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Is ear value an effective indicator for maize yield evaluation?

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A B S T R A C T

Under the scope of a Portuguese regional maize ear competition (the “Sousa Valley Best Ear Competition”), an ear value (EV) formula was developed in 1993 based on published maize trait correlations. This formula had two main purposes, ears evaluation for the ear competition and maize improvement selection. The EV formula included only ear length, kernel weight at 15% moisture, number of rows and number of kernels/ear, with no direct inputs from farmers maize yield.

In order to add a more scientific dimension to this popular maize evaluation approach, four main goals were defined: (1) to test alternative interpretable regression methods to provide new ear value formulas that better estimates the yield potential using ear traits; (2) to develop a new instance ranking method, allowing to select the best new ear value formula to be used on the ear competition; (3) to identify a set of traits that will help farmers on selection toward better yield; and (4) to compare the ranking results obtained by the original EV formula and the newly one developed, using data from the “Sousa Valley Best Ear” competition.

To achieve these goals we analyzed some of the competition winning maize populations, on a multi-location field trial, collecting not only ear, but also field traits and yield. This data was analyzed using multiple linear regression (MLR) and multiple adaptive regression splines (MARS).

A new ranking evaluation measure (PR.NDCG measure) was developed to rank the eleven interpretable regression methods obtained, and our results indicated that the most appropriate formula for yield potential estimation included the original EV traits, but with different coefficients and was entitled adjusted EV (EVA). Ear weight, kernel depth and rachis 2, followed by cob and ear diameters and number of kernels per row were also considered traits of major importance to define potential EV formulas, i.e., contributing to yield increase. Plant stand was the most important field variable for yield potential estimation. We also observed, from comparing EV and EVA ranking, that four of the top ranks maize ears using EV were included on the EVA top ten ranks.

From all the above and due to its simplicity, we conclude that the new EVA formula is a valid starting point for a long term engagement of farmers with maize germplasm development and improvement and an open door to their better understanding of maize quantitative genetics.

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1. Introduction

1.1. Context

Since maize (*Zea mays* L.) domestication from teossinte (*Z. mays* ssp. *parviglumis*) (Doebley, 2004) 6000 to 10,000 years ago, farmers have selected according to multiple traits, such as kernel composition (e.g. sweet corn, starch type), palatability, speed of germination and stalk strength (Wilkes, 2004). Selection of maize landraces by farmers is still a common practice in many countries in the world. Farmers' experience and perception has allowed to translate maize physical traits into meaningful indicators of yield, insect resistance or simple esthetic value (Fitzgerald, 1993). However, a precise description of their selection criteria is not always easy to obtain due to the use of indirect measurements (Pressoir and Berthaud, 2004; Badstue et al., 2007). Moreover, the selection traits are largely confined to ear characteristics, offering a limited scope for further variety improvement (Louette and Smale, 2000).

In the beginning of the twentieth century, both the development of popular maize ear show exhibitions and the implementation of a scientific approach to maize inbred lines (Shull, 1908, 1909), outlined the foundation of modern maize breeding (Hallauer and Carena, 2009; Hallauer et al., 2010a). The maize ears shows exhibitions or maize ear competitions with scorecards became very popular in USA. The scorecard was an idealized list of what a good maize ear should look like and corresponded to a combination of characters. As an example, Iowa corn growers' association defined a score card in which they punctuated general appearance (25 points divided by ear size and shape, filling of butts and tips, straightness of rows, kernels, uniformity), productiveness (60 points divided by maturity, vitality and shelling percentage) and breed type (15 points divided by size and shape of the ear and dent of kernel, grain and cob color and arrangement of rows). A similar score card was established by the Illinois corn Breeder association in 1890 with the purpose of "developing an interest in better seed corn" (Klesselbach, 1922; Winter, 1925; Fitzgerald, 1993; Hallauer et al., 2010a). This combination of traits allowed to set maize ears ideotypes, which gradually changed the selection procedures used by farmers, producers and breeders (Bowman and Crossley, 1908) contributing for the development of better performing cultivars (e.g., 'Reid yellow dent'). This selection was based on single ideotypes depending on a personal concept and success relied on the patience and perseverance of the person performing the selection (Hallauer and Carena, 2009; Hallauer et al., 2010a).

