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Research Article

Evaluation of promising commercial sugarcane genotypes for stability by AMMI analysis

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Abstract
The choice and recommendation of a variety for commercial cultivation are influenced by genotype x environment interaction (GEI)). The complication of genotype by environment interaction (GEI) is that usually involves layout of trials in various seasons, making it difficult to identify the genotype adapted to different environments. Twenty sugarcane clones and four standard checks were evaluated under three environments within the tropical climate. Additive Main Effects and Multiplicative Interaction (AMMI) model was applied to assess the extent of genotype x environment (GE) interaction and also the stability of sugarcane clones across the environments. The significant difference was observed by AMMI analysis among the tested clones and environments. The sum of the first two principal components conferred to 63.6 per cent of the total of G x E interaction. In the present study, the genotypes G24 (Co 88025), G23 (CoV 94101) and G20 (Co 16001) recorded in high mean yield and higher Principal Component Analysis (PCA) scores; hence, these materials specifically suited to the favorable locations. Since the genotypes Co 15021(G19), Co 0240 (G3), and Co 13001(G7) were near the center point of the axes and hence were influenced by the environment. These clones recorded higher cane yield and stability and suitable for cultivation in different environments. The utilization of the AMMI model made it easy for the visual comparison and identification of exceedingly superior genotypes for every set of environments.

Key words
Saccharum spp., AMMI biplot, adaptability, AMMI stability value

INTRODUCTION

Sugarcane (*Saccharum* spp.) is an important industrial crop that contributes 80 per cent within the world's economy, particularly as a staple crop for several products and recently gaining importance for biofuel production. In India, the sugar business is the second largest agro-based business and which contributes considerably to the socio economic development of the state and successively to the country and is to identify high yielding variety with staple performance across the environments. Therefore, the primary objective in any sugarcane breeding programs is high yielding variety with stable yield across the environments is necessary for this country for the continuous supply of raw material. The sugarcane varietal demand across the country is being supported by the varieties of ICAR-Sugarcane Breeding Institute, Coimbatore. Several adaptive trials have been conducted to identify high yielding sugarcane genotypes with wide and specific adaptation to various geographical zones of the country over many years and seasons. Environments involve a wide range of biotic and abiotic factors for the growth and development of the crop cause large variation in genotype (G) × environment (E) interactions (GEI). The account of measuring GEI and perceiving its physiological bases are required to breed effectively superior genotypes for the environments (Vargas *et al*., 2001; Thomason and Phillips, 2006).

Sugarcane breeding is a highly complex ploidy species because of its highly heterozygous nature, high G x E interaction. In multi location yield trials, the performance of genotypes often vary from one location to a different location for yield and quality, thereby indicating a strong

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genotype x environment interaction (GEI). A series of trials are conducted with many genotypes under several environments and studied for their main effects and interactions. This kind of research is useful in the development of sugarcane varieties by determining their average response and rating genotypes based on their response to various environmental conditions. (GE interaction) for traits like yield. The difference occurs in the behavior of cultivars which are contributed by the effect of the genotype × environment (G × E) interaction (Haldane, 1946; Falconer and Mackay, 1996). Due to differential response of genotypes across environments, selection of genotypes becomes a challenge due to change in genotype ranking over testing locations. This type of interaction reduces selection efficiency and therefore the accuracy of cultivar recommended (Crossa and Cornelius, 1997) for commercial cultivation. A stable variety should have a high mean yield with a low magnitude of GEI when grown under varied environments. Breeders should ensure that the particular genotype is selected based on maximum yield and stable performance in various environments by comparing the genotypes (Kumar *et al*., 2009).

Various statistical models help to choose the genotypes, predict their phenotypic response to environmental changes, and thereby reduce the impact of G × E interaction. The GEI is mostly determined by the additive main effects and multiplicative interaction (AMMI) model (Zobel *et al.,* 1988; Umadevi and Manonmani., 2018). The AMMI might be a powerful and robust tool for effective analysis of multi-environment data in breeding programs (Yan *et al*., 2000; Samonte *et al*., 2005). Evaluating the performance of genotypes in different environments, the AMMI model fits well because it effectively divides the main and interaction effects and for the breeder, it provides a relevant interpretation to use the genotype in future breeding programmes. It is used to study the genotypic stability in the different environments using the PCA (principal component axis) scores and AMMI stability value (ASV). The ASV is based on the division of the sum of squares of IPCA1 (First Interactive Principal component analysis) and IPCA2 scores for every genotype (Purchase *et al*., 2000). Genotypes having the least ASV values are considered as widely adapted to various environments and genotypes with large ASV values represent less stable but specifically adapted to a particular environment.

