Yield Stability Differences among Tomato Genotypes Grown in Latin America and the Caribbean

Rodomiro Ortiz¹ and Juan Izquierdo

United Nations Food and Agriculture Organization, Region Latinoamericana y el Caribe, Casilla 10095, Santiago, Chile

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Abstract. The environment substantially affects the performance of tomato (*Lycopersicon esculentum* Mill.) genotypes in Latin America and the Caribbean (LAC). Therefore, stability analysis can be used to select stable, high-yielding genotypes. Nine open-pollinated and six hybrid tomato genotypes and the most representative local tomato cultivar were evaluated at 20 LAC locations. Each cultivar's yield stability was quantified using the regression of individual genotype's yield on the environmental index, which was measured by the mean of all the genotypes grown in an environment. A high-yielding and stable tomato cultivar had a mean yield higher than the general mean, b_1 (coefficient of regression) = 1, s_d^2 (deviation from linearity) = 0, and r^2 (coefficient of determination) > 0.50. 'Narita' (hybrid) and 'Dina RPs' (open-pollinated) were the most stable genotypes for marketable-fruit yield in LAC. 'Flora Dade', an open-pollinated genotype that is grown widely in LAC had unstable marketable-fruit yield. Neither heterogenous composition of an open-pollinated genotype nor heterozygosity per se of the hybrids could explain the yield stability achievement across environments. Therefore, alleles that confer broader adaptation might be required to achieve tomato yield stability across environments. Hence, it is possible to select for yield stability in tomato.

Tomato is an important vegetable crop in Latin America and the Caribbean (LAC), with 252,000 ha grown in the region [Food and Agriculture Organization (FAO), 1986]. The crop is used for local consumption and export. LAC's national programs (NPs) use the introduction of new hybrid genotypes to increase fruit yield and quality and hasten maturity. However, because open-pollinated seeds are less expensive than hybrid seed and open-pollinated cultivars can be propagated by the farmers themselves, some LAC NPs have selected open-pollinated genotypes to meet requirements of small farms.

The United Nations FAO and other international or regional agriculture research centers (IARCs) use regional trials to evaluate new genetic resources. Therefore, new germ-

plasm is shared with NPs that can use it directly or in their breeding programs.

The genotype $\times$ environment (G $\times$ E) interaction is important to plant breeders. The effect of environmental variation on genotype performance suggests that genotype selection is not possible from one environment (either year or location) but that genotypes must be evaluated in diverse environments. Hill (1975) indicated that the genotype classification varies according to the environment in which they

are assessed. Generally, genotypes with consistent yield over many environments are preferred to those with high yield in selected environments. Breeders must select cultivars adapted to unpredictable environmental fluctuations by using replicated yield trials over locations and years, which allows the assessment of the G $\times$ E interaction and proper germplasm selection.

Stoffella et al. (1984) suggested that the selection of tomato genotypes with stable performance should be considered by breeding programs because differences for yield stability were detected among tomato cultivars in yield trials evaluated in Florida. Berry et al. (1988) reemphasized the need to grow advanced tomato breeding lines for several seasons when selecting high-yielding stable genotypes. Izquierdo et al. (1980) and Berry et al. (1988) stated that stability analysis (Eberhart and Russell, 1966) was a useful tool for identifying tomato cultivars adopted by the processing industry in Uruguay and the United States, respectively. Cuartero and Cubero (1982) found that tomato hybrids had higher and more stable yields than their parents in differing environments in Spain. In contrast, Poysa et al. (1986) indicated that tomato genotypes with low yields had greater yield stability than genotypes with high but unstable yields in Ontario, Canada.

Our objectives were to evaluate hybrid and open-pollinated tomato genotypes developed by NPs, IARCs, and private seed companies in diverse LAC environments and to assess their phenotypic yield stability in this region.

Materials and Methods

Nine open-pollinated and six hybrid genotypes and an open-pollinated local cultivar provided by each NP were included in the yield trial. The field layout in each of the 20 locations was a randomized complete-block

Table 1. Marketable-fruit yield and average fruit weight in 20 environments of Latin America and the Caribbean (1987–88).

