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Assessment of Genotype x Environment Interactions of Chickpea Genotypes to High Temperature Tolerance under Different Environmental Conditions

Avinalappa Hotti[1*] and Raghunath Sadhukhan[2]

[1]Protection of Plant Varieties and Farmers' Rights Authority, Branch Office, UAHS, Shivamogga, Karnataka-577204, India.
[2]Department of Genetics and Plant Breeding, Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal -741252, India.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript, managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The present investigation was conducted using twenty two chickpea genotypes including check varieties under different sowing conditions in West Bengal to identify the genotypes that are tolerance to high temperature stress by assessing their genotype x environment (G x E) interactions. The experiment was organised in *Randomized Complete Block Design* with two replications over two consecutive years during 2014-15 and 2015-16. The data obtained from the yield component traits of these genotypes was undergone to two way analysis of variance to understand the existence of genotype by environment interaction. Significant differences in crop phenology were observed among the genotypes of chickpea from all tested environments while the interaction was significant for all the traits under study except number of seeds per pod. Thus, variation in response of the genotypes to different planting condition was observed. After

**Corresponding author: E-mail: avihotti@gmail.com;*

determining the significance of genotype by environment interaction, the data was further subjected to additive main effects and multiplicative interaction (AMMI) analysis in order to estimate the main effect of genotypes as well as genotypic and environmental components of interaction for seed yield of chickpea genotypes. According to the AMMI model, 79.49 and 79.92 per cent of the total sum of squares was attributed to the environmental effects, whereas 20.22 and 17.93 per cent had attributed to genotype, while 0.29 and 2.15 per cent to genotype by environment interaction across the respective years. Hence, the maximum proportion of the variation in seed yield was gained from normal sown condition. The genotypes ICCV 10 and RSG 963 produced equal yield under late sown condition, as demonstrated by the AMMI biplot. Therefore, the adaptability of these genotypes to different environments can be qualitatively assessed and recommended to use in breeding programs targeting of chickpea for growing in warmer areas.

Keywords: Chickpea; G x E interaction; seed yield; AMMI analysis.

1. INTRODUCTION

Among food legumes, chickpea (*Cicer arietinum* L.) is the most predominant crop than common beans (*Phaseolus vulgaris* L.) [1]. Globally, it is being cultivated in more than 50 countries especially in Asia, Africa, Europe, Australia, North America and South America [2]. In India, over 68 per cent of chickpea area has been accompanied by almost all parts of the country as a rainfed crop [3]. Dixit, et al. [4] reported that a major share towards chickpea area (70%) and production (68%) is contributed by India, making largest chickpea producing country in the world. However, India imports large amounts of chickpea in order to meet domestic requirement.

To get optimum growth, chickpea is grown under low temperature and prolonged winter season, as a reason its cultivation is more spread in northern India [5]. The late planting plus expansion of rice and wheat cultivation in this region, results a huge loss in chickpea area as well as pushing chickpeas to warmer and harsh growing environment. Therefore, the main reason for low productivity in chickpea is the adverse ecologies, in which it is grown and its susceptibility to biotic and abiotic stresses [6]. Among abiotic stress, high temperature is the major factor leading to yield reduction [7]. Moreover, the crop sown under residual soil moisture condition exposes to terminal drought and heat stress that limits the flowering period and hasten maturity, thereby causing poor yields [8]. Hence, there is a necessary to tackle abiotic stresses in order to advance the yield potential of this crop by varietal improvement. Besides, there is high demand for expansion in chickpea cultivation provided the genotypes are capable to adapt under late sown conditions are made available.

The genetic improvement of any character is a combination of the genotype of the variety (G), environment (E) and their interaction (G x E). Thus, the study on yield stability and G x E interaction necessitates the consistency of chickpea grain yield to develop a variety that respond optimally and reliably in different environmental conditions over the years [9]. Hence, the effects of G x E interaction to be considered for the development of variety [10]. In order to estimate G x E interaction, the stability analysis can be examined in replicated trails over various environments following environment wise analysis of variance. On the other hand, AMMI (Additive Main Effect and Multiplicative Interaction) and GGE (Genotype and Genotype x Environment Interaction) biplot are the unique tools for data analysis for different environments [11].

