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Yield stability and relationships among stability parameters in faba bean (*Vicia faba* L.) genotypes

Tamene Temesgen[a,*], *Gemechu Keneni*[b], *Tadese Sefera*[a], *Mussa Jarso*[b]

[a]*Kulumsa Agricultural Research Center, P. O. Box, 489, Asella, Ethiopia*
[b]*Holetta Agricultural Research Center, P. O. Box, 2003, Addis Ababa, Ethiopia*

ARTICLE INFO

Article history:
Received 20 November 2014
Received in revised form
27 February 2015
Accepted 3 March 2015
Available online 11 April 2015

Keywords:
Faba bean
G × E interaction
Rank correlation
Stability parameters
Yield stability

ABSTRACT

Sixteen faba bean genotypes were evaluated in 13 environments in Ethiopia during the main cropping season for three years (2009–2011). The objectives of the study were to evaluate the yield stability of the genotypes and the relative importance of different stability parameters for improving selection in faba bean. The study was conducted using a randomized complete block design with four replications. G × E interaction and yield stability were estimated using 17 different stability parameters. Pooled analysis of variance for grain yield showed that the main effects of both genotypes and environments, and the interaction effect, were highly significant ($P \le 0.001$) and ($P \le 0.01$), respectively. The environment main effect accounted for 89.27% of the total yield variation, whereas genotype and G × E interaction effects accounted for 2.12% and 3.31%, respectively. Genotypic superiority index (P_i) and FT3 were found to be very informative for selecting both high-yielding and stable faba bean genotypes. Twelve of the 17 stability parameters, including CV_i, RS, α, λ, S^2d_i, b_i, $S_i^{(2)}$, W_i, σ_i^2, EV, P^{59}, and ASV, were influenced simultaneously by both yield and stability. They should accordingly be used as complementary criteria to select genotypes with high yield and stability. Although none of the varieties showed consistently superior performance across all environments, the genotype EK 01024-1-2 ranked in the top third of the test entries in 61.5% of the test environments and was identified as the most stable genotype, with type I stability. EK 01024-1-2 also showed a 17.0% seed size advantage over the standard varieties and was released as a new variety in 2013 for wide production and named “Gora”. Different stability parameters explained genotypic performance differently, irrespective of yield performance. It was accordingly concluded that assessment of G × E interaction and yield stability should not be based on a single or a few stability parameters but rather on a combination of stability parameters.

* *Corresponding author.*
E-mail address: tt.tolassa@gmail.com (T. Temesgen).
Peer review under responsibility of Crop Science Society of China and Institute of Crop Science, CAAS.

http://dx.doi.org/10.1016/j.cj.2015.03.004

1. Introduction

Faba bean (*Vicia faba* L., $2n = 2x = 12$) is among the most important pulse crops produced in Ethiopia. Ethiopia is the second largest producer of faba bean worldwide, after the People's Republic of China [1,2]. Currently, faba bean occupies 31% of the total area cultivated for pulses in Ethiopia, with 34% of the total annual pulse production in the country [3]. The crop grows at an altitude ranging from 1800 to 3000 m above sea level and receiving an annual rainfall of 700–1100 mm [2]. It is a crop of high economic value [4] with its edible seed serving as an important protein complement in the cereal-based Ethiopian diet, particularly for the poor who cannot afford animal protein [2]. In Ethiopia, faba bean is a suitable rotation crop with cereals [5] and should be a component of a sustainable farming system.

To maintain high agricultural productivity, the development of varieties with high yield potential is the ultimate goal of plant breeders in a crop improvement program. In recent years in faba bean breeding in Ethiopia, special focus has been placed on developing varieties with improved grain yield, large seed size, and resistance to major diseases. In addition to high yield potential, a new cultivar should have stable performance and broad adaptation over a wide range of environments. Genotype × environment (G × E) interaction is of major importance for faba bean breeders, given that phenotypic response to change in environment is different among genotypes [6]. Different authors [7,8] have reported high G × E interaction effects in faba bean genotypes grown in Ethiopia. Strong G × E interaction for quantitative traits such as seed yield can severely limit gain in selecting superior genotypes for improved cultivar development [44]. For cultivars being selected for a large group of environments, evaluating stability of performance and range of adaptation has become increasingly important. Several stability parameters have been proposed to characterize yield stability when genotypes are tested across multiple environments, with each parameter giving different results.

