Phenotypic plasticity of yield components in oat (*Avena sativa* L.)

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Abstract

We measured yield of 29 oat lines in nine environments returning a range from 0.3 to 4.2 t ha^{-1}. Other traits were measured in 4-7 environments. Environment, genotype and their interaction affected all traits ($P<0.0001$); ANOVA was thus largely uninformative. To account for these interactions, we used a plasticity framework showing three types of trait-dependent responses. For grain number and its components, plant height, harvest index, WSC and N at two stages (GS71 and maturity), high plasticity was associated with the ability to capture favourable conditions (90th percentile) and little variation under stress (10th percentile). For biomass at both GS71 and maturity, high plasticity was associated with a trade-off between capacity to capture favourable conditions and growth under stress. For seed size, high plasticity was associated with low seed weight under stress. Yield was closely related to grain number and weakly associated with grain weight. Grain number was negatively related to water soluble carbohydrates at GS71 and maturity, which were in turn negatively related to shoot N concentration. Under favourable conditions, some varieties maintained a high concentration (> 20%) of water soluble carbohydrates at harvest maturity. Selection against this trait could improve yield potential, but residual labile carbohydrates can also be exploited in dual grain-feed varieties, and can provide flexibility for hay growers when logistics preclude cutting at the common water ripe (GS71) target.

Keywords

Stress, yield potential, trade-off.

Introduction

In 2015-2016, Australia produced an average of 1.31 million tonnes of oat grain cultivated over an area of 0.83 million ha (ABARES 2016) fetching an export value of $104 million. The long term average yield in Australia has been 1.6 t ha^{-1}, compared to 6 t ha^{-1}in the UK partially due to water limitations. The aim of this study was to screen oat genotypes to analyse yield and related traits seeking to improve adaptation to stress simultaneously with yield potential using a plasticity framework (Sadras and Richards 2014; Sadras et al. 2016). Yield and phenology were reported in the previous agronomy conference (Mahadevan et al. 2015); here we focus on its components, and concentration of nitrogen and WSC in shoot.

Methods

We measured yield of 29 oat entries in nine environments resulting from the combination of seasons (2012 to 2014) and locations (Pinery, Riverton, Turretfield and Waikerie); other traits were measured in 4-7 of these environments. The entries consisted of advanced breeding lines, released varieties of grain, hay and grazing types which varied in yield, height, growth habit and phenology. Trials were sown in randomised complete block design with three replicates. Plots comprised five rows, 3.2 m long at a spacing of 0.21 m sown at 165 seeds/m^2 at Pinery, Riverton and Turretfield. Waikerie had plots of 6 rows, 5 m long with 0.21 m row spacing sown at 180 seeds m^{-2}. Crops were fertilised with 120 kg ha^{-1} of diammonium phosphate (18%N, 46% p_2O_5). Biomass was measured on oven-dried samples collected from 0.32 m^2 of the centre three rows for hay yield (biomass at GS71) and at physiological maturity. Grain yield and yield components were estimated from the same sample taken at maturity and expressed at 12% moisture. Hay and harvest biomass samples were oven dried, milled through 1 mm (Retsch Cyclone Mill Twister, Retsch, Haan, Germany) and scanned by NIR reflectance spectroscopy (NIR FOSS DS 2500 for hay and NIR FOSS XDS rapid content analyser for harvest biomass samples) to estimate crude protein and water soluble carbohydrates using calibration curve developed by the National Oat Breeding Program which includes representative hay samples selected from the previous three seasons samples (AFIA 2014).

The effect of variety, environment and their interaction on crop traits were quantified using a framework of phenotypic plasticity. Phenotypic plasticity for each trait and variety was calculated as a unit less variance ratio (Dingemanse et al. 2010), and data analysed using percentile-plasticity plots as summarised in Sadras and Richards (2014). Percentiles in our small data set seek to return an objective measure of upper and lower limits of traits, excluding undue influence of extreme values; percentiles return more robust information than minimum and maximum yield (Sadras et al, unpublished). Phenotypic relationships between traits were explored with regression analysis.

Results and Discussion

The difference between average seasonal evaporative demand and rainfall ranged from 412 mm at Waikerie 2012 to 263 mm at Riverton 2013. All traits were influenced by all the three sources of variation; environment, genotype and their interaction. We used a plasticity approach to interpret GxE.

Grain yield was reported previously (Mahadevan et al. 2015). Briefly, it ranged from 0.02 t ha^{-1} for Forester and Riel (hay types) at Waikerie 2012 to 5.5 t ha^{-1} for Mitika and Dunnart (grain types) at Riverton 2013.

Figures 1 and 2 demonstrate the link between the yield components under favourable environment (90th percentile), under stress (10th percentile) and their plasticity. Higher plasticity of the genotypes for grain number per m^2 and its components (panicles per m^2 and grains per panicle), harvest index, plant height, WSC and N at GS71 and maturity, were associated with the ability to capture favorable conditions with no systematic variation under stress. Analysis of residuals showed that, for a given plasticity, grain varieties had higher grain number compared to hay/grazing types in both the environments (Figure 1A). Concentration of WSC and N were reduced from GS71 to maturity for all varieties, but large amounts of residual carbohydrates at maturity (up to 20%) were found under favourable conditions.