Keeping in view, the present investigation was undertaken to identify the chickpea genotypes that are tolerance to high temperature stress by assessing G x E interactions under different planting conditions.

2. MATERIALS AND METHODS

Twenty-two chickpea genotypes including two checks *viz.,* BG-256 and Anuradha were grown in *Randomized Complete Block Design* with two replications under different sowing dates *viz.,* normal sown (E1), late sown (E2) and very late sown (E3) over two consecutive years during 2014-15 and 2015-16 at District Seed Farm (AB Block), Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal. The farm is situated at tropical hot sub-humid climatic zone of eastern India approximately 22º56´ N latitude and 88º32´ E longitude with an average altitude of 9.75 m above mean sea level (MSL). The genotypes were selected based on superior seed yield

Table 1. Origin, pedigree and special features of the chickpea (*Cicer arietinum* L.) genotypes used in the study

Sl. No.	Genotypes[a]	Pedigree	Origin
1	Annigeri 1 (G1)	Selection from local germplasm	ARS, Gulbarga, Karnataka
2	JG 6 (G2)	(ICCV 10 X K 850)x (H208 X RS11)	JNKVV, Jabalpur, Madhya Pradesh
3	RSG 888 (G3)	RSG 44 x E 100 Y	RAU, Durgapura, Rajasthan
4	ICCV 10 (G4)	P 1231 x P 1265	ICRISAT, Hyderabad
5	Chaffa (G5)	Selection from Niphad (MS)	JAU, Junagarh, Gujarat
6	GCP 105 (G6)	ICCL 84224 x Annegeri 1	JAU, Junagarh, Gujarat
7	JAKI 9218 (G7)	(ICCC 37 x GW 5/7) x ICCV 107	PDKV, Akola, Maharashtra
8	JG 14 (G8)	(GW-5/7 x P-326) x ICCL 83149	JNKVV, Jabalpur, Madhya Pradesh
9	JG 16 (G9)	(ICCC 42 x ICCV 88506) x (KPG 59 x JG 74)	PDKV, Akola, Maharashtra and ICRISAT, Hyderabad
10	JG 315 (G10)	Selection from WR 315	JNKVV, Jabalpur, Madhya Pradesh
11	JGG 1 (G11)	Selection from germplasm	JNKVV, Jabalpur, Madhya Pradesh
12	Vikas (G12)	GW 5/7 x Ceylon 2	IIPR, Kanpur, Uttar Pradesh
13	Pusa 372 (G13)	P 1231 x P 1265	IARI, New Delhi
14	Pusa 547 (G14)	Mutant of BG 256	IARI, New Delhi
15	RSG 2 (G15)	Mutant of RS 10	RAU, Durgapura, Rajasthan
16	RSG 945 (G16)	RSG 668 x RSG 817	ARS, Durgapura, Rajasthan
17	RSG 963 (G17)	RSG 524 x PDG 84-10	RAU, Durgapura, Rajasthan
18	RSG 974 (G18)	K-850 x RSG-515	RAU, Durgapura, Rajasthan
19	Vaibhav (G19)	Selection from GP ICCV 91106	IGKV, Raipur, Chhattisgarh
20	Vijay (G20)	P 127 X Annegeri 1	MPKV, Rahuri, Maharashtra
21	Anuradha (G21)	Mahamaya 1 x Radhey	Research station, Berhampur, West Bengal
22	BG 256 G(22)	(JG 62 x 850-3/27) x (L 550 X H 208)	IARI, New Delhi

** Symbol of genotypes in parenthesis*

performance, early maturity and high biomass from previous study (Table 1). Each genotype was accommodated in a row length of two meter, keeping plant to plant distance of 10 cm and row to row distance of 30 cm. The observations on yield and yield attributing traits were collected from three different environments as per the distinctness, uniformity and stability (DUS) guidelines of chickpea.

