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Authors: Khanal, Raja, and Badea, Ana

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ARTICLE

Evaluation of barley testing locations in Ontario

Raja Khanal and Ana Badea

Abstract: To develop new barley cultivars, promising genotypes are evaluated for their performance each year at several test locations representing the target region. In this study, we analyzed the Ontario barley registration trial data from 2015 to 2020 to understand the barley mega-environment in Ontario and to evaluate the suitability of the test locations. The analysis showed that the barley test locations fall into two mega-environments, with a major mega-environment consists of five test locations and a minor mega-environment with a single test location. Among the six test locations used for the barley registration trials, Palmerston was found to be the most desirable for the barley cultivar evaluation representing the Ontario barley growing region. This study also identified OB2930-35, a recently released cultivar, to be both high yielding and stable across Ontario. These findings are useful for future barley breeding and cultivar evaluation in Ontario.

Key words: barley, test location evaluation, mega-environment, GGE biplot.

Résumé : Pour créer de nouveaux cultivars d'orge, on évalue la performance des génotypes prometteurs chaque année dans des lieux différents, représentatifs de la région ciblée. Les auteurs ont analysé les données des essais d'homologation de l'orge réalisés en Ontario entre 2015 et 2020 en vue de mieux cerner le méga-environnement ontarien et de déterminer quels endroits conviendraient le mieux à des essais de ce genre. Leur analyse montre que les endroits choisis pour tester l'orge sont de deux types : un important méga-environnement composé de cinq sites et un plus petit n'en comptant qu'un. Sur les six sites utilisés pour les essais d'homologation de l'orge, Palmerston est celui qui se prête le mieux à l'évaluation des cultivars pour la région typique où l'on cultive cette céréale, en Ontario. Dans le cadre de la même étude, les auteurs ont établi que le cultivar OB2930-35, homologué récemment, donne un rendement élevé stable, partout dans la province. Ces constatations s'avéreront utiles pour les futurs programmes d'hybridation de l'orge et l'évaluation des cultivars en Ontario. [Traduit par la Rédaction]

Mots-clés : orge, sites des essais d'évaluation, méga-environnement, diagramme à double projection GGE.

Introduction

Barley is the fourth most important crop in eastern Canada. In Ontario, the barley production regions range from southern Ontario to northern Ontario. Every year, the Ontario Cereal Crops Committee (OCCC) conducts barley variety registration trials in five to six test locations across Ontario, representing three eco-climatic areas, namely, area 2 (western Ontario), area 3 (eastern Ontario), and area 5 (northern Ontario). However, this classification may not accurately reflect the barley mega-environments (ME) in Ontario, which should be determined by the genotype by environment interaction patterns (Yan 2015).

There are different approaches to delineate a crop production region into MEs based on genotype × environment interaction. Gauch and Zobel (1997) first introduced additive main effect and multiplicative interaction (AMMI) charts to show the 'which-won-where' pattern of a genotype × environment dataset, whereby to divide a target region into MEs. Later on, Yan et al. (2000) developed GGE (genotypic main effect [G] plus genotype × environment [GE]) biplot analysis, which

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R. Khanal. Ottawa Research and Development Centre, Agriculture and Agri-Food Canada, 960 Carling Avenue, Ottawa, ON K1A 0C6, Canada.

A. Badea.* Brandon Research and Development Centre, Agriculture and Agri-Food Canada, 2701 Grand Valley Road, Brandon, MB R7C 1A1, Canada.

Corresponding author: Raja Khanal (email: raja.khanal@agr.gc.ca).

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provides a better graphic to show the 'which-won-where' patterns and ME determination. GGE biplot analysis has been used by numerous researchers for evaluating mean performance and stability of cultivars (Kang et al. 2006; Mohammadi et al. 2009) and in ME analysis for different regions and crops (Luo et al. 2015; Mohammadi et al. 2009; Xu et al. 2014, Yan et al. 2021). Recently, Yan et al. (2021) used GGE biplot to oat data and revealed that the oat growing regions in Canada consist of three oat mega-environments, namely, the Canadian Prairies, southern and eastern Ontario, and the rest of eastern Canada. The objectives of this study were (1) to understand the barley mega-environment in Ontario, (2) to evaluate the suitability of the test locations, and (3) to identify the best cultivars for Ontario.