Joint regression of the mean performance of a genotype on an environmental index (b_i) [9] is the most popular regression approach. The deviation from regression (S^2d_i) is used as a measure of phenotypic stability of the tested genotypes in this approach. Another two-stability parameter similar to the joint regression method [9] has been proposed by Tai [10]. This method involves the partitioning of the G × E interaction effect into two parameters, α and λ, which measure linear response to environmental effects and deviation from the linear response, respectively. This method measures genotypic stability and can be considered as a special form of the regression parameters (b_i) and (S^2d_i), when the environmental index is assumed to be random [11].

An unbiased estimator (σ_i^2) [12] has also been advantageously used for simultaneous selection of high-yielding and stable genotypes [13]. The use of G × E interaction effects for each genotype, squared and summed across all environments, was proposed by Wricke [14] as a measure of stability. This statistics is termed ecovalence (W_i), and is far simpler to compute and more directly related to G × E interaction than statistics proposed by Plaisted and Peterson, 1959 [15]. Genotypes with the lowest values of the above stability parameters are considered to be stable. Francis and Kannenberg [16] measured stability by combining coefficient of variation (CV_i), mean yield, and environmental variance (EV). Genotypes with low CV_i, low environmental variance (EV), and high mean yield are considered the most desirable. Lin and Binns [17] recommended the use of the mean squared distance between genotype *i* and the genotype with the maximum yield within each environment as a genotypic superiority measure (P_i), with genotypes with small P_i values considered to be stable.

Additive main effects and multiplicative interaction (AMMI) [18,19] is gaining popularity and is currently the main alternative multivariate approach to joint regression analysis in many breeding programs [20]. Another approach called the AMMI stability value (ASV), which is based on the first and second interaction principal component axis (IPCA) scores of the AMMI model for each genotype, has also been developed more recently [21]. ASV measures the distance from the genotype coordinate point to the origin in a two-dimensional scatter diagram of IPCA2 against IPCA1 scores. Genotypes with the lowest ASV values are identified by their shortest projection from the biplot origin and considered the most stable. Other stability parameters such as genotypic desirability index (D_i) [22] and mean variance component for pairwise G × E interaction (P^{59}) [23] have also been extensively used. Estimates are made of the range of data and the homogeneity of variance when all these parametric methods are used for stability analysis.

However, univariate nonparametric stability methods are not affected by data distribution. As these methods are based on rank order of genotypes, a genotype is considered stable if its ranking is relatively constant across environments [24]. Several nonparametric methods have been proposed to interpret the response of genotypes to environmental variation. Distribution-free nonparametric stability methods including $S_i^{(2)}$, $S_i^{(3)}$, and $S_i^{(6)}$ have been suggested [25]. The lowest value for each of these statistics indicates maximum stability. Kang [38] assigned ranks for mean yield, with the highest-yielding genotype receiving the rank of 1, and ranks for the stability variance (σ_i^2) of genotypes [12], with the final order of the two genotypes being decided by the sum of the two ranks. The genotype with lowest rank sum is considered the most desirable. Another nonparametric stability method is the stratified ranking technique proposed in [26], where a genotype usually found in the top third for mean performance compared to all entries tested across environments is considered to be a relatively well-adapted and stable genotype.

All of the above and several other techniques have been proposed to characterize stability of yield across a range of environments. Nonetheless, previous studies of faba bean genotypes in Ethiopia have been based either on multivariate statistics such as AMMI [27–29] or on only a few parametric methods [29], with none having used nonparametric methods. The present study was accordingly aimed at performing yield stability analysis using the 17 most commonly used univariate stability methods (12 parametric and five nonparametric), determining the association of different stability parameters, and assessing the use and relative importance of the techniques to improve varietal selection in faba bean.