2.1 Statistical Analysis

Two way analysis of variance was conducted for each trait in order to estimate the variation due to genotypes and environments under different environments using the method outlined by Sundarajan, et al. [12] and suggested by Devasirvatham, et al. [13]. After ascertaining that genotype by environment interaction was significant in the analysis of variance, the data was further subjected to stability analysis. The additive main effects and multiplicative interactions (AMMI) model was used to assess the adaptability and stability for genotypic yields across environment trails and over the years. The AMMI model was as follows [14]:

$$Y_{ge} = \mu + a_g + \beta e + \Sigma_{n=1} \lambda_n Y^2_{gn} \delta_{en} + \theta_{ge}$$

Where,

Y_{ge} is yield genotype by environment μ is grand mean, a_g is genotype mean deviation, μ e is environmental mean deviation, λ_n is Eigen value of PCA (principal component analysis) axes n, Y^2_{gn} and δ_{en} are genotype and environment PCA scores for PCA axes n, N is number of PCA axes retained in the model and θ_{ge} is residuals.

Further, the results of AMMI model were deduced using AMMI1 biplot plotted with the genotypes and environments main effect accordingly [11].

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

Significant differences for all the traits were observed among the genotypes of chickpea from all the tested environments. Similarly, the differences among environments across the years were also significant with respect to the characters under study. Instead, the interaction of environment and genotypes was significant for all the traits, except number of seeds per pod. The maximum variability was observed for number of effective pods per plant over environments and genotypes, while plant biomass across genotype and environment interaction (Table 2). It can therefore be concluded that genotypes responded differently to the different sowing conditions over the years. Krishnamurthy, et al. [15] also recorded highly significant G x E interactions for the studied traits except seeds per pod in a reference collection of 280 diverse chickpea germplasm. Whereas, Devasirvatham, et al. [13] revealed a large treatment difference between stressed and non-stressed conditions for days to first flower, days to 50 per cent flowering, days to first pod formation and days to physiological maturity in chickpea.

3.2 AMMI Analysis

The AMMI model for seed yield of 22 chickpea genotypes in three different environments and over the years is presented in the Table 3. According to the model, 79.49 and 79.92 per cent of the total sum of squares was attributed to the environmental effects, whereas 20.22 and 17.93 per cent had attributed to genotype and only 0.29 and 2.15 per cent to genotype by environment interaction across the respective years. It is therefore, high percentage of the variation in seed yield was explained by environment, this showed that the planting conditions were diverse and there was a large differences among the environmental means. Further, it was suggested that environmental influence is a major factor on seed yield performance of chickpea in the respective sowing conditions. Hence, the presence of G x E interaction was clearly demonstrated by the AMMI model (Fig. 1) in which only one of the principal component axis was significant ($p<0.01$), as a result, 66.25 and 93.70 per cent of the interaction sum of squares were cumulatively observed, of which 33.75 and 6.30 per cent were explained by PCA2, while zero per cent was by PCA3 in both year, respectively. This corroborated the findings of Kanouni, et al. [16] and Funga, et al. [17].

As per the (Fig. 2), the genotypes under late sown condition found on the same line (red lines), which depicts that genotypes produce equal yields in such environment. Therefore, the genotypes *viz.,* ICCV 10 and RSG 963 produced equal yield under late sown condition. On the other hand, if an environment point lies on one side of the red line, the closer genotype (ICCV 10) will produce a higher yield in that environment. Thus, genotypes such as ICCV 10

Table 2. Mean square values (two way ANOVA) and environment mean for ten characters of 22 chickpea genotypes under normal, late and very late sown condition