Material and Methods

Multi-location trials

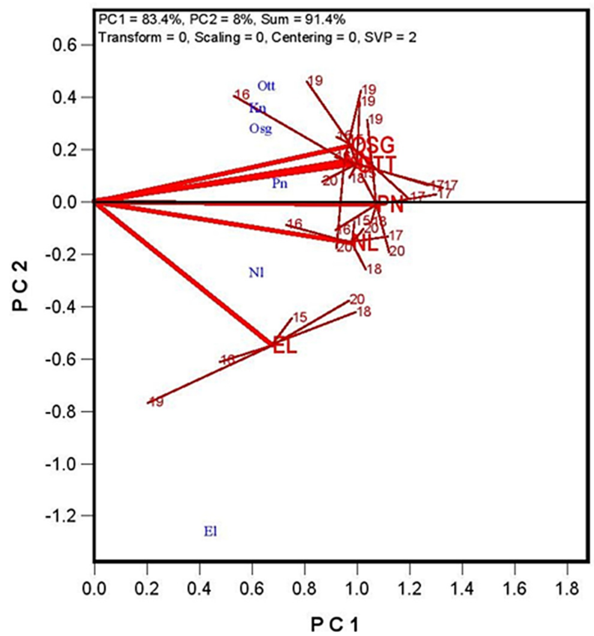
Data from the 2015–2020 Ontario provincial barley registration trials were analyzed in this study. The Ontario barley registration trials were conducted at five or more test locations covering most of the barley growing areas in Ontario. In each year, the same set of breeding lines plus four to five checks were tested at all locations with four replicates using a randomized complete block design. The Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) cereal crop production management practices were followed at each test location and year. The experimental unit was a four- to seven-row plot, 3 m to 7 m long, with 17 cm between rows. The plots were 17 to 20 cm apart, depending on the test locations. Notes on agronomic traits were taken during growth. Upon maturity, the whole plot was combine-harvested and yield, test weight, kernel weight, and other agronomic traits were determined. However, only the grain yield data are reported in this study, as grain yield is the most important breeding objective and the best indicator of adaptation.

Data analysis

Location-grouping (LG) biplot analysis to delineate mega-environments

The mean yield of each genotype across replicates in each trial was first calculated. The mean yield data was then used to calculate a yearly correlation table among test locations. The yearly correlation table was stacked in the form of a trial (location–year combination) by location two-way table. This table was then subjected to singular value decomposition, and the resulting first two principal components was used to generate a LG biplot, which was used to reveal any repeatable genotype by environment interaction and mega-environment differentiation (Yan 2019; Yan et al. 2021).

Fig. 1. Location-grouping (LG) biplot based on the yield data of the 2015–2020 Ontario Cereal Crop Committee Barley Orthogonal Trials. The numbers are different test years and EL—Elora, NL—New Liskeard, Ott—Ottawa, OSG—Osgoode, KN—Kincardine, and PN—Palmerston are test locations. [Colour online.]



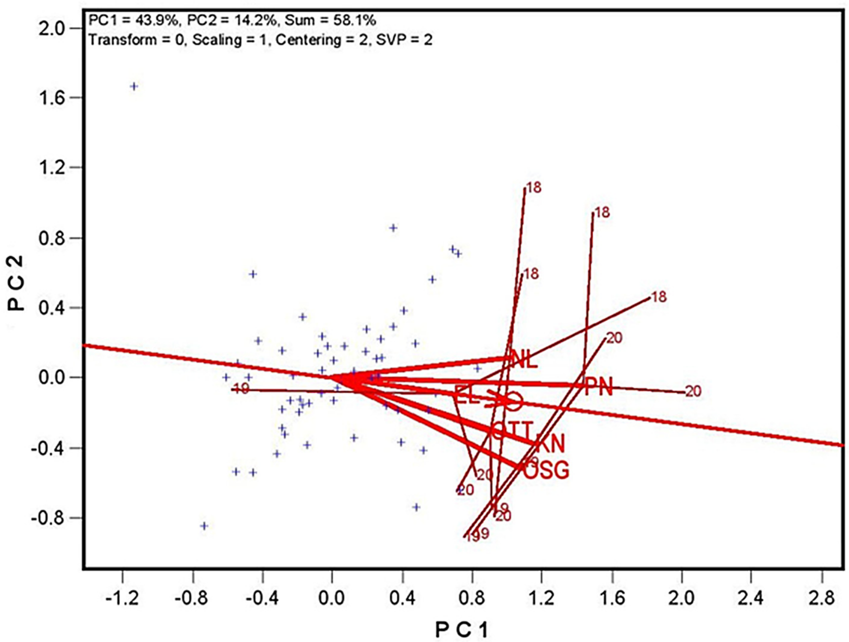
GGE + GGL biplot analysis for test location evaluation

