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Yield stability of rapeseed genotypes under drought stress conditions

Mehdipour Sara[1], Rezaeizad Abbas*, Azizinezhad Reza[1] and Etminan Alireza[2]

Horticulture Crops Research Department, Kermanshah Agricultural and Natural Resources Research and Education center, AREEO, Kermanshah, Iran; [1]Department of Plant Breeding, Science and Research Branch, Islamic Azad University, Tehran, Iran; [2]Department of Biotechnology and Plant Breeding, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran

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Abstract

Genotype by Environment (GxE) interactions of 29 rapeseed genotypes in normal irrigation and irrigation cut off from flowering and silique formation stages have been worked out from the data recorded during three cropping seasons. Combined variance analysis showed a significant variation for year (cropping season), moisture regimes, genotype, genotype x moisture regimes and genotype x year interactions. Results of AMMI model analysis showed that three first genotype x environment principal components (PC) were significant at 1% level of probability and fourth PC at 5% level. These four components explained 35.6, 24.4, 18.4 and 14.8 per cent of the GxE sum of squares, respectively. According to AMMI2 biplot analysis, genotypes such as L155, Neptune, Elvise, Jerry, Gk-Gabriella, Sw102, GKH0224, Julius, GKH3705 and Sarigol were positioned in the center of the biplot so had the least GxE interaction and showed the most general compatibility. Based on simultaneous selection, winter type of genotypes namely, GKH2624, SW102, HW118, GKH3705, Wpn6 and L72 were identified as high yielding and stable whereas, spring genotypes namely, Zabol10, Dalgan, Jerome and Hyola4815 were identified as low yielding with poor stability.

Key words: AMMI analysis, simultaneous selection, parametric statistics, canola

Introduction

The genotype × environment (G×E) interaction reduces association between phenotypic and genotypic values and leads to bias in the estimates of gene effects and combining ability for various characters sensitive to environmental fluctuations (Farshadfar et al. 2011). Due to different response of cultivars to environmental changes, their yield varies from environment to environment. Genotype by Environment interaction (GEI) complicates the identification of superior genotypes for a range of environments and calls for the evaluation of genotypes in many environments to determine their true genetic potential (Yaghotipour and Farshadfar 2007). Numerous methods have been developed to reveal patterns of GE interaction, such as joint regression (Finlay and Wilkinson 1963; Eberhart and Russel 1966; Perkins and Jinks 1968), additive main effects and multiplicative interaction AMMI (Gauch 1992) and type B genetic correlation (Burdon 1977; Yamada 1962).

The additive main effects and multiplicative interaction (AMMI) model is a powerful multivariate method for multi-environmental trials (Romagosa and Fox 1994). The AMMI model combines the analysis of variance for the genotype and environment main effects with principal components analysis of the GEI interaction (Zobel et al. 1988; Gauch and Zobel 1997). Purchase et al. (2000) developed the AMMI stability value (ASV) based on the AMMI model's IPCA1 and IPCA2 (interaction principal components axes 1 and 2, respectively) scores for each genotype. The ASV is comparable with the methods of Eberhart and Russell (1966) and Shukla (1972) stability methods.

To be of practical utility in a breeding or cultivar testing programme, both stability and yield must be considered simultaneously so as to make selection of genotypes more precise and reliable. Several methods of simultaneous selection for yield and stability and relationships among them were discussed

*Corresponding author's e-mail: arezaizad@yahoo.com
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by Kang and Pham (1991). The development and use of Yield-Stability statistic (YSi) has enabled incorporation of stability in selection process (Kang 1993). Kangs yield-stability statistic has been evaluated and found to be useful for recommending varieties for cultivation (Pazdernik et al. 1997). In Kang's Yield-Stability method, genotypes are firstly ranked based on yield, and the genotypes with the highest yield have the highest rank. Then, genotypes rank based on their difference from the mean yield corrects and finally with the help of the Shukla stability index (Shukla 1972), yield and stability of genotypes are determined.