So this study aims to study genotype-environment interaction for cane yield (t/ha) in sugarcane genotypes evaluated across seasons and to evaluate the phenotypic and stability performance of different sugarcane genotypes across seasons using AMMI analysis.

MATERIALS AND METHODS

The experiment was conducted during 2017-18 and 2018- 19 crop seasons. The trials were conducted at M/s. Dharani Sugars and Chemicals Ltd (DSCL), Unit II sugar factory (12.30^{o}N, 79.10^{o}E) located in Tamil Nadu (Tropical region). This factory location is characterized by high temperature and humidity. With erratic rainfall mean five years average of 907 mm. This experimental site represented the tropical India (**Table 1)**.

Twenty promising genotypes developed by ICAR-Sugarcane Breeding Institute, Coimbatore and four standard varieties from early and mid-late maturity groups were multiplied at ICAR-SBI, Coimbatore during January-July 2016 and were supplied for evaluation of yield and juice quality under SISMA for three crop seasons (I plant crop, II plant crop, and ratoon crop) during 2017-18 and 2018-19 seasons. The parentage and the maturity groups of the test entries used in this study are given in **Table 2**.

The experiment comprised genotypes evaluation of plant ratoon crops in two years (**Table 3**). The experiment was conducted in a randomized block design with three replications and the cultivation practices were followed. The plant crops were harvested at 360 days of age and the ratoon in 330 days. Biometrical data on cane yield (t/ha), the number of millable canes (NMC), cane length (cm), cane diameter (cm), and single cane weight (SCW) was recorded. Five canes were selected randomly from each entry in each replications for recording the data. Juice quality parameters such as brix (%), sucrose (%), purity (%), and CCS (%) were estimated at 8, 10 and 12 months of age using the standard procedure (Chen 1985). The data on two plant crop and one ratoon were conducted as three environment of sugarcane clones in each environment and their interaction were assessed. In this research article, the data on cane yield (t/ha) at harvest only were considered to test the adaptability and stability of the clones raised.

The AMMI model was applied to estimate the adaptability and phenotypic stability. According to Farshadfar *et al*. (2011), the AMMI model can be written as

$$Yij = \mu + gi + ej + n \sum k{=}1 \ \lambda k \alpha ik \gamma jk + eij$$

Table 1. Weather data at DSCL unit II,Polur during the experimental period

S.No.	Year	Rainfall (mm)	Temperature (degree celcius)	
			Minimum	Maximum
1	2017	957	25	37
2	2018	928	27	37

Table 2. List of genotypes and code for the analysis

S.No.	Clone	Parentage	Maturity group	Code of genotype
1	Co 0212	Co 7201 x ISH 106	ML	G1
2	Co 0238	CoLk 8102 x Co 775	E	G2
3	Co 0240	Co 86002 x Co 8347	ML	G3
4	Co 06031	BGC2 5021 x Co 88027	ML	G4
5	Co 09004	CoC 671 x CoT 8201	E	G5
6	Co 11015	CoC 671 x Co 86011	E	G6
7	Co 13001	Co 740 x CoT 8201	E	G7
8	Co 13003	Co 86011 x CoT 8201	E	G8
9	Co 13006	CoSnk 03-61 x Co 62174	ML	G9
10	Co 13014	Co 86032 x Co 94008	ML	G10
11	Co 13018	Co 8371 x Co 86011	ML	G11
12	Co 13020	Co 7704 x CoT 8201	ML	G12
13	Co 13021	Co 92024 GC	ML	G13
14	Co 14008	Co 99006 x Co 94008	E	G14
15	Co 14016	Co 86032 x Co 86011	ML	G15
16	Co 14026	Co 98010 x Co 94008	ML	G16
17	Co 15005	(Co 8371 x ISH 69) x (Co 86032x Co 99006)	E	G17
18	Co 15007	ISH 100 x Co 0209	E	G18
19	Co 15021	Co 86032 x Co 86011	ML	G19
20	Co 16001	CoSnk 03-044 x Co 86002	E	G20
21	Co 16002	CoC 671 x Co 86011	E	G21
22	Co 86032	Co 62198 x CoC 671	ML	G22
23	Co 88025	Somaclone of CoC 671	E	G23
24	CoV 94101	Co 7704 × Co 775	E	G24

