

KIT 1.3

Change fundamental plant architecture, physiology and/or biochemistry to maximise water-limited yield potential in wheat, barley, canola and sorghum



Impact

Growers have access to wheat, barley, canola and sorghum varieties possessing transformational improvements in water-limited yield potential.

Summary

- There is accurate information about the economic value of plant characteristics that can underpin improved water-limited yield potential.
- Plant breeders are better able to utilise fundamental research to improve water-limited yield potential.

OVERVIEW

The yield potential (PY) of a crop is defined as the yield of the best current varieties, employing the best current agronomy and where there are no manageable biotic or abiotic stresses restricting yield (Fischer et al 2009). In Australia, the majority of grain crop production occurs under water-limited, rainfed conditions where the crop yield potential is constrained by the spatial and temporal pattern of water availability and to that end yield potential in this context is often referred to as water limited yield potential (PY_w).

Globally, PY has increased substantially over time. This increase in PY has been driven by advances made through plant breeding, including improved Harvest Index (HI) of semi-dwarf wheats, supported by improved agronomic practices (Fischer et al., 1998). There has similarly been genetic progress for PY_w (Sadras and McDonald, 2011), with considerable advances made in aligning crop phenological development to the target production environment leading to improved transpiration efficiency (TE). This has also been supported by advances in agronomic moisture conservation practices (Passioura 2012). Improvements in PY_w have also been driven by the spill-over benefits from fundamental PY advances.

Across many jurisdictions, annual yield increases for many grain crops are plateauing (Parry et al 2011). There is growing international recognition that for some crops gains in PY are becoming more difficult to realise as improvements underpinned by simply inherited traits such as phenology are already well exploited. The impacts of climate change are also believed to be important contributors to plateauing yield increases (Bailey-Serres et al. 2019; Hochman et al. 2017). Increasingly, improvements in PY and PY_w will be reliant upon understanding and manipulating complex (quantitative) genetic, biochemical and physiological processes to augment empirical breeding advances in production environments impacted by greater variability of water supply.

The challenge of delivering transformational improvements in PY and PY_w is a global one and is reflected in the recent establishment of several multinational research initiatives focussed upon modifying fundamental plant processes to drive greater rates of genetic gain including the Realizing Increased Photosynthetic Efficiency (RIPE) program, the International Wheat Yield Partnership (IWYP) and the C4 Rice project (Ort et al. 2015; Reynolds et al. 2019; Ermakova et al. 2019).

Crop physiologists describe PY_w according to the following equation:

$$PY_w = \text{transpiration } (T) \times \text{transpiration efficiency } (TE) \times \text{harvest index } (HI)$$

where T is the quantity of water taken up and transpired by the plant, TE is the efficiency of biomass creation from water captured and HI is the efficiency with which biomass is converted to grain. As such, improvements in PY_w can come from improving the way crops capture and store water and how they convert the water to dry matter and ultimately grain (Passioura 1983). The Key Investment Target (KIT) 1.3 is therefore structured around these key components of PY_w.

KIT 1.3 outlines GRDC's investment priorities for raising the PY_w of wheat, barley, canola and sorghum. The strategy focusses upon improved industry knowledge of the value of different plant physiological, architectural and biochemical processes



which could be manipulated to raise PY_w and the delivery of improved breeding selection tools to support the development of grain varieties with:

- A. Enhanced water uptake (T)
- B. Enhanced conversion of water to biomass (TE)
- C. Enhanced conversion of biomass to yield (HI)

The overall focus of KIT 1.3 is raising the yield ceiling and as such there is a strong strategic emphasis on the effective and timely transfer of fundamental research outputs to Australian breeding companies and the rapid translation of such outputs into new varieties with enhanced PY_w . Other KIT strategies describe the investment priorities for realising increases in PY_w in new varieties through improved agronomy (KIT 1.5) or the delivery of improved abiotic and biotic yield protection traits (KIT 1.1, KIT 1.2, KIT 1.7, KIT 1.8, KIT 3.1, KIT 3.3 and KIT 3.4).

FUTURE RD&E FOCUS

SCOPE – Enhanced water uptake

Knowledge and improved breeding selection tools are developed to enhance crop water capture.

Increasing the quantity of water captured and transpired by a plant is one mechanism by which PY_w can be maximised. The genetic approaches to increasing plant water uptake include improving crop water access and extraction (eg root architecture) and reducing the proportion of growing season water lost to evaporation (eg rapid soil shading through early vigour).

