

FINAL REPORT

DAQ00014

Sorghum crop improvement - manipulating height for yield advance in sorghum

PROJECT DETAILS

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Summary

Achieving genetic advances in grain yield in sorghum are currently slow. However, yield increases of up to 10% have been associated with increased plant height. Detailed physiological studies were undertaken to examine the basis of a previously poorly understood relationship between plant height and sorghum yield. The results of field and single plant studies conducted at Hermitage Research Station from 2002-2005 indicated enhanced partitioning to above ground organs may be responsible. Results were incorporated into a PhD thesis and analysis of these findings contributed to the formulation of strategies to manipulate plant height for yield increase in sorghum.

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Conclusions

Research findings showed sorghum grain yield and profitability may benefit from the deployment of taller varieties. However, a more detailed assessment is needed of the effects of particular dwarfing genes or plant height per se on grain yield, based on advances made in this study. This follows analogies with wheat, where studies have analysed how interactions between semi-dwarfing genes, genetic background and environmental factors affect the relationship of plant height and grain yield and also where favourable plant characteristics are fixed before the introduction of dwarfing genes. Nonetheless, there is considerable potential for selection of "tall shorts" in sorghum. This approach has the potential to lead to a step change of up to 10% in sorghum grain yield in some environments. This yield change would represent a significant step up given the current rate of genetic progress is around 1% per annum. In the past, grower acceptance of taller sorghums has been low. This is due to the perception, and in some cases, the reality of higher levels of lodging in tall sorghum varieties. The association of height with lodging also needs further research particularly given the possibility of combining height with the deployment of a stay-green trait. This results in a significant improvement in standability.

Recommendations

A number of recommendations arise from the findings of this research:

1. Increase the understanding of the effects of major and minor dwarfing genes on grain yield by further studies with other major dwarfing genes and different genetic backgrounds.
2. Assess the effects of major dwarfing genes on important breeding material within the breeding program.
3. Select slightly taller types among 3-dwarf hybrids exploiting minor dwarfing genes.
4. Control lodging through introduction of stay-green.

Outcomes

Economic Outcomes

This study increased the understanding of the relationship between plant height and grain yield in sorghum. Understanding this relationship offers the opportunity for improved crop yield. This is currently advancing at a slow rate. In wheat, semi-dwarfing genes introduced to control lodging in high-yielding environments, was accompanied worldwide by a substantial increase in wheat yield. This success was partly due to direct pleiotropic effects of the semi-dwarfing genes on yield per plant through increased allocation of biomass to grain. The effects of wheat semi-dwarfing genes have been studied extensively across a wide range of genotypic backgrounds and environments. This understanding allowed successful deployment of these genes to maximise yield in a variety of cropping situations. In sorghum, a standard complement of three dwarfing genes is routinely introgressed in all Australian genotypes to allow harvesting by combine harvesters. However, little was previously known about the physiological basis of the relationship between plant height and grain yield. The findings from this study, which show positive association of yield with height through increased allocation of mass to above ground organs, allow sorghum breeders to exploit dwarfing genes in a more informed way and manipulate plant height for yield increase. Grain yield increases of up to 10%, due to plant height, have been observed. Given the high heritability and relatively simple

genetic control of height, taller germplasm could be developed rapidly. Furthermore, lodging can be successfully controlled by inclusion of other traits, such as stay-green. Considering the current slow rate of genetic advance in grain yield, these findings represent a valuable avenue for increased profitability in sorghum production.

Social Outcomes

Increased profitability of sorghum crops will directly enhance the viability of rural communities throughout north-eastern Australia as it plays a major role in cropping enterprises in the Northern Grain Belt.

Achievements/Benefits

Plant height in sorghum is controlled by four major dwarfing genes (*dw1*, *dw2*, *dw3*, *dw4*). The standard height of all Australian grain sorghum hybrids is achieved by introgression of three of these four major genes. Remaining variation in plant height among such 3-dwarf hybrids in Queensland Department of Primary Industries and Fisheries (QPDIF) breeding trials has been found to explain a significant proportion of the variation in grain yield with increases of up to 10% in some of the taller plants. The current rate of genetic progress for grain yield in sorghum is slow (around 1% per year). Given the high heritability and relatively simple genetic control of height, taller germplasm could be developed quickly. Prior to this study and contrary to the situation in wheat, the physiological basis of the relationship between plant height and grain yield was poorly understood in sorghum. This project aimed to increase this understanding with the ultimate outcome of providing scope for yield increase in sorghum crops by selecting for height within the 3-dwarf material.

