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# Genotype by environment interaction of tomato blossom-end scar size

Yonatan Elkind, Ofra Bar-Oz Galper, Jay W. Scott[1] & Nachum Kedar
*The Hebrew University of Jerusalem, Faculty of Agriculture, Dept. of Field Crops, Vegetables and Genetics, P.O. Box 12, Rehovot 76100, Israel; [1] Gulf Coast Research & Education Center, IFAS, University of Florida, 5007 60th Street East, Bradenton, FL 34203, USA*

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**Summary**

Large blossom-end scar is a disorder in tomato fruit which reduces its marketability. The disorder is affected by genotype and by several environmental factors and therefore the genotype by environment interaction was studied by stability analysis. Blossom-end scar size was recorded for 4 tomato cultivars grown in 6 fields. The blossom-end scar size (BSC) was affected by the genotype, the field and their interaction. Stability analysis revealed that most of the interaction resulted from different stability of the cultivars. Heterogeneity of the slopes was significant ($P < 0.0013$). The stability slopes were 0.29, 0.74, 1.11 and 1.85 for BR-214, FA-38, Hayslip and Suncoast, respectively. The stability slopes seemed to associate with the means of the cultivars over all environments, which were 1.57, 2.92, 3.84 and 5.43, respectively. Analysis of a blossom-end scar index (BSI), which also takes fruit size into account, revealed stability similar to BSC. It was concluded, that selection for small BSC under most conditions would yield cultivars with small and stable BSC under most growing environments, however differences between genotypes in non-inducing environments are expected to be small.

## Introduction

The blossom-end or stylar scar (BS) of tomato (*Lycopersicon esculentum* Mill.) fruit consists of corky tissue which develops at the distal end of the fruit. A large BS reduces the value of the fruit by affecting its appearance and reducing shelf-life due to leakage of juice and/or enhancing pathogen development (Fortney 1958; Sherman & Allen, 1981). BS size is affected by genotype as well as by environmental factors such as low temperature (Knavel & Mohr, 1969; Rylski, 1979) and possibly by wind. Tomatoes produced under outdoor conditions are exposed to changing and unpredictable environments, in which several environmental factors may vary. Thus, a stability analysis approach seemed appropriate to study genotype by environment interaction. In this approach a number of cultivars are grown in various fields. Each field represents a different environment and the mean of all the cultivars in a certain field serves as a measure of its environmental effect on the trait. Then, the stability of each cultivar is estimated by regression of its means within fields on the fields' mean. Heterogeneity of the slopes indicates that the genotypes differ in their stability (Yates & Cochran, 1938; Eberhart & Russell, 1966; Lin et al., 1986).

The aim of this work was to study the genotype by environment interaction of BS by stability analysis and thus provide guidelines for selection of cultivars with small BS across wide environmental conditions.

## Materials and methods

*Cultivars.* The cultivars studied were Suncoast and Hayslip, open pollinated cultivars from GCREC, Bradenton, Florida and FA-38 and BR-214, F1 hybrids bred at the Faculty of Agriculture, Rehovot, Israel.

*Plant growth and experimental design.* In each of the 6 fields, these 4 cultivars were arranged in a randomized complete block design with 5 plants per plot and 2 blocks. The plants were grown using the standard commercial practices of each area. The locations and temperatures of the experimental fields are in Table 1.

*Sampling and measurement.* About 3 months after planting, 10 ripe fruits were harvested from each plant, excluding fruits of the first truss. The large and small diameter of the BS of each fruit were measured with a digital caliper with an accuracy of 0.02 mm. The geometric mean of the 2 measurements served as the measure of the blossom-end scar in mm and will be referred as BSC. Likewise, the large and small diameters of each fruit were also measured and the ratio between BSC and the geometrical mean of the fruit diameters was multiplied by 100 to give the blossom-end scar index (BSI).

*Data analysis.* The BSC mean of each plot (50 fruits) was analyzed by PROC GLM of SAS (SAS, 1985) using the following model:

$$Y_{ijk} = \mu + S_i + SB_{ik} + \alpha_j + \beta_j Y_i.. + S\alpha_{ij} + E_{ijk} \quad (1)$$

where $Y_{ijk}$ is the mean BSC of a plot in the $i^{th}$ growing field of the $j^{th}$ cultivar in the $k^{th}$ plot. $\mu$ indicates the mean, $S_i$ the effect of the growing field, $SB_{ik}$ the blocks within the field, $\alpha_j$ the cultivar effect, $S\alpha_{ij}$ is the interaction between field and cultivar and $E_{ijk}$ is the error. $\beta_j$ is the slope of cultivar j on $Y_i..$, which is the mean of all the cultivars in field i. It is a mixed model in which $\mu$, $\alpha_j$ and $\beta_j$ are fixed and the rest are random effects.