The number, shape and spatial arrangement of roots (root architecture) is important for maximising water uptake and has been the focus of increasing international research activity in grain crops. Recent work has shown that the rate of root growth and root angle correlate with increased water uptake and yield in some cereal crops. This research has identified a fast growing, narrow-angled root ideotype that is proposed to deliver a yield benefit in deep soil profiles lacking subsoil constraints (El Hassouni et al. 2018; Robinson et al. 2018) and has mapped QTL associated with this trait (Richard et al. 2015; Richard et al. 2018; Alahmad et al. 2019). Potentially beneficial root architectures for other Australian environments have not been described.

In the absence of chemical and physical constraints, canola root systems have been shown to have the potential to extend more than 2m down the soil profile and access deep soil moisture (Lisson et al. 2007). Despite canola having the potential for deep rooting and root hydraulic conductance superior to wheat, canola is more sensitive to water stress than wheat (Kirkegaard et al. 2020). Physiological analysis of this difference in sensitivity suggests that differences in traits related to the aerial parts of canola plants, such as stomatal conductance, are the primary determinant of canola's higher sensitivity to water stress (Hess et al. 2015).

A common impediment to the adoption of root architectural traits by Australian breeding companies is a lack of compelling field-based yield data defining the value proposition of such traits in different target production environments and across multiple seasons. A further constraint to the identification and deployment of root architectural traits has been the availability of cost effective and scalable root phenotyping methods and selection tools to support their use (Atkinson et al. 2019). Quantifying the yield benefit of putatively beneficial root architectural traits with a view to providing an incentive for breeders to select traits in this way is important. Plant breeders will only use root architecture phenotypic selection methods if it can be shown that they are more effective or efficient at improving yield than direct selection for yield in the target environment. Direct yield selection can indirectly or passively select for root traits of benefit in that target environment. For example, field analysis of phenotypic changes associated with genetic gain in South Australian wheat varieties released over a five decade timeframe has identified that, in southern Australian cropping environments, breeders selecting for yield have passively or indirectly selected for reduced root length density and increased nitrogen uptake per unit root length (Aziz et al. 2017).

Enhanced early crop/seedling vigour has been proposed as an important trait for improving PY_w of winter grain crops in rainfed, winter rainfall dominated cropping environments (Condon 2020). Enhanced early crop vigour leads to improved establishment, faster leaf area development and more rapid canopy closure resulting in a reduction in soil water loss



via evaporation and increased weed competition (Rebetzke and Richards, 1999). In environments where moisture stress during anthesis and grain-filling is common, improving the efficiency of early season water capture represents a potential mechanism for improving grain yields. A recent modelling study simulating the impact of early vigour on wheat growth and yield across major climate types in Australia reported early vigour could increase yield by 16 per cent (Zhao et al. 2019). However, there are contrasting views as to the value of early vigour in Australian cropping environments since there is the potential for greater early growth to exacerbate terminal moisture stress. Moreover, past field studies with early vigour lines have delivered variable results (Richards et al., 2002). In addition, evaluation of some modern Australian wheat cultivars and breeding lines has revealed that yield advances have been underpinned by a conservative pattern of water use, based upon a number of traits including reduced leaf area (Izanloo et al. 2008; Bennett et al. 2012). Similar observations have been made in some other crops (Zaman-Allah et al. 2011; Blessing et al. 2018). Notwithstanding these observations, wheat germplasm with enhanced early vigour is currently under evaluation by some Australian breeding programs. As such, the value proposition of the early vigour trait in different production environments is being evaluated by industry. Depending upon this evaluation, cost-effective, high throughput phenotyping tools, such as that described by Cowley et al. (2014), may be required to support deployment of this genetically complex trait (Moore and Rebetzke, 2015).

Future Focus

GRDC will continue to investigate genetic opportunities to improve crop water capture. Future investment in this area will support:

Investment Outcome 1.3.1 – Plant breeders and researchers have knowledge of and selection tools for plant characteristics that can maximise water uptake.

Given the genetic complexity of root architectural traits, combined with the difficulty associated with phenotyping root traits in the field, breeding programs require compelling field data to promote adoption of such traits. The yield benefits of such traits in different regions, soil types and across seasons will need to be established and conveyed together with the value proposition of directly selecting for such traits over selection for yield alone. The provision of advanced genetic tools which support deployment of quantitative root traits in modern genomic prediction driven breeding programs will be required.