where Yij = the yield of the ith genotype in the jth environment, gi is the mean of the ith genotype minus the grand mean;λk is the square root of the eigenvalue of the PCA axis k;αik and γjk are the principal component scores for PCA axis k of the ith genotype and the jth environment, respectively; eij is the residual value. The environment and genotypic PCA scores are expressed as unit vector times the square root of λk; i.e., environment PCA score = $\lambda k\ Yik$; genotype PCA score = $\lambda k \alpha ik$.

AMMI stability value (ASV) was calculated for each genotype by the contributions of principal component axis scores (IPCA1 and IPCA2) to the interaction sum of squares. IPCA1 represents the response of the genotypes that are proportional to the environments associated with the GEI and the second principal component (IPCA2) provides information about cultivation locations that are accountable to G x E crossover interaction.

The AMMI stability value (ASV) was described by Purchase *et al*. (2000) as follows:

$$ASV = \sqrt{\left[\frac{IPCA1_{sumofsquare}}{IPCA2_{sumofsquare}}\left(IPCA1_{score}\right)\right]^2 + \left(IPCA2_{score}\right)^2}$$

Where, SSIPCA1/SSIPCA2 is that the weight of the IPCA1 value. This is calculated by dividing the sum of squares IPCA1 by the sum of squares IPCA2. It is interpreted that the larger IPCA score irrespective of its sign (positive or negative value), the genotype is more adapted to a particular environment only whereas the genotype is more stable across all the environments if the score of ASV is smaller.

Table 3. Details of environment and their notations

S.No	Planting season	Environmental notation
1	First plant crop planting in February 2017 at DSCL Unit II ,Polur	E1
2	II plant crop planting in February 2018 at DSCL Unit II ,Polur	E2
3	Ratoon of crop E1 in 2018 at DSCL Unit II ,Polur	E3

Table 4. Combined ANOVA for cane yield (t/ha) of 24 sugarcane genotypes tested in three environments by AMMI model

Source of variations	df	Sum of squares (SS)	Mean sum of squares (MS)	Per cent	Per cent
				Explained	Accumulated
Genotypes	23	12482.79	542.73*	52.3	-
Environments	2	49877.90	7184.12*	50.8	-
GxE interaction	46	5073.83	110.30*	11.66	-
IPCA 1	24	3229.10	134.55*	63.6	63.6
IPCA 2	22	1844.71	83.85	36.4	100

RESULTS AND DISCUSSION

Genotype, environment, and GEI interactions were estimated by the additive main effect and multiplicative interaction (AMMI) model and presented in **Table 4**. In this study, the ANOVA for cane yield (t/ha) was significant for genotype, environment, and GEI. GEI was inferred by changes in the relative performance of genotypes across various environments. The effects of environment followed by genotype and genotype by location interaction effects were responsible for the variation. Because of high variation in soil types and atmospheric conditions among the environments may cause the high environmental variances. This has been documented from the findings of Meena *et al.* 2017 reported in sugarcane and Abate, 2020 in maize. In the present study the results of ANOVA, the twenty-four genotypes revealed that the mean square of the first interaction principal component axis (IPCA1) was found to be highly significant ($P<0.001$) whereas the second IPCAs captured in non-significant variation. In the present study, the variation could be almost equally contributed by the genotypic effects (52.3%) and environmental effects (50.8%), whereas the effects of GEI contributed was less (11.66%) for the cane yield in sugarcane. In the present study, the effects of genotype and environment coincided with the findings of Rea *et al.* (2017) and Meena *et al.* (2017). When the IPCA1 score was almost zero or equal to zero, it was assumed that the clone was having a small and stable interaction.

