Study of genotype x environment interaction in rice (*Oryza sativa* L.) by stability estimates

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ABSTRACT

Twenty genotypes of late maturing group of rice were tested at four different locations in randomized complete block design (RCBD) with two replications to compare the stability estimates methods of Wrick's ecovalence , Shukla stability variance, Tai   α and λ of stability analysis along with Eberhart and Russel model using Spearman's rank correlation coefficients. The results indicated that the sum of squares for genotype x environment interaction (GEI) was found significant. All the three components i.e. environment (Lin.), G x E (Lin.) and pooled deviations were found highly significant and accounted for 86.8, 7.9 and 5.2 per cent of sum of squares, respectively. Genotypes NWGR-3006, IET19140, IET19123, IET19147 and IET19160 were found stable, high yielding genotypes adaptable to all the environments. Genotype IET19146 was stable and well adaptable to favorable environment. According to Wricke's ecovelence and shukla's stability variance, genotypes IET19147, NWGR-3006, IET19114, NWGR-3113 and NWGR-3213 were considered to be the most stable. Genotype IET19143 due to its higher ecovalence and shukla's stability variance was considered as most unstable genotype. The genotypes namely NWGR-3113, NWGR-3006, IET19147 and IET19114 were located in the average stability region and NWGR-3213 into the above average stability region. IET19132 and IET19143 were highly unstable in performance as it had highest λ value. The rank correlation coefficient between bi-Eber and Tai's α were perfect positive and also positive perfect correlation was observed between Wi^2 and Sh-$σ^2$. S^2_{di} had positive and high rank correlation with Wi^2, Sh-$σ^2$ and Tai λ. The stability estimates Wi^2, Sh-$σ^2$, Tai's α and Tai's λ would be used in place of Eberhart and Russel model. According to all methods, genotypes IET19147 and NWGR-3006 were identified as high yielding and stable genotypes.

Key words: Genotype x environment interaction, rice, stability models comparison

Knowledge of genotype x environment interaction (GEI) can help plant breeders to reduce the cost of extensive genotype evaluation by eliminating unnecessary testing sites (Kang and Magari 1996). Conversely, the presence of a large GEI may necessitate the establishment of additional testing sites. Hence, if cultivars are being selected for a large group of environments, stability and mean yield across all environments are more important than yield for specific environments (Piepho 1996).

Different stability estimates are proposed to measure the stability of genotypes tested under wide range of environments (Fernandez *et al.* 1989). Among them, Eberhart and Russell model, 1966 is widely used

to determine GEI. Regression analysis is extensively used to study stability, in which genotype means are not statistically independent of the environmental Index (EI) on which they are regressed (Shukla 1972; Fernandez 1989). Wrick's ecovalence (1962) and Shukla stability variance (1972) measure stability on the basis of the contribution of a genotype to the GEI sum of squares while Tai (1971) proposed partitioning the GEI effect of the ith genotype into stability statistics α and λ based on the principles of structural relationship analysis. The α measures the linear response of the environmental effect and λ measures the deviation from the linear response in terms of the magnitude of the error variance. A genotype having α = 0 and λ= 1 was

considered of average stability. Therefore, in the present study the different methods *i.e.* Wrick's ecovalence (1962) and Shukla stability variance (1972), Tai (1971) parameters of stability were estimated and compared with the common method Eberhart & Russel Model (1966) used presently by using same data set of multi-location trials on rice and to find the stable genotype/(s) for further breeding programme.

MATERIALS AND METHODS

Multi-location trial on rice was conducted in Gujarat state for the present study. Twenty genotypes of late maturing group were tested at four different locations (Nawagam, Vyara, Dabhoi and Thasra) along with one check GR-103 during wet season 2006. The experiments were laid out in randomized complete block design (RCBD) with two replications. Recommended package of practices were followed under different locations. The net Plot size was 4.2m x 2.2m with inter and intra raw spacing of 20cm and 15cm, respectively at each location. The data of these trials were subject to ANOVA and different stability estimates were estimated.

Analysis of variance (ANOVA)

The data on MLT were analysed on pooled basis using the following model of RBD.

The statistical model for pooled analysis

$$Y_{ij} = \mu + G_i + E_j + (GE)_{ij} + \varepsilon_{ij} \text{ (Pooled)}$$

Eberhart and Russell model

Eberhart and Russell (1966) suggested the following model

$$Y_{ij} = \mu_i + b_i I_j + \delta_{ij}$$

Where b_i = regression coefficient
I_j = Environmental Index
δ_{ij} = deviation due to regression

Ecovalence (W_i^2)

Wricke (1962) defined the concept of ecovalence as the measure of stability. It is the contribution of each genotype to the GEI sum of square across environment and expressed as under.

$$W_i^2 = \sum_{j=1}^{q} \left[\overline{Y}_{ij} - \overline{Y}_{i.} - \overline{Y}_{.j} + \overline{Y}_{..} \right]^2$$

W_i^2 = ecovalence of ith genotype
$\overline{Y}_{ij}$ = mean performance of ith genotype in the jth envirnoment
$\overline{Y}_{i.}$ = mean performance of ith genotype
$\overline{Y}_{.j}$ = mean performance of jth envirnoment
$\overline{Y}_{-}$ = overall mean
i = 1,2,..., p (number of genotype)
j = 1,2,..., q (number of environments)

Shukla's Stability variance (Sh-σ_i^2)