Specifically, different selection paths could lead to the same results on yield comparative tests; e.g., the 'Krug' maize population, that was not selected to meet score card standards, yielded similarly to the 'Reid yellow dent' maize population that was selected according with score cards (Hallauer et al., 2010a).

In Portugal, a maize show was initiated in 1992 at Paredes city. The regional "Sousa Valley Best Ear" competition started as a local and amateur initiative with the purpose of electing the best maize ears within the Sousa Valley Region. The "Sousa Valley Best Ear" competition, is still active nowadays due to its recognition by the community. It tracks interesting germplasm and proactive farmers, promotes rural human development on both anthropological and sociological aspects and its ear value formula is a pedagogic tool for farmers by providing information on relevant traits to be considered for ear evaluation and, indirectly, for breeding selection.

This region is one of the most important Portuguese maize production areas, where traditional maize varieties with technological ability for bread production are still currently produced and improved by farmers, representing a rich source of interesting traits and germplasm for modern maize breeding.

1.2. Questions, motivations and applications

According to the best of our knowledge, there are no reports on studies to select the best formula that relates maize ears traits, the most popular farmer evaluation approach, with the measured yield with such specificities as to be used with the extended objectives of the Sousa Valley best ear' competition. However selection indexes since its introduction (Smith, 1936) and development (Williams, 1962; Lin, 1978; Baker, 1986) have been routinely used by breeders where selection is influenced by the relative weight they give to each trait. Visual acuity and experience fine-tune their final decisions. In this sense plant breeding has been considered an art rather than a scientific method (Hallauer et al., 2010a).

Initially, the evaluation of the "Sousa Valley Best Ear" was based on the total number of kernels per ear. However, the maximum number of kernels per ear could be found in a popcorn ear (e.g. 164 g for popcorn versus flint 'Pigarro' with 345 g for thousand kernel weight), presenting smaller kernels, and meaning that the competition could be won by small ears against larger ears with larger kernel sizes, but smaller number of kernels (Moreira, 2006). To solve this ear value problem, an empirical formula to be used on the following editions was developed by Silas Pêgo, a Portuguese maize breeder, specialist in participatory breeding approaches (Moreira, 2006). With this formula Silas Pêgo saw an opportunity not only to fulfill the initial function of the competition (i.e. to select the best maize ear based on the ear grain yield prediction on the kernel weight at 15% moisture), but also to advice farmers about selection or traits that could be used to improve yield.

Silas Pêgo's ear value formula (EV formula) was defined as:

$$EV = \frac{0.6 \times KW + 0.2 \times L + 0.15 \times R + 0.05 \times KN}{4} \quad (1)$$

where KW stands for kernel weight (grams) at 15% moisture, L for ear length (centimeters), R for kernel row number and KN for total number of kernels.

The traits included in the formula, and their respective coefficients, were selected based on published correlations with yield (Hallauer et al., 2010a). Exception was the number of kernels that was kept for historical reasons, since it was the first trait to be evaluated on the 1st year competition. In particular, the kernel weight at 15% moisture was chosen because it expresses directly the ear grain yield (the most important yield trait) and has a genetic correlation of 0.25 with yield (Hallauer et al., 2010a). The ear length and kernel row number were also chosen due to their established positive genetic correlations with yield (0.38 and 0.25 respectively) (Hallauer et al., 2010a). However, despite its superiority among the genetic correlations, it is known that the ear length is not successfully used in indirect selection to increase grain yield (Hallauer et al., 2010b). This can be explained by the lack of proper alleles combinations, so as by the low heritability and epistatic genetic correlations with other traits (Hallauer et al., 2010a). In this way, its attributed coefficient was only of 0.2 and subsequently a smaller 0.15 was attributed to kernel row number taking into consideration the respective correlations with yield. However, ear length and kernel row number are negatively correlated (−0.16). In this way, maximization of both traits, by selecting longer ears and higher kernel row numbers, would emphasize the ear fasciation trait expression. Fasciation describes the enlargement of the plant apex by unregulated proliferative growth (Jones, 1935; Taguchi-Shiobara et al., 2001; Busch and Benfey, 2010) and is normally characterized by abnormal flatten ear types with higher kernel row number (Pego and Hallauer, 1984). These traits are still highly important to Portuguese farmers in traditional agricultural systems. Indeed during a collecting mission that took place in 2005 (Vaz Patto et al., 2007), 56% of the collected traditional maize landraces had some degree of fasciation versus the 10% observed during the 1980's collecting