The AMMI results also showed that IPCA1 and IPCA2 explained that the interaction sum squares of 100 per cent , indicating that the first two IPCA were sufficient to explain GEI in cane yield of sugarcane genotypes. This result was similar to the previous findings of Meena *et al.* 2017 and they indicated that the finest predictable AMMI model was with only two interaction principal component axes. The IPCA1 and IPCA2 accounted for 63.6% and 36.4% respectively and together contributed 100 per cent of the variability in cane yield of the 24 genotypes tested at three locations. This was in agreement with Mattos *et al.* (2013), Usha Rani *et al.* (2017) and Regis *et al.* (2018) who suggested that GEI pattern is collected in the first principal components of analysis. Average cane yield recorded 102.28 t/ha and 65.26 t/ha for II plant crop and ratoon, respectively (**Table 5**). Among the 24 genotypes, 13 genotypes were observed on the right side of the midpoint of the perpendicular line and exhibited higher cane yield than the average yield (87.86 t/ha). The clones in their order of maximum yield were Co 06031 (114.50t/ha), Co 13014 (109.32t/ha), CoV 94101 (101.77t/ha), Co 11015 (99.52t/ha), Co 0240 (97.79t/ha), Co 14016 (97.51t/ha), Co 16001(96.78t/ha), Co 15021 (96.64t/ha),Co 86032 (95.22t/ha),Co 13020 (92.38t/ha). Co 13001 (90.83t/ha), Co 88025 (90.74t/ha) and Co 14008 (88.21t/ha).The genotypes with minimum yield was Co 15005 with an average cane yield of 61.26t/ha followed by Co 0238 (69.07t/ha). The genotypes with varied performance in response to environments have concluded that the clones were more variable and less stable across environments.

Based on the mean cane yield of genotypes across the environments the maximum yield was recorded as 106.21t/ha (G10) and the minimum as 58.51t/ha (G17) yield. The environmental mean cane yield ranged from 105.17t/ha (E1) to 54.41t/ha (E3) and the grand mean cane yield over environments and genotypes is 83.35t/ha (**Table 6**). The environments were described for their stability based on their ASV. The environments E3 (5.01) and E2 (4.14) with the highest ASV were said to be the least stable environments, while E1 (0.87) with the least ASV was the stable environment which may be useful for the breeder to choose a better environment for further sugarcane breeding program. Our findings are in agreement with the results of Yan, (2000).

The measuring of stability value quantitatively is called AMMI Stability Value (ASV), which was developed by Purchase *et al*. (2000). The ranking of genotypes to rank genotypes through the AMMI model was considered to be the most appropriate single method of describing the stability of genotypes. In **Table 5**, scores of IPCA1 and IPCA2 for each genotype cane yield and the corresponding AMMI stability value (ASV) which was calculated, and their ranks were presented**.** It is concluded that the variety with a high mean yield and the least ASV score is the most stable (Rea *et al*., 2017) and for the breeder, this strategy will be useful in the sugarcane breeding program. Based on this, the lowest ASV having higher cane yield over the grand mean such as 0.248 (Co 15021), 1.098 (Co 0240),

Table 5. Interaction principal components (IPCA) Values of sugarcane genotypes

Genotypes	Clone	Mean yield (t/ha)	IPCA1	IPCA2	ASVi	Rank
G1	Co 0212	86.78	-1.361	1.921	3.060	18
G2	Co 0238	69.07	2.011	-1.901	4.001	20
G3	Co 0240	97.79	-0.510	0.637	1.098	2
G4	Co 06031	114.50	0.827	2.283	2.703	14
G5	Co 09004	69.93	-1.429	-0.569	2.565	13
G6	Co 11015	99.52	-2.716	-2.553	5.397	24
G7	Co 13001	90.83	0.661	0.118	1.163	3
G8	Co 13003	86.96	1.331	-1.010	2.540	11
G9	Co 13006	74.58	1.453	-0.123	2.546	12
G10	Co 13014	109.32	-2.309	2.026	4.520	21
G11	Co 13018	83.83	-1.347	0.723	2.467	10
G12	Co 13020	92.38	-0.008	1.951	1.951	6
G13	Co 13021	78.21	-1.031	-2.038	2.722	15
G14	Co 14008	88.21	-1.990	-1.343	3.733	19
G15	Co 14016	97.51	-2.595	-0.159	4.545	22
G16	Co 14026	83.71	1.061	0.052	1.858	4
G17	Co 15005	61.26	0.324	-1.885	1.968	7
G18	Co 15007	69.70	1.651	-0.356	2.911	16
G19	Co 15021	96.64	0.069	-0.216	0.248	1
G20	Co 16001	96.78	1.259	0.126	2.207	9
G21	Co 16002	73.56	1.178	-0.029	2.062	8
G22	Co 86032	95.22	-0.789	1.296	1.894	5
G23	CoV 94101	101.77	1.532	1.457	3.052	17
G24	Co 88025	90.74	2.728	-0.411	4.793	23
	Grand Mean	87.86				
E1	I Plant crop	96.67	-6.073	0.870	0.870	1
E2	II Plant Crop	102.28	3.903	4.138	4.138	2
E3	Ratoon	65.26	2.170	-5.007	5.007	3