Drought stress is one of the most important limiting factors in crop production worldwide. Drought is brought about when there is insufficient moisture for maximum or potential growth of crops (Blum 2012). Currently, there are no economically viable technological means to facilitate crop production under drought. However, development of crop plants tolerant to drought stress might be a promising approach (Farroq et al. 2009). Due to genotype×environment interaction which is mainly due to the severe environmental conditions, the select drought tolerant varieties is difficult (Ehdaei 1993). Farmers in the cold temperate regions of Iran cultivate summer crops in April-May, thus eliminate rapeseed irrigation and irrigate the summer crops. The irrigation cut off at this time coincides with flowering and silique formation of rapeseed. Therefore, identification of rapeseed genotypes, which produce high yielding-stability under drought stress at flowering and silique formation stage is very important. For this purpose, it is tried to introduce rapeseed genotypes with high yield that having relative stability of grain yield under late season drought stress conditions using different stability statistics.

Materials and methods

Experimental design and plant materials

Yield stability of 29 rapeseed genotypes were evaluated under three irrigation regimes including normal irrigation, irrigation cut off from the flowering and silique formation stages. In each irrigation regime, rapeseed genotypes were planted in a randomized completely block design with three replications from October 2013 for three cropping seasons at Islamabad-Gharb agricultural research station, Kermanshah, Iran. Therefore, yield stability of rapeseed genotypes were evaluated in 9 environments (a combination of three cropping seasons and three moisture regimes). Meteorological information in the experiment site for the two growing seasons is presented in Table 2.

Statistical analysis

Combined analysis of variance using balanced ANOVA across three cropping seasons and three moisture regimes was computed using SAS 9.1 program. Homogeneity of residual variances was tested prior to a combined analysis over moisture regimes in each cropping season using Bartlet's test (Steel et al. 1996). Result are significant at p<0.01. Accordingly, the data collected were homogenous and all data showed normal distribution.

The AMMI model, which combines standard analysis of variance with PC analysis (Zobel et al. 1988), was used to investigate of G × E interaction. In AMMI model the contribution of each genotype and each environment to the GEI is assessed by use of the biplot graph display in which yield means are plotted against the scores of the IPCA1 (Zobel et al. 1988).

The AMMI model is:

$$Y_{ijk} = \mu + \alpha i + \beta j + \sum_{n}^{N} \lambda_n \gamma_{in} \delta_{jn} + p_{ij} + \varepsilon ijk$$

$$ASV = \sqrt{\frac{SSIPCA1}{SSIPCA2}(IPCA1)^2 + (IPCA1)^2}$$

(Relationship 1)

where Y_{ijk} is the observed mean yield of genotype *i* in environment *j*; μ is the grand mean; α_i is the genotype main effect; β_j is the environment main effect; λ_n is the eigenvalue of the interaction principal component analysis (IPCA); *n*, γ_{in}, δ_{jn} and are the genotype and environment scores for the IPCA axis *n*; p_{ij} is interaction residual; *N* is the number of IPCA retained in the model; and εijk is the random error term.

AMMI stability value (ASV) was calculated for each genotype according to the relative contributions of the principal component axis scores (IPCA1 and IPCA2) to the interaction sum of squares.

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

(Relationship 2)

Where $\frac{SSIPCA1}{SSIPCA2}$ is the weight given to the

Table 1. List of rapeseed genotypes studied

S.No.	Genotypes	S.No.	Genotypes
	Winter type		**Spring type**
1	Opera	1	1RGS 003
2	Ahmadi	2	Sarigol
3	L 72	3	Zafar
4	SW 102	4	Dalgan
5	Karaj 1	5	Julius
6	Okapi	6	Jacomo
7	GKH 3705	7	Jerry
8	GKH 2624	8	Jerome
9	GKH 0224	9	Zabol 10
10	Gabriella	10	HYOLA 401
11	Neptune	11	HYOLA 481
12	Elvise		
13	HW 118		
14	HL 2012		
15	WPN 6		
16	L 155		
17	HL 3721		
18	Karaj 2		

Table 2. Meteorological information of Islamabad-e-gharb Research Station during the 2014-15 and 2015-16 growing seasons