## Results

In Fig. 1 the mean BSC of each cultivar within a field is plotted against the mean of the field. The rank of the cultivars in all the fields was highly consistent. Suncoast always had the largest BSC and BR-214 always the smallest one. With one exception, Hayslip had a larger BSC than FA-38. The absolute difference between the cultivars appears to depend on the mean of the field, the higher the field's BSC mean, the greater the difference between cultivars (Fig. 1a). The stability slopes were 0.29, 0.74, 1.11 and 1.85 for BR-214, FA-38, Hayslip and Suncoast, respectively (Table 2). Heterogeneity of the slopes was significant ($P < 0.0013$) indicating that at least some of the slopes differ from one another (Table 3). Furthermore, the stability slopes seem to associate with the means of the cultivars, which were 1.57, 2.92, 3.84 and 5.43, respectively (Table 2), i.e., the higher the cultivar mean, the greater the slope. Field × cultivar interaction was significant ($P < 0.0278$, 4 in Table 3), but became non-significant when the heterogeneity of the slopes was incorporated into the model ($P < 0.5476$, 4.2 in Table 3).

Analysis of BSI, which presents the ratio between the BSC and fruit size, behaved similar to

*Table 1.* Location, planting date and average monthly maximum and minimum temperatures during the 2 month period covering flowering and fruit development

| Field | Area | Planting date | Monthly average temperature °C | |
|---|---|---|---|---|
| | | | minimum | maximum |
| 1 | Rehovot | 15/4/86 | 12°–15° | 25°–28° |
| 2 | Rehovot | 18/5/86 | 15°–17° | 27°–30° |
| 3 | Rehovot | 2/6/86 | 18°–20° | 30°–32° |
| 4 | Mivhor | 2/5/86 | 13°–18° | 25°–31° |
| 5 | Besor | 30/7/86 | 20° | 32° |
| 6 | Rehovot | 1/5/87 | 13°–16° | 27°–30° |

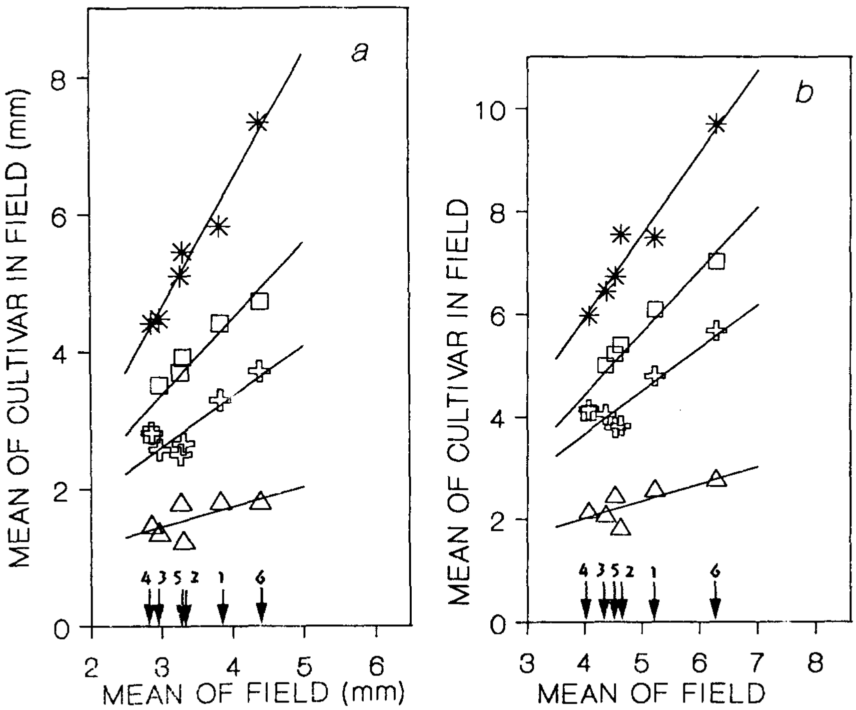


*Fig. 1.* Plot of cultivar mean within a field versus field mean in stability analysis of tomato fruit blossom-end scar size (a) and index (b). Arrow indicate fieldnumber and mean. △ -BR-214, ✤ -FA-38, □ -Hayslip, * -Suncoast.

BSC graphically (Fig. 1b) and statistically (Table 3). The stability slopes of BSI were 0.33, 0.84, 1.22 and 1.60 for BR-214, FA-38, Hayslip and Suncoast, respectively (Table 2) and heterogeneity of the slopes was significant ($P < 0.0044$, Table 3). As with BSC, the stability slopes of BSI seem to be related to the means of the cultivars (Table 2).

**Discussion**

The size of the blossom-end scar of the tomato fruit was studied by growing 4 cultivars in 6 fields of different planting dates in different areas. The BSC was affected both by genotype and by environment. The interaction between genotypes and the environment mostly resulted from different stability of the cultivars. This conclusion is based on the finding that, when the heterogeneity of slopes was incorporated into the model, the field × genotype