1.163 (Co 13001), 1.858 (Co 14026), and 1.894 (Co 86032) were considered as the stable genotypes across all environments, whereas the varieties with high ASV, Co 11015 (5.397), Co 88025 (4.793), Co 14016 (4.545) and Co 14008 (3.733) were considered to be suitable for the specific environment even though they recorded higher cane yield than the grand mean. The remaining varieties were considered unsuitable to any environment since they had a less average yield whatever may be the ASV rank. Since the most stable genotypes do not necessarily offer the best yield, both high cane yield and less ASV should be considered concurrently in sugarcane breeding programmes. (Rea *et al*., 2017 and Tena *et al*., 2019).

The most powerful interpretive tool for the AMMI model is Biplot Analysis. Biplots are graphs to identify the interrelationships between genotypes and environments which are plotted on the same axes (Vargas and Crossa 2000). There are two basic AMMI biplot, the AMMI 1 biplot, where the main effects of cane yield (genotype mean and environment mean) and IPCA1 scores for both genotypes and environments are plotted against each other. On the other hand, the second is AMMI 2 where scores for IPCA1 and IPCA2 are plotted. There was no consistent yield performance across three environments by many of the genotypes. The effect of each genotype and environment, IPCA1 vs. the means (**Fig. 1**) and IPCA2 vs. IPCA1 (**Fig. 2**) biplots are shown. In **Fig. 1**, the main effect (Mean cane yield) was indicated by x-coordinate, the effects of the interaction (IPCA1) were indicated by the y-coordinate. IPCA1 values positioned nearer to the center point of the axis indicated a lesser interaction than those found far from the axes.

The genotypes Co 13020 (G12), Co 15021 (G19), and Co 06031 (G4) had a low positive interaction with a

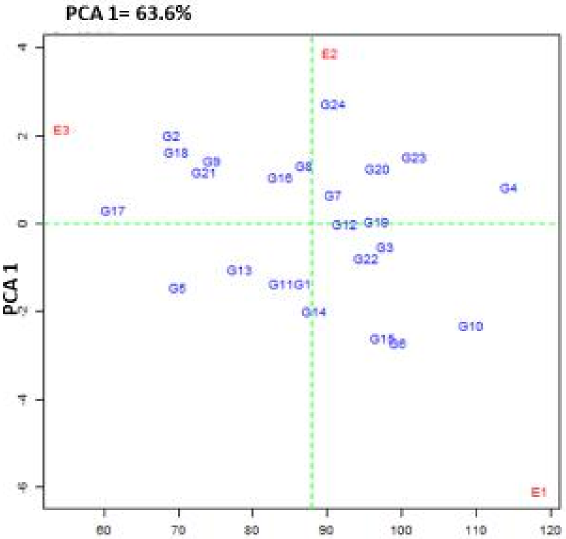

Fig 1. AMMI biplot showing the PCA1 Vs Mean cane yield (t/ha)