SCOPE – Enhanced conversion of water to biomass

Knowledge and improved breeding selection tools are developed to optimise crop growth and build the resources to maximise yield potential.

Transpiration Efficiency

Transpiration Efficiency (TE) reflects a “summary” of how much water a plant used during the growing season. TE is difficult to measure or even estimate. Current approaches to measure TE apply indirect phenotyping methods, such as carbon isotope discrimination (which links photosynthesis and transpiration) and, more recently, thermal imaging. Both methods allow in-field studies, but only thermal imaging is high-throughput.

The movement of CO₂ and water into and out of plants is primarily controlled by stomata and as such, stomata number, development and response are a major component of TE. Consequently, there has been increasing research focussed upon manipulating stomatal number, arrangement and regulation (responsiveness) as a vehicle to raising crop PY_w. The genetic control of stomata is well known in model plant species (Chaerle et al. 2005; Bertolino et al. 2019; Kimura et al. 2020). Despite this, with few exceptions (Hubbart et al. 2018), data describing the yield impacts of manipulating stomata in grain crop species has come from controlled environment (glasshouse and growth room) experiments (Dunn et al. 2019). Such experiments typically consider the biochemical consequences of stomatal modifications at a leaf level and involve studies on individual plants. However, several studies have highlighted the differences between a single plant environment and a crop canopy environment and how this can impact upon the value of stomatal traits in a typical production setting. For example, Condon et al. (2002) reported that the quantum of differences in TE amongst Australian wheat genotypes evaluated under glasshouse studies were significantly lower under field conditions because of crop canopy boundary layer effects. To support the transfer of fundamental model-species derived knowledge into grain crops, validation of predicted performance increases in target production environments and under crop canopy conditions will be required.



Mesophyll conductance (G_m)

Once CO₂ enters the leaf through stomata, it moves by diffusion from the leaf air spaces to the inside of the chloroplasts (where fixation takes place). The flow of CO₂ is affected by the properties of the structures it needs to travel through (cell walls, cell membranes, chloroplast membranes) and the distance travelled. The ease of CO₂ flow is called Mesophyll conductance and impacts the concentration of CO₂ inside the chloroplast (thus available for photosynthesis).

As with TE, measurements of G_m are difficult and have therefore tended to focus on indirect methods and rely on mathematical modelling that is still evolving. Reducing G_m has been proposed as a target to enhance photosynthesis (by increasing CO₂ concentration in the chloroplast) and potentially yield (Lundgren and Fleming 2019). Proposed pathways to improve G_m are through modifying:

- Internal leaf anatomy: mesophyll cell size and number define the cell area exposed to CO₂
- Cell wall properties (thickness and composition).
- Membrane aquaporins: these “protein pores” in the membrane may facilitate CO₂ flow

However, seeking to improve G_m may result in undesirable trade-offs such as potentially reducing water use efficiency (water flows in the opposite direction to CO₂). Changes in internal leaf anatomy may also incur higher use of Nitrogen, Phosphorus or Carbon, or impact leaf size or shape, which could affect radiation interception.

Photosynthesis and Energy Use Efficiency (EUE)

Enhancing photosynthesis is increasingly being reported as a key approach to raising crop yield potential and is a field of research which has seen a significant increase in private and public-sector investment and research activity over the past decade (Furbank et al. 2020). Numerous components of the plant photosynthetic process have been proposed as targets for manipulation and modification (Zhu et al. 2010; Simkin et al. 2019) including converting C₃ crops to the more efficient C₄ photosynthesis metabolism (von Caemmerer et al. 2012) as well as introducing elements of algal photosynthetic processes to crops (Zhu et al. 2004). Manipulation of some of these targets has delivered plants with enhanced photosynthesis and increased biomass production (Driever et al. 2017; Salesse-Smith et al. 2018). Recently, Kromdijk et al. (2016) and South et al. (2019), reported large increases in biomass production of field grown tobacco plants modified for improved adaptation to fluctuating light conditions and reduced photorespiration, respectively. Whether such biomass increases can be created in crop species and converted to grain yield remains to be seen.

The evaluation of plants with modified photosynthesis under field production conditions is critical. It is important to assess whether predicted improvements in leaf-level photosynthetic efficiency can deliver when scaled up to the crop canopy level in the field. It is also important to provide breeders with relevant data regarding the yield improvement which can be expected from manipulating photosynthesis.