Month	2015-2016 Temperature (^{o}C)				2014-2015 Temperature (^{o}C)				2013-2014 Temperature (^{o}C)			
	Av.	Max.	Min.	Preci. (mm)	Av.	Max.	Min.	Preci. (mm)	Av.	Max.	Min.	Preci. (mm)
Sept.- Dec.	10.9	31.6	–7.2	201.4	10.6	30.4	–4.2	140.6	10.8	33.4	–11.4	330.0
Dec.-Mar.	3.7	21.2	–12.4	227.7	4.6	20.2	–8.8	98.4	5.1	19.0	–8.8	221.2
March-June	18.1	37.4	–4.6	70.9	17.4	37.4	–1.6	67.8	15.2	33.6	–2.8	177.4

Av = Average; Min. = Minimum; Max. = Maximum; Preci. = Precipitation

IPCA1 value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. The larger the IPCA score, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller ASV scores indicate a more stable genotype across environments. The simultaneous selection for yield and stability in crop performance also used based on Kang's rank-sum method (Kang 1993). This yield-stability statistic (YSi) component is basically based on Shukla's (1972) stability variance statistic.

Results and discussion

The results of combined analysis of variance for the grain yield of 29 rapeseed genotypes across 3 cropping seasons and 3 moisture regimes showed that environments including cropping seasons and moisture regimes had significant effect on grain yield at 1% level of probability. Genotypes were significantly different with respect to grain yield at 1% level of probability.

Genotype×year interaction for grain yield at 5% level of probability and genotype × moisture regimes at 1% level was significant (Table 3). This result showed varied response of rapeseed genotypes to different cropping seasons and moisture regimes. In other words, the yield stability of rapeseed genotypes in different environments was significantly different. Therefore, it is necessary to assess grain yield stability of these genotypes using stability statistics. The significance of genotype × environment interaction for rapeseed grain yield has also been reported in other studies (Marjanovic-Jeromela et al. 2008; Pourdad and Jamshid Mohgadam 2013; Miah et al. 2015; Nowosad et al. 2016, 2017).

AMMI model results based on the model presented by Clay and Dombek (1995) in 9 environments for grain yield showed that additive effects of environments and genotypes were significant at 1% probability level (Table 4). Main additive effect of environment and genotype for grain yield were 48.7% and 31% of a total sum squares, respectively. So the highest variation in grain yield was due to the effect of environments, while genotypes had a moderate effect on grain yield variation, so that the environment main effect represented had the highest effect on seed yield (Table 4).

Table 3. Mean of squares for grain yield during three cropping years and under normal irrigation, irrigation cut off from silique formation and flowering stage

Source of variation	d.f.	Mean squares
Year	2	206206846**
Moisture Regimes**	2	2710386**
Year x Moisture Regimes	4	5277132***
Replication (Year x Site)	18	1471065
Genotype	28	22123222**
Year x Genotype*	56	670565*
Moisture Regimes x Genotype**	56	966209**
Year x Moisture Regimes x Genotype	112	513188^{ns}
Error	504	457475
CV (%)		23.2

d.f. = Degrees of freedom; ns = non-significant; * and ** significant at 5% and 1% levels, respectively

The first three components of genotype x environment interaction were significant at 1% level of probability and the fourth component at the 5% level. These four components explained 35.6, 24.4, 18.4 and 14.8 per cent of the GxE sum of squares, respectively. Distribution of genotypes and environments based on the first component of GxE and the average grain yield is shown in Fig. 1. Genotypes and environments that have high values for the first component (positive or negative), have a great GxE interaction. On the contrary, genotypes and environments that have low values for first component have a low GxE interaction. Genotypes such as GKH3705, Elvise, GK-Gabriella, L155, Jerry, Ahmadi, and GKH2624 had the lowest values for the first component of GxE interaction, respectively (Table 5). Therefore, these genotypes are considered as stable genotypes with high general compatibility. The above mentioned genotypes, except Jerry, were of winter-type growth and their grain yield,

Table 4. AMMI analysis of 22 rapeseed genotypes in 9 environments for seed yield

Source of variation	D.F.	MS	%SS	SS
Environment	8	121949934**	48.7[a]	975599474
Genotype	28	22123223**	31.0[a]	619450242
Genotype x Environment	224	665788**	7.4[a]	149136561
IPCA1	35	1519857**	35.6[b]	53194991
IPCA2	33	1056460**	23.4[b]	34863191
IPCA3	31	884159**	18.4[b]	27408931
IPCA4	29	762247*	14.8[b]	22105166
Residue (noise)	96	120461	7.7[b]	11564283
Error	504	457475	11.5[a]	230567460
Total	782	6708409		2001232907