Characters	Environment		Genotypes		Environment x Genotypes		Environment mean of each character			First year (2014-15)			Second year (2015-16)		
	d.f.	Mean squares	d.f.	Mean squares	d.f.	Mean squares	NS	LS	VLS	NS	LS	VLS	NS	LS	VLS
Days to 50 per cent flowering	4	555.50***	21	681.51***	84	5.51***	56.50	53.20	49.50	56.92	53.70	49.00	56.20	52.70	50.11
Days to maturity	4	1395.80***	21	766.31***	84	10.11***	114.20	109.01	103.00	113.80	109.11	102.21	114.60	108.81	103.02
Plant height (cm)	4	1236.11***	21	246.10***	84	7.01***	51.80	47.10	41.31	51.21	47.40	41.50	52.51	46.90	41.12
Plant biomass (g)	4	2765.80***	21	5095.90***	84	25.61***	129.42	123.90	114.00	127.80	122.11	109.71	131.01	125.71	118.40
Number of pods per plant	4	1847.51***	21	1228.21***	84	9.31***	87.90	82.82	75.12	86.51	82.02	73.11	89.42	83.60	77.10
Number of effective pods per plant	4	2770.80***	21	1263.81***	84	8.11***	84.31	78.20	68.70	83.50	76.50	68.70	85.21	79.92	68.70
Number of seeds per pod	4	2.30***	21	5.11***	84	0.03^{NS}	2.01	1.81	1.61	1.91	1.81	1.61	2.12	1.70	1.60
100 seed weight (g)	4	314.82***	21	175.71***	84	1.12*	21.40	18.70	16.10	21.12	18.21	15.72	21.71	19.31	16.41
Harvest index (%)	4	402.00***	21	152.80***	84	4.90*	40.32	38.10	34.40	39.42	37.01	33.90	41.20	39.31	34.82
Seed yield per plant (g)	4	1856.21***	21	1473.31***	84	5.91*	52.40	48.02	39.61	50.61	46.31	37.81	54.31	49.62	41.50

*NS, normal sown; LS, late sown; VLS. Very late sown; * P<0.05; ** P<0.01; *** P<0.001; NS, Non-significant*

Table 3. AMMI analysis for seed yield of 22 chickpea genotypes at three different environments over two years (2014-16)

Source of variation	d.f.	Seed yield per plant (g)							
		First year (2014-15)				Second year (2015-16)			
		Mean squares	F Ratio	Probability	Explained percentage	Mean squares	F Ratio	Probability	Explained percentage
Environment (E)	2	1871.46	3321.67	0.00***	79.49	1845.30	538.89	0.00***	79.92
Genotype (G)	21	700.88	1244.00	0.00***	20.22	783.39	228.78	0.00***	17.93
G x E	42	1.28	2.27	0.00***	0.29	10.54	3.08	0.00***	2.15
PC1	22	1.61	2.86	0.00***	66.25	18.86	5.84	0.00***	93.70
PC2	20	0.90	1.60	0.08^{NS}	33.75	1.39	0.43	0.98^{NS}	6.30
PC3	18	0.00	0.00	1.00^{NS}	0.00	0.00	0.00	1.00^{NS}	0.00
Residual (G x E)	66	0.56			0.00	3.42			0.00
Total	**191**								

and RSG 963 in the current study were assigned to their adaptive environments. Funga, et al. [17] and Kanouni, et al. [16], Yan and Kang, [18] also reported similar results in their investigation.