Recently, Wu et al. (2019) applied advanced modelling, validated with wheat and sorghum field biomass and yield data, to quantify that enhancing several components of photosynthesis could in combination result in yield improvements of up to 20 per cent (Rubisco carboxylation rate, electron transport and mesophyll conductance). In wheat, the maximum predicted yield increase (5.4 per cent) was achieved by improving the three components of photosynthesis simultaneously. Improving only one component of photosynthesis results in higher yield in the case of electron transport only (3.7 per cent yield improvement). The study reported that higher yield improvements (up to 9.2 per cent), could be achieved if photosynthesis was decoupled from transpiration. The link between photosynthesis and transpiration is not well understood, but other research results suggest that this link can be broken.

The majority of energy acquired through photosynthesis and fixed into carbon is used by plants in general maintenance (Amthor, 2000). Two to four times as much carbon is lost through respiration than is harvested as crop yield (Amthor et al. 2019). Energy Use Efficiency (EUE) is a relatively new concept based upon the premise that even small improvements in plant energy efficiency have the potential to enable more fixed carbon to be allocated to grain, improving yield. Despite an increasing body of research investigating EUE, to date it has yet to demonstrate its value as a breeding target.

Australia is a global leader in photosynthesis and EUE research and is well placed to capitalise on fundamental research outputs. Much of the current photosynthesis research focuses upon modifying the photosynthetic capacity of the plant (ie maximum assimilation rate), but recent research is also highlighting the importance of the understanding and manipulation of photosynthetic dynamics (ie rapid response of the plant to changing environmental conditions). Recently, Acevedo-Siaca et al. (2020) reported significant natural variation in photosynthetic induction by increasing light intensity in rice and highlighted the potential of accelerating induction as a means of boosting photosynthetic efficiency.



Both photosynthesis and EUE currently rely heavily on simulation modelling to select target genes and pathways for crop enhancement, due to the inherent complexity of the traits and the lack of high-throughput phenotyping tools. However, with a few exceptions (Wu et al. 2019), most models are generally not descriptive enough to validate links with yield, which adds another obstacle to the translation of research from lab to field. In addition, despite current effort in developing visual/hyperspectral imagery, fluorescence measures and other tools to estimate photosynthesis and EUE, there is still uncertainty around how such tools should be interpreted and their value to plant breeders. Moreover, these measurements are frequently influenced by environmental conditions such as light intensity, light incidence angle or air temperature. This complicates their deployment in field conditions. Airborne- and satellite-mounted imaging systems have been proposed as a potential solution (Camino et al., 2019).

Modifying crop canopy architecture is another mechanism which has been proposed to improve photosynthetic productivity in grain crops. Erect leaf morphology has been proposed as a desirable canopy-level trait across a range of grain crops (Virk et al. 2004; Richards et al. 2019). It is proposed that erect leaf morphology will increase light penetration to lower layers of the canopy and should maximise net photosynthesis. Additionally, the trait has been reported as resulting in reduced susceptibility to photoinhibition (inhibition of photosynthesis caused by damage due to high levels of light) and reduced risk of overheating (Burgess et al. 2015). However, several studies have reported that the erect 'ideotype' when tested in the field did not outyield the best elite cultivars with conventional architecture (Brescghello and Coelho, 2013) or was not associated with historical yield improvement trends (Hammer et al. 2009). As with root architectural traits, such studies highlight the need for compelling field-based yield data to inform breeder use of canopy architectural traits. Many of these traits can be readily assessed with existing tools, including visual estimations.

Future Focus

GRDC will continue to investigate the development of tools which support breeding of varieties with improved carbon capture processes and optimal biomass accumulation patterns. Future RD&E in this area will target the following:

Investment Outcome 1.3.2 – Plant breeders and researchers are accelerating the transfer of relevant knowledge from other species to wheat, barley, canola and sorghum.

The conservation of many stomatal regulation and carbon capture and deposition processes across plant species presents opportunities to transfer knowledge of fundamental biochemical processes from model plant species such as *Arabidopsis thaliana* to grain crops such as canola. Despite a large basic knowledge base, manipulating fundamental plant processes to raise crop PY_w is likely to be technically challenging and will require interaction between a range of research disciplines from basic plant biochemistry through to field-based crop physiology, simulation modelling and the rapidly evolving field of machine learning.