Environment	Country	Marketable fruit yield (t·ha ⁻¹)	Avg fruit wt (g/fruit)
Santiago	Chile	89.8 a ^z	115 de
Curacavi	Chile	82.2 b	113 de
La Molina, Lima	Perú	75.1 c	121 c-e
Portoviejo	Ecuador ^y	29.8 d	159 a
Comayagua	Honduras	26.5 de	91 gh
Baja Vera Paz	Guatemala	26.4 de	125 cd
Villa S. Antonio	Honduras	26.2 d-f	88 gh
Colina, Chacabuco	Chile	24.5 d-g	114 de
Estanzuela, Zacapa	Guatemala	22.4 e-g	116 c-e
Chillán	Chile	21.5 e-g	128 c
Portoviejo	Ecuador ^s	20.3 f-h	144 b
S. Andres, La Libertad	El Salvador	20.0 gh	111 ef
Palmira, Cali	Colombia	15.4 hi	141 b
Cogutepque, Cuzcatlán	El Salvador	14.0 i	97 gh
Constanza	Dominican Republic	12.6 ij	98 fg
S. Antonio, Alajuela	Costa Rica	7.6 jk	86 gh
Sapecho, Alto Beni	Bolivia	6.5 k	56 i
San Cristobal	Dominican Republic	6.3 k	84 h
Colonia, Igavi	Bolivia	4.0 k	43 i
Bélem, Bragantina/Para	Brazil	2.7 k	53 i

^zMean of the 15 (nine open-pollinated and six hybrid) tomato genotypes. Means followed by the same letter were not statistically different according to Tukey's test at $\alpha = 0.05$.

^yTomatoes planted on 7 June 1987.

^sTomatoes planted on 10 July 1987.

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¹Current address: International Institute of Tropical Agriculture (IITA), Oyo Road PMB 5320, Ibadan, Nigeria. International mailing address: IITA, c/o Lambourn, 26 Dingwall Rd., Croydon, CR9 3EE, England.

design with four replications of each cultivar (Table 1). Plots consisted of 36 plants, four rows of nine plants each. The experimental unit consisted of five plants, each from the middle two rows. The distance between rows was 1.5 m with 0.5 m between plants. The common agronomic management was used in each field location.

Yield was evaluated for ripe fruit according to each genotype maturity. Fruit with diameters >48 mm were considered marketable. Marketable-fruit yield and average fruit weight (grams/fruit) were recorded on a per plot basis, and the method and plot size were the same in all locations. Soil condition (type, percentage of organic matter, natural fertility, pH), N-P-K fertilization, meteorological data (temperature, daylength, rainfall), and disease and pest management were recorded for each environment (Izquierdo et al., 1988).

Combined analyses of variance, using complete data sets (no missing plots or treatments), were performed following a mixed model (Nevado and Ortiz, 1985) for marketable-fruit yields and average fruit weights. Locations and cultivars were considered as random and fixed variables, respectively, in the combined analyses.

The performance of the hybrid and open-pollinated genotypes across locations was studied by an analysis of simple effects using a single degree-of-freedom contrast at $P \leq 0.05$. For each variable location and genotype, means were compared using Tukey's test at $P \leq 0.5$.

Each cultivar's phenotypic stability for marketable-fruit yield and average fruit weight was assessed using simple linear regression (Eberhart and Russell, 1966; Finlay and Wilkinson, 1965; Yates and Cochran, 1938). A genotype was considered to be stable if b_1 (coefficient of regression) = 1, s_d^2 (deviation from linearity) = 0, and r^2 (coefficient of determination) > 0.50. The stability characteristic b_1 was considered consistent if its standard error (s_b) was not significantly different than zero. This was indicated in the analysis of variance by a nonsignificant deviation from linear regression mean square (s_d^2).

The determination of high- and stable-yielding genotypes for marketable-fruit yield and average fruit weight was performed by plotting the mean of the cultivar (x axis) vs. the stability coefficient b_1 (y axis). Nine data spaces were defined by drawing lines parallel to each axis (Fig. 1), two lines parallel to the y axis from yield either significantly lower or higher than the grand mean, and two lines parallel to the x axis from b_1 values statistically different than 1.0. Cultivars located in the area where yield was greater than the grand mean and $b_1 \leq 1$ were regarded as stable- and high-yielding genotypes (Marquez, 1976; Stoffella et al., 1984).