The genotype main effects plus genotype × location interaction (GGL) + genotype main effects plus genotype × environment interaction effect (GGE) analysis was used for the evaluation of the test location. In this analysis, the placement of each test location in the biplot is determined by the average coordinates PC1 and PC2 of the environments derived for the same locations in different years (Yan 2015). This placement represents the average performance of a location in separating the genotypes over years. The projection of the test location onto the average environment axis (AEA) in an integrated measure of the representativeness of the test location for the mega-environment. A long projection means the test location is representative of a target environment in all or most years and can be used as a core test location.

GGE biplot analysis for genotype evaluation

In Ontario, data from more than nine station-year of registration test are required to make a decision on whether a barley breeding lines can be supported for registration. GGE biplot was used to visualize the mean yield and stability of the set of genotypes tested in two years from 2019 and 2020, treating each trial (location-year combination) as an environment. A genotype by environment two-way table was first generated, each

Fig. 2. The GGL + GGE biplot for the Ontario mega-environment based on the 2015–2020 data. The line that passes through the biplot origin is the average environment axis for the mega-environment. The + signs are genotypes, numbers are different years, and EL—Elora, NL—New Liskeard, Ott—Ottawa, OSG—Osgoode, KN—Kincardine, and PN—Palmerston are test locations. [Colour online.]



value being the mean across replicates within a trial. The environment mean was then subtracted from each value to form a new genotype by environment two-way table, which contains only G and GE. This table was then subjected to singular value composition and the resulting first two principal components were used to generate a GGE biplot. There are many functional forms or views for a GGE biplot (Yan 2001; Yan and Kang 2002; Yan and Tinker 2006). The average-environment-coordination view was used to visualize the mean and stability of the cultivars. The analyses were conducted using the GGE biplot software (Yan 2001).

Results and Discussion

Ontario barley mega-environments

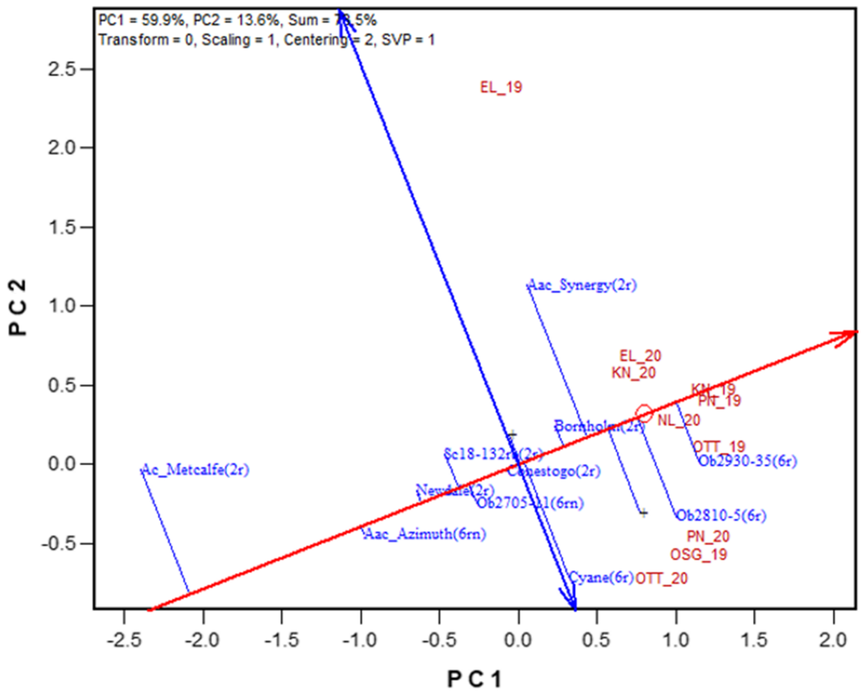
The LG biplot presented in Fig. 1 shows the mean placement of each test location and its distribution in different years. The six test locations fell into two clearly separated groups or mega-environments, indicating repeatable GE. The first group included only a single test location, Elora (EL) from area 2. The other group included five test locations from area 2, 3, and 5. After removing Elora (EL) from Fig. 1, all other test locations fall within a close cluster (data not shown), confirming that these five test locations belong to a single mega-environment. The LG biplot also shows large yearly variations for each location; this is unrepeatable GE.