Ongoing cross-disciplinary research collaboration within Australia and continued leverage of international research knowledge and capacity will be critical to capturing value from the basic knowledge base worldwide. To maximise the likelihood of delivering translatable outputs from research investments targeting such fundamental plant processes, mechanisms which support improved breeder and researcher interaction and collaboration will need to be established.

Investment Outcome 1.3.3 – Plant breeders and researchers have knowledge of and selection tools for plant characteristics that optimise conversion of water to biomass.

Validation of Photosynthesis and EUE as profitable breeding targets will need to occur and must be supported by improvements in simulation models and the development of high-throughput, field-deployable (scalable) phenotyping tools that provide heritable trait measurements. Additionally, an increased focus on how water is used through the season rather than total water use will be required. To inform this, the co-limitations of photosynthesis and transpiration, will need to be better defined and will need to be considered in a crop canopy context as opposed to individual plants.

Future focus will be applied to exploiting canola as a crop model for evaluation and transfer of basic knowledge from *Arabidopsis* and other species given clearer path to market opportunities for different genetic manipulation technologies in canola.



SCOPE – Enhanced conversion of biomass to yield

Knowledge and improved breeding selection tools are developed to deliver maximum yield potential.

Phenology is the seasonal timing of plant development and is a key determinant of crop yield. The length of the vegetative developmental phase determines plant biomass and the length of the reproductive developmental phase sets final flower and grain number. Crop yield can be maximised by manipulating phenology to optimise these developmental phases to best balance total biomass and harvest index (Flohr et al. 2018; Hunt et al. 2019). Across plant species, phenological traits are controlled by a limited number of genes of relatively large effect making them good targets for manipulation (Trevaskis 2018).

To maximise crop yield, it is important that the optimal combinations of phenology genes are defined for different environmental conditions. Knowledge of the genetic control of phenology is well established in wheat (Steinfart et al. 2017; Bloomfield et al. 2018), barley (Cuesta-Marcos et al. 2015; Ford et al. 2016) and sorghum (Mace et al. 2013) but less so in canola. The genetic elucidation and manipulation of phenology in canola provides an opportunity to significantly improve canola adaptation to different Australian cropping environments and deliver a step-change in canola PY_w in the short term (Kirkegaard et al. 2016; Nelson et al. 2016). In crops with an indeterminate flowering habit such as canola, there is no upper limit on final flower and grain number, but it is possible that a determinate flowering habit may maximise PY_w .

Many of the recent advances in PY_w of cereal crops have been driven by breeders increasing the number of grains produced per spike (Wurschum et al. 2018). Different mechanisms for manipulating inflorescence architecture have been applied to different crops to drive this potential increase in grain number per spike including increased floret fertility in wheat and barley (Koppolu and Schnurbusch, 2019; Sakuma et al. 2019) and increased inflorescence branching in rice (Miura et al. 2010). Manipulation of reproductive branching as well as manipulation of floret fertility and abortion are promising strategies to maximise grain number and potentially increase yield (Sakuma and Schnurbusch 2020). Wheat and barley varieties with highly branched inflorescences have been described for many years, but it is only relatively recently that the genes and molecular pathways that regulate inflorescence branching have been identified (Dobrovolskaya et al. 2015; Poursarebani et al. 2015). Similarly, the genetic and biochemical control of floret fertility and abortion has begun to be dissected in many crops (Sakuma et al. 2019; Jiao et al. 2018; Youssef et al. 2017; Guo and Schnurbusch 2015), although many elements of these fundamental processes remain unclear (Sakuma et al. 2017). In addition, improved understanding of the processes controlling spikelet number presents a further avenue for potential manipulation of grain number (Boden et al. 2015; Gauley and Boden 2019).

Reducing vegetative branching by inhibiting tillering in wheat has been shown to significantly increase grain number per spike, however this has not necessarily translated to an increase in crop yield in the field (Mitchell et al. 2012). Manipulating fundamental reproductive or vegetative branching, floret fertility and abortion and spikelet number processes have the potential to increase crop yield, however it will be important to ensure that increases in grain number at the plant level can be scaled up to the crop level.

