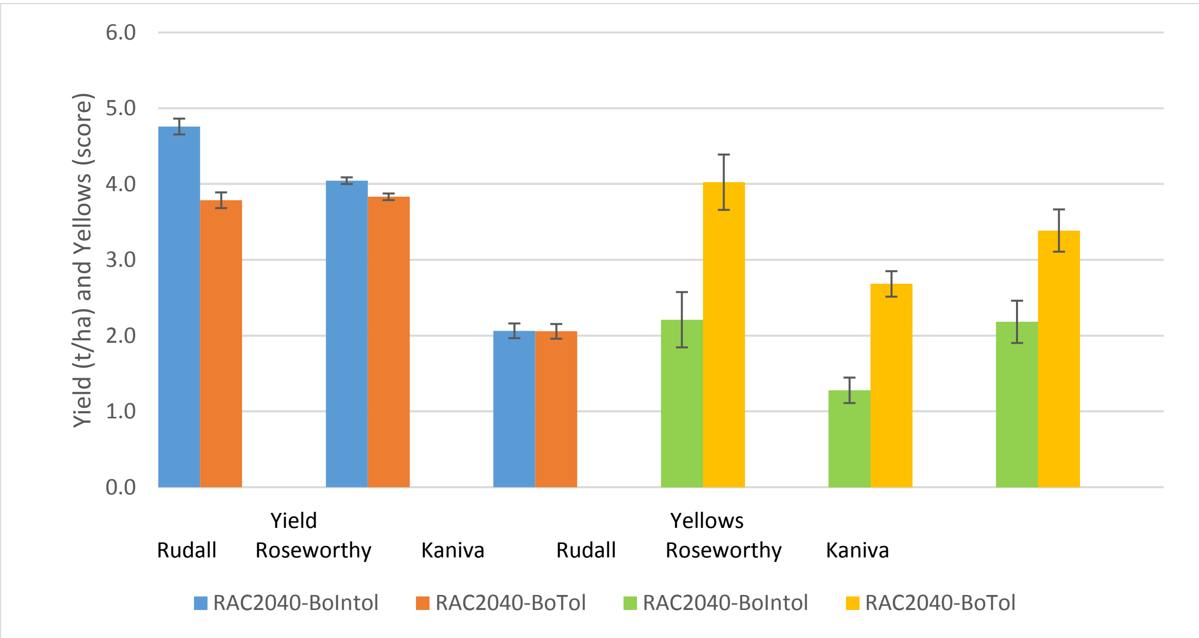

Figure 8: A comparison of average yields and yellows scores of the RAC2040 boron tolerant and intolerant lines in the Rudall, Roseworthy and Kaniva yellows field trials, 2015 (0 = green, 9 = 100% yellow).

Take-home messages

- At this stage it appears there is no significant yield effect associated with yellows.
- There is a nutritional aspect to the yellows.
- Adding nitrogen can lessen the visual appearance of the yellows, but it is not the cause.
- The Boron tolerance gene has some role in the yellows, but it is not the whole story. Scepter, like Mace, is boron tolerant but shows much less yellowing than Mace.

References

Schwenke, GD, Simpfendorfer, SR, & Collard, BCY 2015, 'Confirmation of chloride deficiency as the cause of leaf spotting in durum wheat grown in the Australian northern grains region', *Crop & Pasture Science*, 66, 122–134

For further information please contact:

James Edwards, Wheat Breeder 0427 055 659

Dan Vater, Marketing Manager 0427 188 919