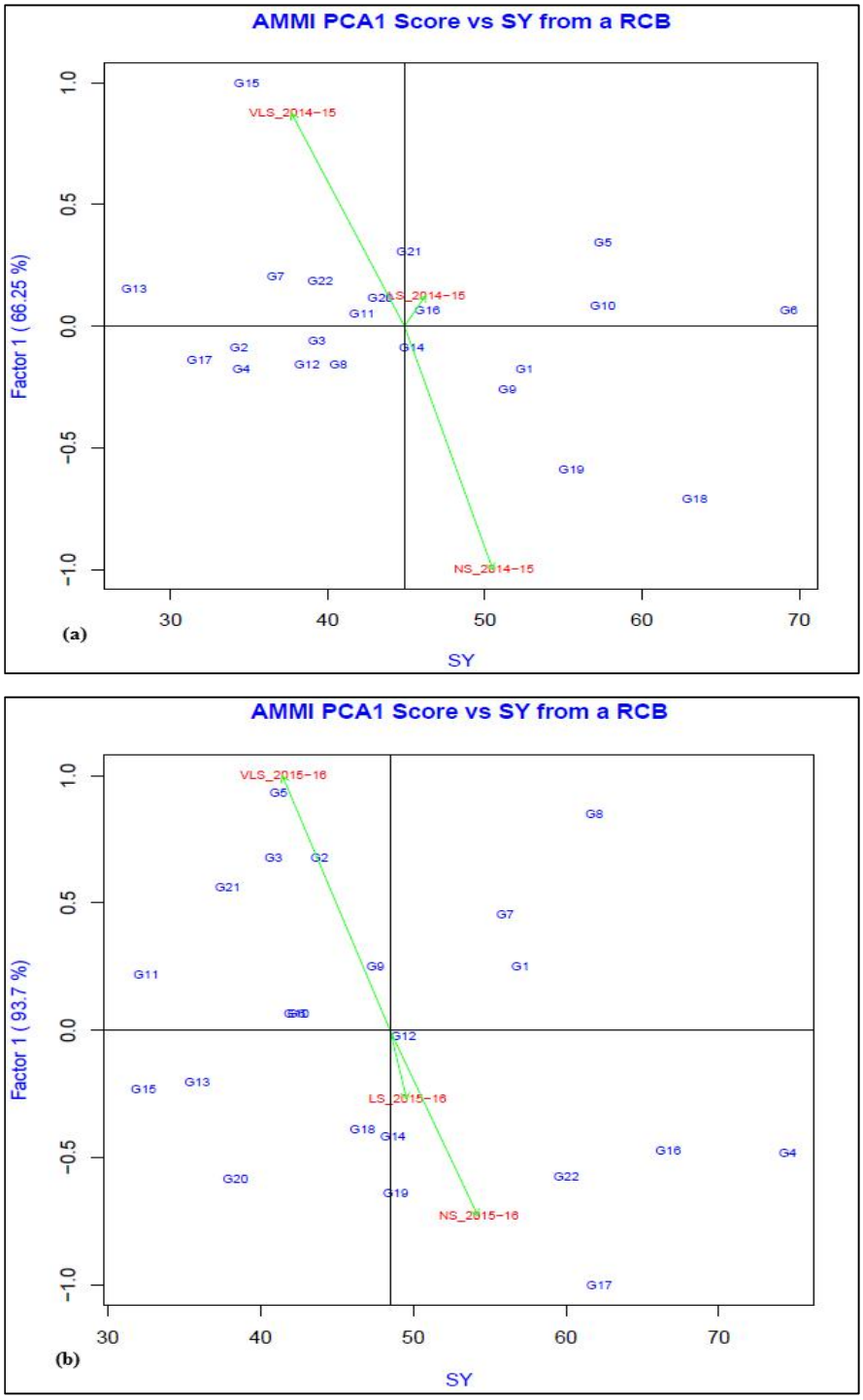

Fig. 1. Plot of Genotype and Environment PCA 1 scores versus seed yield (SY). G1 - G22 with blue color represent genotypes while environments are represented by letters and their respective years in red color (a, first year and b, second year) (NS: normal sown; LS: late sown; VLS: very late sown)