High plasticity of biomass at GS71 (hay yield) and at harvest associated with the capacity to capture favorable environments but with tradeoffs under stress (Figure 2A and Figure 1E). Hay types had higher and wider range of plasticity (0.6 to 2.2 for biomass at GS71 and 0.5 to 2.9 for harvest biomass) than their grain type counterparts (0.7 to 1.3 for hay yield and 0.5 to 1.5 for harvest biomass). Hay varieties Forester and Riel had the highest plasticity (> 2.5) for biomass and low plasticity (< 0.6) for grain yield. Grain weight showed a differential response to stress with a negative association (10th percentile); higher plasticity resulted in poorer grain size, while they remained non-responsive under favorable environments (Figure 1B).

Yield related to grain number, and weakly to grain weight. Grain number was driven by number of grains per panicle, and to a lesser extent by panicles per m^2, in contrast to wheat and barley where ears per m^2 is more important. Grains per m^2 was inversely related to WSC at GS71 and at maturity. WSC and N at both stages were negatively related. For this collection of genotypes and environments, selection for high plasticity for yield could improve both yield potential and stress adaptation.

Conclusion

Phenotypic plasticity quantified as variance ratio, was used to capture the effect of genotype x environment interactions for yield related traits in oat. Genotypes were better discriminated for yield in favorable environments; selection for yield plasticity can improve both yield potential and drought adaptation. Yield was strongly related to grain number which related negatively with WSC at GS71, and residual carbohydrates at harvest. Residual WSC at maturity suggests opportunities to improve yield potential by selection against this trait, or exploiting this attribute in dual hay-grain varieties.