In principle, cultivar evaluation should be conducted for each mega-environment so that mega-environment specific cultivars can be selected and the repeatable GE utilized. However, since the mega-environment represented by Elora (EL) has only a single test location, it is unlikely to be sufficient to select suitable cultivars for this mega-environment. Furthermore, the correlations between the two mega-environments were positive on average, as indicated by the acute angles between Elora (EL) and the other test locations. Thus, it would be best to select cultivars for both mega-environments based on data across all six test locations, with the understanding that the best cultivar(s) selected may not be the best for the mega-environment represented by Elora.

Evaluation of test location

The GGE + GGL biplot based on the 2018–2020 data were used for test location evaluation (Fig. 2). The GGE + GGL biplot using data from all six years was not possible due to too many missing values. The cosine of the angle between a test location and the average environment axis (the red line with an arrow, AEA) is an indication of the representativeness of the test location for the target environment, and the scope of the yearly placements of a test location is a measure of its stability across years in representing the target environment. The projection of the test location onto the average environmental axis is an indication of the desirability of a location to be used as a core test location (Yan 2015). Figure 2 shows the GGE + GGL biplot based on the 2018 to 2020 data at the six test locations. All six test locations in the larger mega-environment appeared representative of the mega-environment at deferent degrees as

Fig. 3. The mean yield performance and stability of different barley cultivars (lines) based on genotype and genotype by environment interaction (biplot) analysis grown across nine Ontario barley variety registration trials (EL_19—Elora 2019, EL_20—Elora 2020, KN_19—Kincardine 2019, KN_20—Kincardine 2020, NL_19—New Liskeard 2019, NL_20—New Liskeard 2020, OSG_19—Osgoode 2019, OTT_19—Ottawa 2019, and Ott_20—Ottawa 2020). [Colour online.]



indicated by the acute angles with the average environment axis. The location Palmerston (PL) was slightly more representative because it had a more acute angle with the AEA and a longer projection onto the AEA. One the other hand, the test location Elora (EL) had a dramatically shorter projection onto the AEA, indicating that it had inconsistent results over years, hence a poor test location to represent the Ontario barley growing region. This is consistent with what is seen from the LG biplot based on the 2015 to 2020 data (Fig. 1). Consequently, Elora (EL) cannot be used as a core test location for breeding for Ontario. However, Elora (EL) may be useful for culling unstable cultivars.

Cultivar evaluation based on mean yield and stability

In Ontario, more than nine station-year of registration test data are required to make a decision on whether a barley breeding line can be supported for registration. Therefore the GGE biplot based on the 2019–2020 trial data that represent ten station-year of evaluation is presented to show the mean and stability of the barley genotypes tested in those years, treating each location–year combination as an environment. The mean and stability of cultivars are visualized on the GGE-biplot as shown in the Fig. 3. The red line with a single arrow is the AEA, the arrow pointing to higher mean yield. The blue line with two arrows pointing higher instability in either direction. Thus, the new six-row barley line OB2930-35 yielded the highest and were relatively stable across all trials in these two years. The six-row barley line OB2810-5 had the second highest mean yield and was less stable than OB2930-35. The two-row barley cultivar AAC Synergy had a higher yield than the two-row check Bornholm but was unstable, due to its exceptionally good yield at Elora in 2019 but poor yield at Palmerston (PL) and Ottawa (OTT) in 2020 and Osgoode (OSG) in 2019. The genotype OB2930-35 was supported for registration by OCCC in January 2021 and licensed to SeCan for seed production and marketing in April 2021.

Conclusions

Applying GGE biplot analysis, GGE + GGL biplot analysis, and LG biplot to multi-year data from Ontario variety registration trials led to a good understanding of the barley mega-environments and test locations in Ontario. The Ontario barley growing regions, as represented by the six test locations, showed two different mega-environments, with a major mega-environment of five test locations from area 2, 3 and 5 and a minor mega-environment with one test location Elora (EL) from area 2. The location Palmerston (PL) was the most representative of the mega-environment. The GGE-biplot analysis identified barley cultivar OB2930-35 as both high yielding and stable, which was supported for registration and licensed to SeCan for seed production and marketing.

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