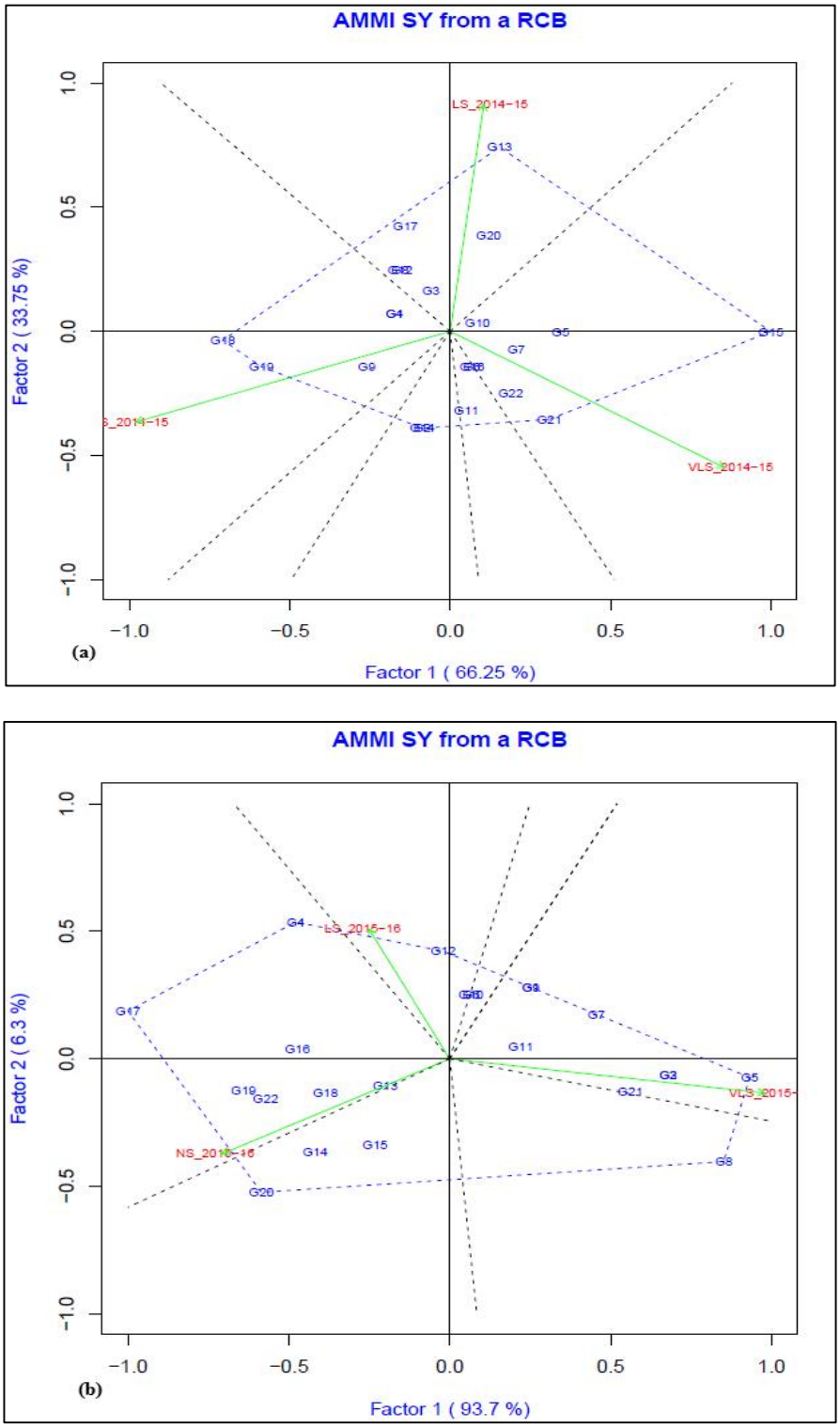

Fig. 2. Plot of PCA1 versus PCA2 scores of seed yield (SY). G1 - G22 with blue color represent genotypes while environments are represented by letters and their respective years in red color (a, first year and b, second year) (NS: normal sown; LS: late sown; VLS: very late sown)

4. CONCLUSION

As per the AMMI model, the maximum proportion of the variation in seed yield was gained from normal sown condition. Hence, most of the genotypes exhibited environment specificity. Alternatively, the AMMI biplot helps to predict comparative performance of a given genotype in a given environment by assessing the relationships among and between environments and genotypes on the graph, so current results has shown that the genotypes *viz.,* ICCV 10 and RSG 963 produced equal yield under late sown condition. Thus, these genotypes could be used to grow under such environmental conditions. Further, the adaptability of these genotypes to different environments can be qualitatively assessed and recommended to use in breeding programs targeting warmer areas.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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