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Trade off between yield increase and yield stability in three decades of barley breeding in a tropical highland environment

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Abstract

Yield progress due to crop breeding for smallholder farmers in developing countries has been slow because of complex genotype-by-environment (GE) interaction and a lack of concordance between selection and target production environments. The objectives of this study were to: (i) assess GE interaction and identify its genotypic and environmental causes for grain yield, (ii) demonstrate the direction of yield progress during the last three decades vis-à-vis high yield and stress environments, and (iii) suggest an appropriate selection strategy to develop full-season food barley (*Hordeum vulgare* L.) cultivars in central highlands of Ethiopia. Sixteen barley genotypes were tested in a factorial combination of two levels each of sowing date (at the start of main season rain versus 20 days after) and fertilizers (none versus 41 kg ha^{-1} N + 20 kg ha^{-1} P) in 1998, 1999 and 2002 on a Eutric Nitosol at Holetta, Ethiopia. Genotypic sum of squares accounted for 12% and GE interaction for 19% of G + E + GE sum of squares. Genotype-by-year interaction was the largest source of GE interaction. Mean genotype grain yields in 1998 were not correlated with those either in 1999 or in 2002 but the latter two were. Improved food barley genotypes had above average vegetative duration, individual plant weight and leaf width at heading and interacted favorably with environments where season-end moisture stress was low. Farmers' cultivars that were early maturing with high harvest index, spike number and vegetative vigor interacted positively with environments where season-end moisture stress was high. Baleme, the local cultivar around Holetta, was late maturing but had little contribution to GE interaction. In Ethiopia, yield progressed due to food barley breeding under low season-end moisture stress but declined slightly under intermediate and high season-end moisture stresses until 2001. Nonetheless, yield trends were positive under all the three scenarios when Dimtu, a variety selected under low and high fertilizer inputs and released in 2001, was included. Yield stability is as important as yield potential for subsistence farmers in risk-prone environments such as in Ethiopia. This in part explains the current state of poor adoption of improved barley cultivars and may call for reorientation of food barley breeding strategy to minimize risks while increasing yields. It is suggested that future barley breeding efforts should include season-end drought stress as a target selection environment.

Keywords: Barley; Genotype-by-environment interaction; Moisture stress

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1. Introduction

Risk aversion in crop production is a prime survival strategy for subsistence farmers in poor countries. Notwithstanding this, both farmers and governments aspire to capture as much as possible of the crop yield potential in order to increase production. Ideally, crop breeding programs in such countries should strive for cultivars with both high and stable yields. Genetic yield potential improvement was, however, known to decrease yield stability (Ceccarelli and Grando, 1991; Calderini and Slafer, 1999; Simmonds, 1991) because of the complexity posed by crossover GE interactions. In the presence of such interactions, discordance between selection and target production environments was implicated for the lack of breeding progress in marginal environments (Simmonds, 1991; Ceccarelli, 1994). Nonetheless, to corroborate this assertion, empirical data on the direction of yield progress of historical cultivars released by a crop improvement program of a developing nation vis-à-vis local landraces in stress and high yielding conditions is scanty.

In barley grown in a Mediterranean environment where the incidence of unpredictable stresses is high, Ceccarelli (1994), Ceccarelli and Grando (1991), Ceccarelli et al. (1992, 1998) and van Oosterom et al. (1993) demonstrated the importance of direct selection in a representative low yielding target environment in order to make yield progress in that environment. Nevertheless, there are few reports on a breeding strategy relevant to areas where the probability of favorable seasons is substantial but risk aversion is critical. Ceccarelli and Grando (1991) suggested that selection of barley cultivars for subsistence farmers should be based on performance under low yielding conditions. However, farming for subsistence is not a choice but a necessity imposed by socio-economic and natural disadvantages, both circumstances that farmers aspire to avoid. In such a scenario, breeding for low yielding conditions may result in cultivars that ensure yield stability and minimize risk, but force farmers to trade security for economic growth.

Recently, Tollenaar and Lee (2002) argued that most of the genetic gain in maize yields in the USA is associated with stress tolerance accruing from improvement in genotype-by-management interaction, and concluded that high yield potential and yield stability may not be mutually exclusive. Work on maize at CIMMYT has also demonstrated breeding progress for mid- to late-season drought tolerance while maintaining yield potential under well-watered conditions by simultaneously selecting under stress and non-stress conditions (Beck et al., 1996; Chapman et al., 1997). Nonetheless, such an achievement requires a priori characterization of the stress environment and improved understanding of the nature of environmental variables and genotypic traits responsible for crossover GE interactions among the winning genotypes (Beck et al., 1996; Basford and Cooper, 1998).

Recent advances in statistical tools, such as the additive main effect and multiplicative interaction (AMMI), factorial regression, partial least squares, and GGE biplots have provided better tools for the analysis and interpretation of GE interaction for grain yield in multi-environment trials (Zobel et al., 1988; Crossa et al., 1990; Vargas et al., 1998, 1999; Yan et al., 2000). In GGE or GE analysis models such as AMMI, information on external environmental or genotypic covariates can be associated with principal component scores (Yan and Hunt, 2001; Vargas et al., 1999) to elucidate genotypic and environmental causes of GE interaction. Nonetheless, environmental or genotypic information cannot be modeled directly in such analyses. Vargas et al. (1998, 1999) suggested partial least squares regression as a more direct and parsimonious linear model for interpretation of GE interaction when there are many explanatory variables that are highly correlated.

Weather variables and genotypic traits were often used as covariates in statistical analyses and interpretation of the underlying causes of GE interaction in cereals (Saeed and Francis, 1984; van Oosterom et al., 1993; Vargas et al., 1998, 1999; Signor et al., 2001). In barley, earliness is an adaptive trait in drought prone areas such as the Mediterranean environment and is a factor for many of the GE interactions reported in the literature (van Oosterom et al., 1993; Jackson et al., 1993; Young and Elliot, 1994; Kamali and Boyd, 2000). Although earliness implies drought escape as a mechanism for high yield under stress, breeding for wider adaptation by conscious selection in stress environments while maintaining yield advantage in high yielding environments should be possible