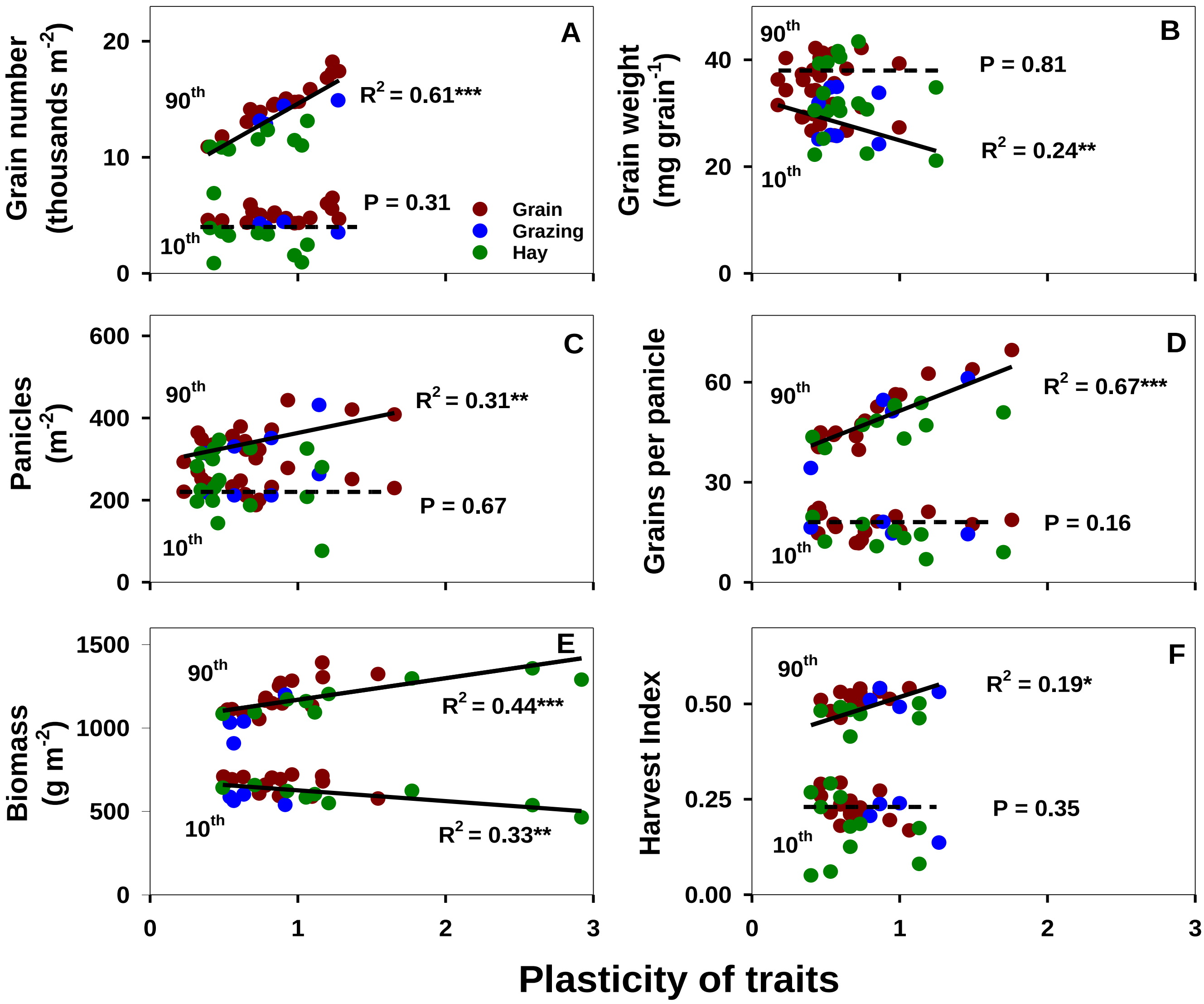

Figure 1. Associations between yield components and their phenotypic plasticity of 29 oat entries under favourable (90th percentile) and stressful (10th percentile) conditions (A) grain number, (B) grain size, (C) panicles m-2, (D) grains per panicle, (E) biomass and (F) harvest index. Symbols represents grain (red), hay (green) and grazing (blue) oat types.

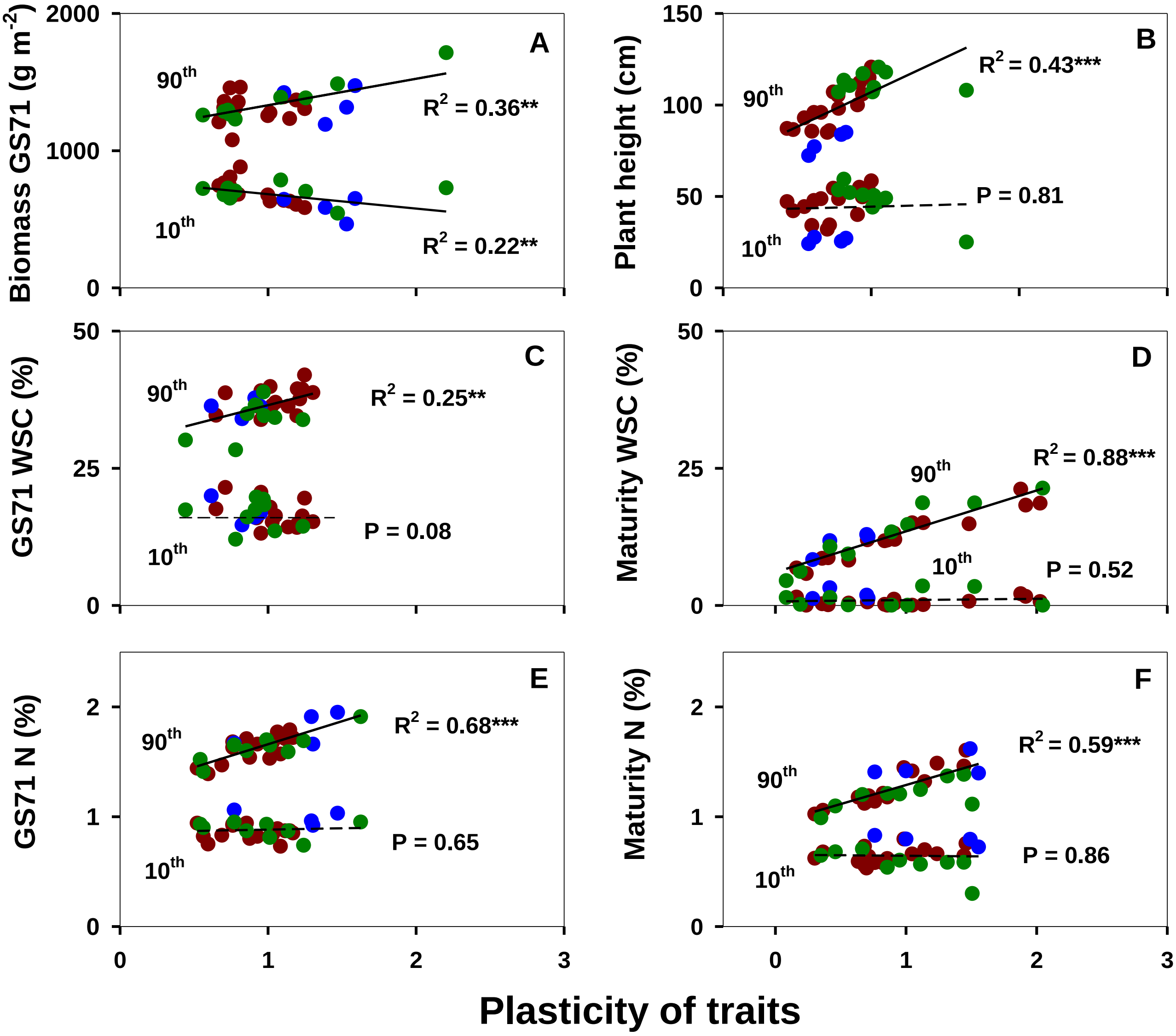

Figure 2. Associations between (A) biomass GS71 , (B) plant height, (C) GS71 WSC, (D) hay N, (E) maturity WSC and (F) maturity N and their phenotypic plasticity of 29 oat entries under favourable (90th percentile) and stressful (10th percentile) conditions. Symbols represents grain (red), hay (green) and grazing (blue) oat types.

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