Results and Discussion

Marketable-fruit yield and average fruit weight were significantly different among environments (Tables 1 and 2). There was variation among environments for marketable-fruit yield and average fruit weight across

LAC (Table 1). Santiago, Chile, and Para, Brazil, produced the highest and lowest marketable-fruit yield at 89.8 and 2.7 t·ha⁻¹, respectively. Peru and Chile also had environments with high marketable-fruit yield. The highest average fruit weight (159 g) was obtained in Portoviejo (Ecuador), when the crop

was planted in early June; the lowest (43 g) was recorded in Igavi, Bolivia. Average fruit weight was higher than the general mean in Ecuador, Colombia, the South Pacific countries, and Guatemala.

Genotypes were significantly ($P \leq 0.01$) different for marketable-fruit yield and aver-

Fig. 1. Regression coefficients (b_1) of the cultivar means over environmental index plotted against cultivar means over the 20 environments for (A) marketable-fruit yield and (B) average fruit weight. The numbers are cultivar codes indicated in Table 3.

Table 2. Combined analysis of variance for marketable-fruit yield and average fruit weight of 15 tomato cultivars evaluated in randomized complete-block designs with four replications at 20 Latin American and Caribbean locations.

Source of variation	df	Mean squares	
		Marketable-fruit yield (t·ha ⁻¹)	Avg fruit wt (g/fruit)
Locations (L)	L - 1 = 19	39389.291**	55826.814**
Replications (R)/L	L (R - 1) = 60	181.520	593.597
Cultivars (C)	C - 1 = 14	2280.304**	47231.935**
Open-pollinated vs. hybrid cultivars	1	15858.072**	269085.240**
C × L	(C - 1)(L - 1) = 266	505.199**	2104.240**
Pooled error	(C - 1)(R - 1)L = 840	75.525	377.013
Coefficient of variability (%)		32.43	18.64

**Significant at $P \leq 0.01$.

Table 3. Means^a and stability characteristics^b for marketable-fruit yield and average fruit weight of 15 tomato genotypes averaged over 20 locations in Latin America and the Caribbean (1987–88).

Genotype code ^a	Cultivar (source ^w)	Marketable-fruit yield (t·ha ⁻¹)				Avg fruit wt (g)			
		$\bar{X}$	b_1^v	s_b^u	r^2	$\bar{X}$	b_1^v	s_b^u	r^2
1 (OP)	Catalina (MAG, Costa Rica)	27.8 b–d	1.09	0.06**	0.90	85 g	0.85	0.14**	0.46
2 (OP)	Dina RPs (IDIAP, Panama)	29.4 a–d	0.94	0.09**	0.72	116 c–f	1.02	0.12**	0.65
3 (OP)	Licapel-21 (ICA, Colombia)	16.8 g	0.46**	0.09**	0.38	65 h	0.46**	0.09**	0.36
4 (OP)	Trique (INTA, Argentina)	25.5 de	0.91	0.05**	0.88	141 a	1.47**	0.16**	0.67
5 (H)	Apla (Vilmorin, France)	27.4 cd	1.15	0.03	0.98	109 ef	1.14	0.07	0.87
6 (H)	Narita (Royal SLuis, Holland)	31.1 a–c	1.04	0.05	0.94	118 c–e	0.95	0.10**	0.71
7 (H)	Contessa II (Petoseed, USA)	30.4 a–c	1.20*	0.08**	0.93	130 b	1.55*	0.25**	0.48
8 (H)	Luxor (Petoseed, USA)	32.2 ab	1.32**	0.05**	0.86	145 a	1.44**	0.13**	0.76
9 (H)	BHN-39 (BHN Research, USA)	32.5 ab	1.13**	0.06	0.96	112 d–f	1.17	0.20**	0.45
10 (OP)	Angela Gigante (Asgrow, USA)	20.1 fg	0.74**	0.07**	0.76	66 h	0.46**	0.09**	0.32
11 (H)	Sunny (Asgrow, USA)	33.9 a	1.43**	0.06**	0.94	121 b–d	1.20	0.16**	0.58
12 (OP)	CL 5915-223 (AVRDC, Taiwan)	18.8 g	0.70**	0.08**	0.49	56 h	0.42**	0.08	0.40
13 (OP)	CL 5915-93 (AVRDC, Taiwan)	21.5 e–g	0.63**	0.10**	0.49	65 h	0.36**	0.07	0.38
14 (OP)	NC EBR-2 (NCSU, USA)	24.8 d–f	1.14	0.12**	0.69	123 bc	1.37	0.19**	0.55
15 (OP)	Flora Dade (Petoseed, USA)	29.0 b–d	1.25**	0.08**	0.86	107 f	1.16	0.17**	0.50

^aMean of the 15 (nine open-pollinated and six hybrid) tomato genotypes. Means separation according to Tukey's test at $\alpha = 0.05$.