The most significant genetic intervention that led to increased harvest index (HI) and yield in wheat and rice was the introduction during the green revolution of semi-dwarfing genes which delivered improved harvest index through greater allocation of resources to the developing ear instead of the stem. While successful, some of these height controlling genes have negative pleiotropic effects (Ellis et al. 2004) including decreases in coleoptile length and seedling leaf area (Rebetzke and Richards, 1999). Moreover, the introduction of dwarfing genes in some crops has not been accompanied by the increase in yield seen in wheat and rice. For example, in sorghum introduction of dwarfing genes provided lodging resistance and allowed for mechanical harvesting but had a negative effect on grain yield per plant (Jordan et al. 2003). The prevalence of lodging in sorghum and head loss in barley indicate that other mechanisms to reduce height or to increase stem strength which do not also limit water access are required. It is possible that there may be better alleles or alternative genes to reduce height and increase yield that have not been considered due to the dominance of the green revolution semi-dwarfing genes (Chandler and Harding, 2013; Ford et al. 2018).

Sink strength of developing florets and grains has been shown to have a significant effect on final grain number and grain weight (Ji et al. 2010). Competition for photosynthates from other tissues reduces photosynthate availability for developing grains, negatively impacting both grain number and grain size. Currently, little is known about the mechanisms, molecular pathways and genes that control the flow of photosynthates to developing florets and grains. A greater understanding of



these mechanisms may identify ways to increase the sink strength of developing florets and grains, increasing grain number, grain weight and yield.

In addition to total water use, how plants use water throughout the season is an important determinant of final crop yield in Australian rainfed production systems. This is particularly important given current climate modelling studies are predicting significant changes in the spatial and temporal pattern of rainfall across many grain cropping regions in Australia (Crimp and Howden, 2019). Delayed leaf senescence during grain filling (staygreen) is one mechanism which has been proposed for balancing supply and demand of water to improve the efficiency with which the crop converts water to biomass and grain yield (Borrell et al. 2014). The value of the staygreen phenotype in water-limited environments has been well described for sorghum (Jordan et al., 2012) but not to the same extent for wheat, barley or canola.

Many plant species have evolved seed shattering (or pod dehiscence) to maximise seed dispersal and species survival in the wild. However, for domesticated crop species, particularly those under broadacre production, shattering is typically a deleterious trait which results in significant yield losses. For example, shattering in canola, typically has resulted in yield losses of 5–10 per cent (Liu et al. 2016). Reducing the propensity towards shattering in canola and head loss in barley is important in the context of maximising the value extracted from improvements in canola and barley PY_w . Germplasm with reduced shattering in canola and reduced head-loss in barley has been identified (Liu et al. 2016; Lee 2019). In addition, understanding of the genetic and biochemical basis of pod dehiscence in canola has benefited from fundamental research undertaken in Arabidopsis and provides an avenue for gene-based manipulation employing new technologies such as gene editing (Dong and Wang, 2015). Accelerating the transfer of such material to Australian breeding programs together with fit-for-purpose selection and manipulation tools will be a future priority.

Future Focus

GRDC will continue to invest in the development of knowledge and tools that maximise HI of wheat, barley canola and sorghum. Future RD&E will target the following:

Investment Outcome 1.3.4 – Plant breeders and researchers have knowledge of and selection tools to manipulate flowering processes and structures of wheat, barley, canola and sorghum to optimise grain number in relation to water availability and biomass.

This will encompass knowledge of the best combinations of phenology genes to optimise floral architecture and HI and improved understanding of the genetic control of floral initiation and floret mortality to maximise final grain number. Research that establishes whether the promise of altered vegetative and floral branching and increasing grain sink strength is a viable/feasible strategy for increasing grain number and size in Australian water-limited production environments will be required. Collaboration with international experts in floral development will be important to making gains addressing these fundamental questions.

It will also be important to determine if the reliance on green revolution semi-dwarfing genes to reduce height has constrained our ability to increase HI in wheat.

Investment Outcome 1.3.5 – Plant breeders and researchers have knowledge of and selection tools to manipulate haying-off processes to maximise yield.

Defining the value proposition of staygreen, including the production environments where the trait consistently delivers value will be required to support breeder deployment.

Investment Outcome 1.3.6 – Plant breeders and researchers have knowledge of and selection tools to minimise post grain-fill yield losses.

Developing approaches to break the nexus between height and yield will be key to driving genetic gain and reducing the incidence of lodging in sorghum. New mechanisms to improve stem strength to reduce head loss in barley will need to be considered. Accelerating transfer of sources of resistance to shattering in canola and leverage of basic knowledge from Arabidopsis will be a focus area.



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