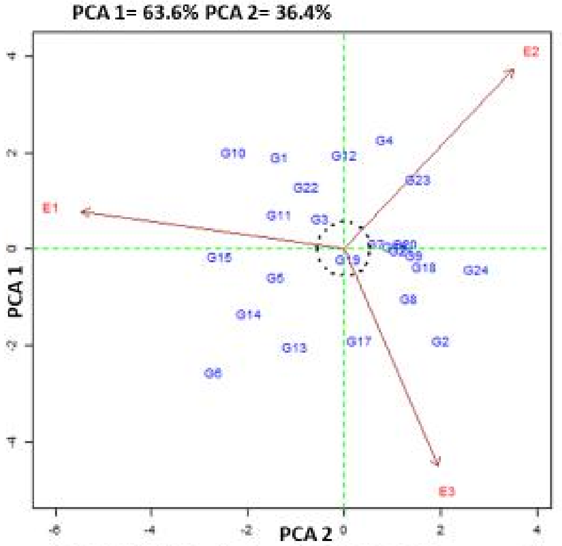

Fig 2. AMMI biplot showing the PCA1 Vs PCA 2 corresponding to cane yield (t/ha)

Table 6. Mean cane yield (t/ha) of 24 sugarcane genotypes across the environments

S.No.	Entry	I Plant crop	II Plant crop	Ratoon	Mean
1	Co 0212	123.45	92.01	40.75	85.41
2	Co 0238	62.27	71.64	49.50	61.14
3	Co 0240	122.69	101.03	60.04	94.59
4	Co 06031	90.07	129.76	71.40	97.08
5	Co 09004	99.98	64.60	36.23	66.93
6	Co 11015	114.31	80.94	72.95	89.40
7	Co 13001	99.61	96.49	58.22	84.77
8	Co 13003	92.28	90.57	61.46	81.44
9	Co 13006	106.00	82.33	44.89	77.74
10	Co 13014	146.62	111.29	60.72	106.21
11	Co 13018	113.47	84.15	43.83	80.48
12	Co 13020	119.25	103.01	49.14	90.47
13	Co 13021	95.41	68.35	52.72	72.16
14	Co 14008	120.52	77.48	57.16	85.05
15	Co 14016	141.14	89.31	59.22	96.56
16	Co 14026	91.65	90.66	52.30	78.20
17	Co 15005	80.26	57.32	37.95	58.51
18	Co 15007	66.31	77.26	41.61	61.72
19	Co 15021	123.58	98.61	64.42	95.53
20	Co 16001	108.71	104.81	65.43	92.98
21	Co 16002	77.22	80.63	42.81	66.88
22	Co 86032	117.59	100.09	53.56	90.41
23	Co 88025	114.91	116.37	64.34	98.54
24	CoV 94101	96.67	102.28	65.26	88.07
	Mean	**105.17**	**90.46**	**54.41**	**83.35**

higher main effect and made them the most preferable for selection. The genotype Co 15005 (G17) had a low negative interaction as evident from their low IPCA1 score. These clones may be treated as having high adaptability to different environments because these clones were less influenced by environments. Thus, it was clear from **Fig.1**, the genotypes plotted at the right-hand side of the grand mean level and near to PCA1 = 0 line were found as Co 13001 (G7) and Co 06031 (G4) and were adapted to all environments. Those genotypes G24 (Co 88025), G23 (CoV 94101), and G20 (Co 16001) with high mean yield and large PCA1 scores resulted in specific adaptation to the favorable environments. These were also detected by Meena *et al.* 2017 and Regis *et al.* 2018 in sugarcane. The genotypes stationed near the origin of the biplot showed greater stability over the environment while those clones were distant from the biplot origin indicates their instability and specific adaptability over the environments (Kumar *et al.,* 2018).

The stability of the genotypes as well as the extent of interaction effects of each genotype and environment, AMMI biplot were drawn using IPCA 1 and IPCA 2 scores (**Fig.2**). The large interaction effect was interpreted by those genotypes positioned far from the center point and was found to be sensitive while the genotypes positioned near the origin are not sensitive to environmental interaction. The clones Co 15021(G19), Co 0240 (G3), and Co 13001(G7) were found to be close to the origin, and therefore unaffected by environment. These clones were identified as stable clones with high cane yield and thus making them suitable for cultivation in a variety of environments.

Cane yield is a measurable trait that was greatly influenced by the environment. The role of the breeder and plant scientists is to evolve new varieties with maximum yield and performing consistently across the various environments. To reduce the effect of GE interaction, both yield and stability of variety should be considered simultaneously. Multi-location evaluation over the years and seasons will provide the information for the selection of cultivars in terms of productivity and fitness. Those genotypes which showed higher productivity and wider adaptation would be recommended for wider adaptation and commercial cultivation further could be utilized in the further breeding program.

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