^bStability characteristics: b_1 , coefficient of regression; s_b , SE of coefficient of regression; r^2 , coefficient of determination.

^cO = open-pollinated, H = hybrid.

^wIDIAP = Instituto de Investigaciones Agropecuarias, ICA = Instituto Colombiano Agropecuario, INTA = Instituto Nacional de Tecnología Agropecuaria, AVRDC = Asian Vegetable Research and Development Center, NCSU = North Carolina State Univ.

^v b_1 is significantly different than 1 at $\alpha = 0.05$ (*) or 0.01 (**), respectively.

^uDeviation from linear regression mean squares (s_b^2) significantly different than zero at $\alpha = 0.01$ (**).

age fruit weight across the 20 locations (Table 2). On average, the hybrids had significantly ($P \leq 0.01$) higher yields and fruit weight than the open-pollinated genotypes over the 20 LAC environments (Table 3).

The $G \times E$ interaction was significant ($P \leq 0.01$) for marketable-fruit yield and average fruit weight (Table 2). This result indicates that the genotypes had different productivity responses across LAC environments. Therefore, marketable-fruit yield and average fruit weight stability were evaluated to find those genotypes with high but stable yield across the environments (Table 2). The hybrid 'Narita' and the open-pollinated cultivar Dina RPs were considered genotypes with high and stable marketable-fruit yield (Fig. 1A). Three hybrids ('Narita', BHN-39, and 'Sunny') and one open-pollinated genotype ('Dina RPs') were considered to have high and stable average fruit weight (Fig. 1B). However, their stability characteristic b_1 was regarded as inconsistent because s_b was > 0 for all four genotypes (Table 2). Another hybrid, 'Apla', had an average and stable average fruit weight, with a consistent stability characteristic b_1 ($s_b = 0$).

The coefficient of determination indicated that most of the sum of squares of the $G \times E$ interaction from combined analysis of the regional trial in LAC was due to linear responses of each genotype to environmental fluctuations (as measured by the environmental index) (Table 2). This suggests that s_b^2 could not be included as stability criteria for the LAC regional trial.

'Narita' and 'Dina RPs' may be selected as potential cultivars for LAC because both genotypes had stable and above average marketable yields (Fig. 1A). Various arguments could be used to explain the results we obtained for marketable-fruit yield stability. Simple explanations would take each genotype's genetic structure into consideration. For example, the phenotypic stability of 'Dina RPs' (an open-

pollinated genotype) could be regarded as the result of its high plasticity due to its heterogeneous composition, and marketable fruit stability achieved by 'Narita' (hybrid) could be related to its heterozygosity. However, neither heterogeneous composition nor heterozygosity per se are good enough explanations for the achievement of marketable-fruit yield stability as demonstrated by other open-pollinated and hybrid genotypes. Therefore, alleles that confer broad adaptation should be considered in explaining marketable-fruit yield stability in hybrids or open-pollinated tomato genotypes. Our results also indicate that it is possible to select for marketable-fruit yield stability in tomato.

Other cultivars, such as 'Apla' (hybrid), 'Catalina', 'Trique', and NC-EBR (open-pollinated genotypes), achieved marketable-fruit yield stability, but they had average marketable-fruit yield (Fig. 1A). High-yielding commercial hybrids, such as 'Sunny', 'Luxor', and 'Contessa II', were sensitive to environmental fluctuation ($b_1 > 1$) for marketable-fruit yield, which suggests that these hybrids achieve high yield only in favorable environments. This result agrees with an earlier report by Poysa et al. (1986) who used similar methods. In that study, Poysa et al. mention that many high-yielding, useful, tomato genotypes would be identified as unstable by regression analysis.

Hybrid cultivars could be used in some LAC countries with adequate technology and proper environment for tomato production. Hybrids could have high yields, large fruit size, and yield stability, whereas open-pollinated genotypes selected by NPs also should be considered for use in LAC, especially in those countries with a low input in agriculture or with unpredictable environments. Indeed, open-pollinated genotypes had higher marketable-fruit yield than the hybrids and adequate average fruit weight in some LAC environments.

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