*Table 2.* Mean and stability slopes for blossom-end scar size (BSC mm) and index (BSI) of the 4 cultivars

| Cultivar | BSC (mm) | | | | BSI | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SE | Slope | SE | Mean | SE | Slope | SE |
| BR-214 | 1.57 | 0.10 | 0.29 | 0.19 | 2.30 | 0.13 | 0.33 | 0.18 |
| FA 38 | 2.92 | 0.10 | 0.74 | 0.19 | 4.37 | 0.13 | 0.84 | 0.18 |
| Hayslip | 3.84 | 0.10 | 1.11 | 0.19 | 5.46 | 0.13 | 1.22 | 0.18 |
| Suncoast | 5.43 | 0.10 | 1.85 | 0.19 | 7.30 | 0.13 | 1.60 | 0.18 |

interaction became non significant (Table 3). Furthermore, almost no change in rank of the different genotypes was observed across all the fields. BSC of BR-214 hardly changed in the various environments, with a minimum of 1.27 mm and a maximum of 1.8 mm, whereas Suncoast had a much larger range from 4.4 mm to 7.3 mm. The differential stability was also expressed by the regression slopes which were 0.29 and 1.85 for BR-214 and Suncoast, respectively. Genotype by environment interaction as found in this study may be removed by suitable transformation (e.g., logarithmic).

Across the 4 cultivars tested, the stability seemed to be associated with the size of the BS. A cultivar with small BS is less affected by the environment than a cultivar with large BS. Eberhart & Russell (1966) also found correlation between the stability slope and the genotype mean for yield of corn. If the association observed with our 4 genotypes is generally true, it may suggest that the genetic constitution of a cultivar determines its degree of sensitivity to the environmental factors affecting BS. Those factors might be wind, high or low temperature and other unknown factors.

The environmental factors in the stability analysis are incorporated into the model by the field mean. An alternative method for analyzing genotype × environment interaction is regression on some environmental factors such as temperature (Freeman, 1973). Low night temperature (5° C or 8° C) at the flower bud development period induced large BS (Knavel & Mohr, 1969; Rylski, 1979). In the present study the mean monthly temperature during fruit development did not correlate with the field's mean BSC. Field 6 which had the highest BSC (4.39 mm) was not characterized by extreme temperatures in comparison to the other fields (Table 1). Therefore, in the environments tested, temperature per se could not be the major factor affecting BS size. It should be noted that short-term extreme temperatures, which may affect BSC, are not indicated in monthly mean.

It seems that at the locations of our trials the temperature did not reach low values. Probably other environmental factors, singly or in combination, affected the BS in the fields tested. Agrotechnical practices such as fertilizer treatments and pruning are known to affect BS size (Asano, 1984; Sike & Coffey, 1976).

Scar tissue usually develops in response to wounding (Fortney, 1958; Fleuriet & Deloire, 1982). Therefore, specific and unknown environmental factors may cause a wound in the BS while the fruit develops. This wound may result from damage to the pistil by the above factor. The genotype differences may reflect different tendency to form and enlarge the scar and the environmental factors may vary in their tendency and intensity to induce wound forming.

Since in the results of BSC and BSI, which accounts for fruit size, were similar, differences in blossom-end scar size were not associated with fruit size.

BS is one of the quality attributes of tomato fruit,

*Table 3.* ANOVA of blossom-end scar size (BSC in mm) and index (BSI) of 4 cultivars grown in 6 fields

| No | Source | d.f. | BSC | | | BSI | | | Error term |
|---|---|---|---|---|---|---|---|---|---|
| | | | S.S. | F | P > F | S.S. | F | P > F | |
| 1 | Field | 5 | 13.6 | 3.3 | 0.0487 | 25.0 | 5.0 | 0.0160 | 2 + 4 − 5[1] |
| 2 | Block within field | 6 | 3.4 | 3.5 | 0.0169 | 4.1 | 2.6 | 0.0566 | 5 |
| 3 | Cultivars | 3 | 94.1 | 75.7 | 0.0001 | 155.7 | 88.1 | 0.0001 | 4 |
| 4 | Field × cultivar | 15 | 6.2 | 2.6 | 0.0278 | 8.8 | 2.2 | 0.0567 | 5 |
| 4.1 | Heterogeneity[2] | 3 | 4.5 | 10.1 | 0.0013 | 5.7 | 7.5 | 0.0044 | 4.2 |
| 4.2 | Field × cultivar | 12 | 1.7 | 0.9 | 0.5476 | 3.1 | 0.9 | 0.5176 | 5 |
| 5 | Error | 18 | 2.9 | | | 4.8 | | | |

[1] The corresponding degrees of freedom for the pooled F test based on Scheffe (1959).

[2] The field × cultivar interaction is partitioned into two components 4.1 and 4.2.

but it is usually only noted under conditions under which large BS causes economical damage. As the environmental factors affecting the traits hardly can be changed under outdoor conditions, a high stability of small BS is most important. Assuming that the results of this study, limited to 4 cultivars only, will have general significance, they indicate that it is feasible to select genotypes which will maintain small BS under adverse environmental conditions. The selection can be made under most growing conditions, even when in a specific field BS size is not problematic (less than 3 mm). It is conceivable that under ideal condition differences between cultivars will become too small for effective selection. However, in a field with a large average BS, the selection for small BS would be easier and more efficient (Brown et al., 1983). Furthermore, a few tester lines grown in the same field can provide good indicators for the strength of the environmental factors affecting BS in this field and assist in deciding the required selection intensity.

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