D.F. = Degree of freedom; HS = Mean Slim of Square; SS = Su; a = Per cent from total of sum of squares; b: Per cent from sum of squares for interaction effect

In accordance with this results reported by Nowosad et al. (2016), 69.82 % of the total yield variation was explained by environment, 13.67 % by differences between genotypes, and 8.15 % by genotype by environment interaction. Also, in the study of Bibi et al. (2018), the environments had more influence (86.65%) on treatment sum of squares as compared to the interaction of genotype x environment (9.4%) and genotypes (2.65%), respectively. Multi environment evaluation of wheat genotypes under drought stress indicated the reduction varying from 9 to 19% in respect of no. of tillers, 1000 grain weight and grain yield obviously due to environmented factors affecting stability (Kumar et al. 2018).

except for Jerry, was more than the average yield of other rapeseed genotypes. The results showed that the highest positive coefficients for the first component of GxE belonged to normal irrigation regime (E1, E4 and E7) and these environments had the highest contribution to first component of GxE interaction.

The first component of GxE explained only 36.6% of the sum of squares, and thus in order to use the contribution of the second component, the AMMI2 model was used (Fig. 2). This biplot explained 59% of GxE interaction. The genotypes that were close to the center of the AMMI2 biplot had less GxE interaction and have higher general compatibility that could be

Table 5. Values of IPCA1 to IPCA4 for interaction effect components of seed yield of rapeseed genotypes

No.	Genotype	Grain yield ($kg.ha^{-1}$)	IPCA1	IPCA2	IPCA3	IPCA4	AMMI stability value (ASV)
1	OPERA	3497	13.0	-5.2	–18.7	–9.2	20.5
2	Ahmadi	2935	–2.3	22.8	3.5	–25.0	23.0
3	L72	3816	–8.1	10.1	–2.9	–4.9	16.0
4	SW102	3941	9.4	0.4	–4.6	–1.6	14.4
5	KARAJ1	3188	4.6	22.3	–7.0	7.1	23.3
6	OKAPI	3314	–8.4	20.6	–11.3	13.9	24.3
7	GKH3705	3869	0.2	-11.2	–10.1	–14.7	11.2
8	GKH2624	3994	–2.4	8.5	–5.4	0.5	9.3
9	GKH0224	3782	12.7	4.8	0.7	–7.5	20.0
10	GK-GABRI	3157	1.3	9.8	4.1	2.6	10.0
11	NEPTUNE	3593	4.5	-1.2	4.3	0.2	6.9
12	ELVISE	3481	0.8	-7.3	–19.0	15.1	7.4
13	HW118	3919	19.0	6.8	4.5	13.1	29.8
14	HL2012	3564	12.8	-1.5	9.5	15.4	19.5
15	WPN6	3843	12.3	-5.7	16.4	12.0	19.6
16	L155	3653	2.7	4.3	4.1	9.4	6.0
17	HL3721	3086	17.7	-6.2	–6.8	–17.3	27.7
18	KARAJ2	3519	14.0	-20.9	–4.1	–1.5	29.9
19	RGS003	1953	–12.3	-18.2	–0.2	1.3	26.1
20	SARIGOL	1871	–5.1	-10.6	4.6	–2.5	13.2
21	ZAFAR	2395	–18.9	-5.2	14.5	6.5	29.2
22	DALGAN	1457	–17.8	-1.5	–6.8	–3.5	27.2
23	JULIUS	2101	5.3	-9.1	11.6	–1.3	12.2
24	JACOMO	1897	13.6	4.1	1.8	1.6	21.1
25	JERRY	2247	–2.1	8.1	21.7	–13.3	8.8
26	JEROME	1628	–6.3	-13.9	–8.4	1.4	16.9
27	ZABOL10	1138	–26.8	1.5	–14.3	3.9	40.9
28	HYOLA401	2275	–20.2	-7.6	17.4	–3.9	31.8
29	HYOLA481	1560	–13.3	1.2	0.9	2.4	20.3

introduced for most environments. In contrast, genotypes away from the center of the biplot had a special compatibility as also indicated by Gauch and Zoble (1997). According to AMMI2 biplot, genotypes such as L155, Neptune, Elvise, Jerry, Gk-Gabriella, SW102, GKH0224, Julius, GKH3705 and Sarigol were positioned in the center of the biplot and therefore, had the least GxE interaction displaying the most general compatibility. Most winter-type genotypes interacted positively with normal irrigation conditions (E1, E4 and E7), on the other hand most spring-type genotypes interacted positively with drought stress conditions but negatively with normal condition irrigation (E2, E8, E9, E2 and E5) (Fig. 2). In a study by Nowosad et al. (2016), results of AMMI2 showed that some genotypes had high adaptation, however, most of them had specific adaptability.