A physiological determinants of growth framework was used to examine plant growth and development of three isogenic pairs of sorghum lines differing in one major dwarfing gene (2-dwarfs versus 3-dwarfs). Genetic marker studies confirmed that the most likely dwarfing gene conferring the height difference within each of the isogenic pairs was *dw3*. Detailed physiological field and pot experiments were carried out at Hermitage Research Station between October 2002 and April 2005. Physiological determinants of plant growth such as biomass accumulation, partitioning between various plant organs, phenology, canopy dynamics, radiation and water use efficiencies and photosynthetic capacity were measured on an individual plant basis. In some cases, incorporation of *dw3* led to a significant reduction in plant biomass, which was not sufficiently offset by an increase in harvest index to avoid yield reduction. Grain yield reductions from dwarfing of 10 to 20% resulted in those cases. This is contrary to the situation in wheat, where the semi-dwarfing genes have direct pleiotropic effects on grain number (therefore increasing harvest index) while only moderately reducing plant biomass. This ultimately results in increased grain yield per plant for dwarf plants. The observed reductions in biomass in sorghum were associated with reduced tiller number and a reduction in radiation use efficiency (RUE) in the short types. Subsequent experiments suggested that an increase in allocation of biomass to the roots, rather than differences in photosynthetic capacity or respiration, was the main cause for the apparent reduction in RUE. However, due to plant-to-plant variability and difficulty in accurately measuring root-total biomass ratio, studies with greater replication are required to confirm this hypothesis.

It was also found that interactions with genetic background (and environment) moderated the effects of *dw3*, resulting in smaller height, biomass and grain yield reductions in some isogenic pairs. The effects of dwarfing genes on grain yield therefore need to be assessed separately for different genetic backgrounds. A positive correlation between plant height and yield was also observed in a population that was fixed for the major dwarfing genes, but showed variation in peduncle and panicle length, which are under control of minor dwarfing genes. This suggests there is scope for selection of taller plants among the standard 3-dwarfs to increase yield potential, especially as lodging may be controlled by means other than height reduction (e.g. stay-green).

These findings show that through careful assessment of the effects of dwarfing genes a considered manipulation of plant height has the potential to achieve grain yield increase in sorghum. Given the current low rate of genetic yield advance, this represents an opportunity to increase the profitability of sorghum and deliver economic benefits to growers.

The results of these studies have been published at several conferences and collated in a PhD thesis completed at the University of Queensland.

Other research

As the present study was restricted to three genetic backgrounds and one major dwarfing gene, it is conceivable that assessments of other major dwarfing genes in different genetic backgrounds relevant to current breeding efforts may further

improve an understanding of the relationship between plant height and grain yield and aid in the development of sorghum germplasm with increased yield potential. The understanding of physiological mechanisms would benefit from further studies into partitioning of biomass to the roots, as there seemed to be genotypic differences with regard to this characteristic, but plant-to-plant variability restricted unequivocal conclusions from the current research. Further research on the contribution of peduncle and panicle growth to the association of height with yield within 3-dwarf material is warranted.

Additional information

List of Publications

George-Jaeggli B, Broad IJ, Hammer GL, Jordan DR (2004) Is increased radiation use efficiency in *Sorghum* related to increased height? In '4th International Crop Science Congress New directions for a diverse planet'. (Published online: [http://www.cropscience.org.au](http://www.cropsscience.org.au): Brisbane, Australia, 26 Sep - 1 Oct, 2004.)

George-Jaeggli B, Broad IJ, Hammer GL, Jordan DR (2004) Is increased radiation use efficiency in sorghum related to increased height? In 'Research Conference Faculty of Natural Resources, Agriculture and Veterinary Science 2004'. (The University of Queensland): Gatton, Australia, 5 Nov, 2004.)

George-Jaeggli B, Hammer GL, van Oosterom EJ, Jordan DR (2006) Tall sorghum plants use water more efficiently than short ones. In '5th Australian Sorghum Conference'. (Eds AK Borrell, RG Henzell and DR Jordan). (Range Media Pty Ltd. Published on CDROM: Gold Coast, Australia, 30 Jan - 2 Feb, 2006.)

George-Jaeggli B, Hammer GL, Borrell AK (2006) Integrating water use with whole-plant photosynthesis and respiration measurements using a custom-built gas-exchange chamber. In 'ComBio 2006'. (Australian Society for Biochemistry and Molecular Biology. Published online: <http://www.asbmb.org.au/combio2006/index.html>: Brisbane, Australia, 24-28 Sep, 2006.)