The AMMI model does not make provision for a quantitative stability measure, such a measure is essential in order to quantify and rank the genotypes according to their yielding stability, the ASV measure

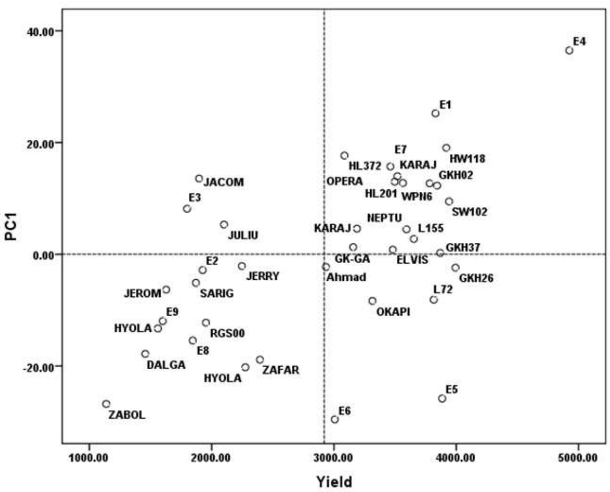

Fig. 1. Distribution of rapeseed genotypes based on the first component of GxE interaction and mean grain yield

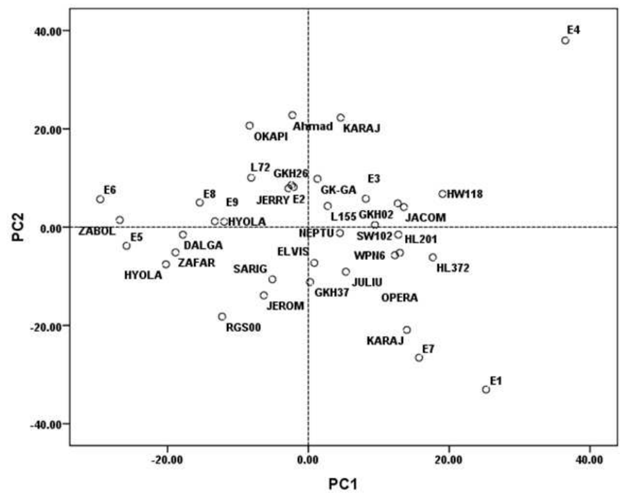

Fig. 2. Distribution of rapeseed genotypes based on the first and second components of GxE interaction

was proposed by Purchase et al. (2000) to cope up with this problem. In fact, ASV is the distance from zero in a two dimensional scattergram of IPCA1 (interaction principal component analysis axis 1) scores against IPCA2 scores. Since the IPCA1 score contributes more to GE sum of square (Table 4), it has to be weighted by the proportional difference between IPCA1 and IPCA2 scores to compensate for the relative contribution of IPCA1 and IPCA2 total GE sum of squares. In ASV method, a genotype with least ASV score is the most stable, accordingly genotypes such as L155, Neptune, Elvise, Jerry, Gk-Gabriella, SW102, GKH0224, Julius, GKH3705 and Sarigol had the lowest values for the ASV statistic and hence were considered as stable genotypes (Table 5). Among above mentioned genotypes, some genotypes such as Neptune, Elvise, Gk-Gabriella, SW102, GKH0224, GKH3705 had high mean grain yield.

In accordance to the ASV statistic, Karaj2, HW118, HL3721 and Dalgan had the highest values of ASV and hence, were considered unstable genotypes (Table 5). According to the present results, it could be concluded that the ASV resulted in selection of genotypes such as Sarigol and Jerry as stable genotypes but does not have high average grain yield. Generally ASV was significantly correlated with mean yield. Therefore, this parameter allow the identification of genotypes adapted to environments with unfavorable growing conditions like drought stress condition (Mohammadi and Amri 2008).

Based on the simultaneous selection of yield and stability, genotypes such as L72, Wpn6, GKH3705, HW118, SW102 and GKH2624 were identified as high yielding and stable whereas, the genotypes such as Zabol10, Dalgan, Jerome and Hyola4815 were identified as low yielding and less stable cultivars (Table 6).

Among the high yielding-stable genotypes mentioned above, the SW102 was introduced in Iran as Nima in 2017 and L72 as Nafis in 2018 both being open pollinated cultivars. All selected genotypes based on simultaneous selection for yield and stability were winter-type and had the highest grain yield. It seems that when the grain yield of genotypes is close to each other, this method is considered more efficient to select high-yielding and stable genotypes, while based on AMMI method it maybe led to select genotypes with low stability due to small contribution to the first and second components of GxE interaction, but low grain yield. In some studies such as of Dashtaki et al. (2004), effectiveness of the simultaneous selection for yield and stability method to select high yielding and stable genotypes has been emphasized. Moghadam (2005) compared the simultaneous selection for yield and stability with other stability statistics and concluded that this measure due to the emphasis given on stability component could be more reliable.

In general, the results showed that winter-type rapeseed genotypes grown in cold and temperate climatic conditions of Iran have higher yield and yield

Table 6. Stability analysis of rapeseed genotypes using simultaneous selection for yield and stability

No.	Rapeseed genotypes	Seed yield (kg.ha^{-1})	Rank of grain yield	Adjusting rank	Adjustment to rank	Shukla ($\acute{o}^2i$)	Stability rating	YS
1	OPERA	3497	18	1	19	17764029	–8	11
2	Ahmadi	2935	12	0	12	21177571	–8	4
3	L72	3816	24	2	26	7486513	–8	18
4	SW102	3941	28	2	30	3993220	–8	22
5	KARAJ1	3188	15	0	15	18650269	–8	7
6	OKAPI	3314	16	0	16	19404757	–8	8
7	GKH3705	3869	26	2	28	6089686	–8	20
8	GKH2624	3994	29	2	31	17576831	–8	23
9	GKH0224	3782	23	2	25	8595767	–8	17
10	GK-GABRI	3157	14	0	14	4509718	–8	6
11	NEPTUNE	3593	21	1	22	1798484	–8	14
12	ELVISE	3481	17	1	18	15552883	–8	10
13	HW118	3919	27	2	29	12275429	–8	21
14	HL2012	3564	20	1	21	9573085	–8	13
15	WPN6	3843	25	2	27	9755923	–8	19
16	L155	3653	22	1	24	2564831	–8	15
17	HL3721	3086	13	0	13	20082660	–8	5
18	KARAJ2	3519	19	1	20	16752963	–8	12
19	RGS003	1953	7	–2	5	25857391	–8	–3
20	SARIGOL	1871	5	–2	3	18791402	–8	–5
21	ZAFAR	2395	11	–1	10	18266477	–8	2
22	DALGAN	1457	2	–3	-1	30781190	–8	–9
23	JULIUS	2101	8	–2	6	21996752	–8	–2
24	JACOMO	1897	6	–2	4	47725780	–8	–4
25	JERRY	2247	9	–1	8	11354064	–8	0
26	JEROME	1628	4	–3	1	40537062	–8	–7
27	ZABOL10	1138	1	–4	-3	61729498	–8	–11
28	HYOLA401	2275	10	–1	9	14485308	–8	1
29	HYOLA481	1560	3	–2	1	32722551	–8	–7

Total Mean=4066 kg.ha^{-1}
Least significant difference ($LSD_{0.05}$) =307; YS = Yield satbility

stability. However, there is large variation among winter-type genotypes for grain yield and grain yield stability.

Authors' contribution

Conceptualization of research (SM, AR, RA, AE); Designing of the experiments (SM, AR); Contribution of experimental materials (SM, AR); Execution of field/ lab experiments and data collection (SM, AR, RA, AE); Analysis of data and interpretation (SM, AR, RA, AE); Preparation of manuscript (SM, AR, RA, AE).

Declaration

The authors declare no conflict of interest.

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