Shukla's stability variance (1972) is based on the residual $(GE_{ij} + e_{ij})$ matrix in a two-way classification. The variance of a genotype across environments is the stability measure calculated as under

$$Sh\text{-}\sigma_i^2 = \frac{p}{(p-2)(q-1)} \sum_{j=1}^{q} (\overline{Y}_{ij} - \overline{Y}_{i.} - \overline{Y}_{.j} + \overline{Y}_{..})^2 - \frac{SS_{GxE}}{(p-1)(p-2)(q-1)}$$

Where Sh-σ^2 = Shukla's stability variance
SS_{GxE} = sum of squares due to GxE interaction

Tai's α and λ

Tai (1971) gave two stability parameters α and λ very similar to the regression coefficient and the deviation from regression, respectively. They were estimated as under

$$\alpha_i = \frac{\left(\sum_j \varepsilon_j (ge)_{ij} / (q-1) \right)}{msl - msb/(pr)}$$

$$\lambda_i = \frac{\left(\sum_j ge_{ij}^2 / (q-1) \right) - \alpha_i \left(\sum \varepsilon_j (ge)_{ij} \right) / (q-1)}{(p-1)mse/(pr)}$$

Where ε_j = Environmental effect

$(ge)_{ij}$ = G x E interaction effect

msl = Mean square of location

msb = Mean square of block

mse = Mean square of error

q = number of environments

p = number of genotypes

r = number of replications

A method of setting up prediction intervals for $\alpha_i = 0$ (corresponding to $b_i = 1$) and confidence intervals for $\lambda_i e"1$ ($\lambda_i = 1$ corresponds to $\delta_{ij} = 0$) so that varieties can be distributed into different stability regions has been suggested by Tai (1971). The region which includes varieties with the expectation of $\alpha = 0$, $\lambda = 1.0$ for example, is the one enclosed by the prediction intervals of $\alpha = 0$ and the confidence intervals of $\lambda = 1$ at a certain probability level. A perfectly stable variety has $(\alpha_i, \lambda_i) = (-1, 1)$.

Tai gave the following prediction intervals for these two stability statistics. The following prediction limits corresponding to $\alpha_i = 0$ was computed as below

$$\pm t_a = \sqrt{\frac{\lambda(p-1)mse \times msl}{(msl-msb)[(q-2)msl-(t_a^2+q-2)msb]}}$$

A theoretical confidence interval for the hypothesis that $\lambda_i = 1$, i.e. $\delta_{ij} = 0$ at the probability of p is for $\lambda_0 > 1$ is

$$F_{(n_1,n_2)} = \lambda_0 F_a \left[\frac{m\lambda_0}{2\lambda_0 - 1}, n_2 \right]$$

Using the prediction limit of $\alpha i = 0$ the results were presented through graph to identify genotypes with average, above average and below average stability.

In Figure, areas I, II and III indicate regions of average, above average and below average stability, respectively. A variety located toward the right hand side of the figure indicates a behavior of unpredictable performance. It should be noted that larger the λ value the more difficult it is to show a significant difference between the α estimate and $\alpha = 0$ and hence the α statistic becomes less meaningful in interpreting the linear response of a variety over varying environments.

RESULTS AND DISCUSSION

Eberhart and Russell model

Analysis of variance was carried out over locations as per Eberhart and Russell (1966) and the results are presented in Table 1. The results indicated that the sum of squares for genotype x environment interaction was found significant which accounted for 12.1% variance. In stability analysis, environment and GEI component were further partitioned into environment (linear), G x E (linear) and pooled deviations from regression.

ANOVA (Table 1) indicated that the sources of variation for Environment + (G x E) was found highly significant. All the three components *i.e.,* environment (Lin.), G x E (Lin.) and pooled deviations were found highly significant and accounted for 86.8, 7.9 and 5.2 per cent of sum of environment and GEI (Shinde *et al*. 2004; Laghari *et al*. 2003 and Hugo-Ferney *et al*. 2006).

The stability parameters for all the genotypes are given in Table 2. Eberhart and Russell emphasized the need of considering both linear (b_i) and non-linear (S^2_{di}) components of genotype-environment interaction in judging the stability of genotypes. Rank of b_i value was given on the basis of $b_i - 1$. All the values of bi were found significant when tested for $\beta_i = 0$ except for IET19132 and found non-significant for $\beta i = 1$ except for genotypes NWGR-3213, IET19132, IET19143, IET19146 and GR 103. Out of twenty one genotypes, thirteen had non-significant S^2_{di} which indicated their stability over environments.

Genotypes NWGR-3006, IET19140, IET19123, IET19147 and IET19160 had higher mean yield, unity regression coefficient ($b_i = 1$) and non-significant S^2_{di}. Thus they were stable, high yielding genotypes which can be adapted to all the environments. Genotype IET19146 had higher mean than overall mean, b_i significantly greater than 1 and non-significant S^2_{di},

Table 1 . Analysis of variance for Stability model (Eberhart and Russell model, 1966).

Sources of Variation	df	SS	MS	%
Genotypes	20	18.4843	0.9242*	-
Env.+ (G x E)	63	219.7287	3.4878**	100.0
Environment(Lin.)	1	190.8186	190.8186**	86.8
G x E (Lin.)	20	17.4015	0.8701**	7.9(60.2)
Pooled Deviation	42	11.5086	0.2740**	5.2(6.0)
Pooled Error	80	7.6496	0.0956	-
Total	167	-	-	-

* and ** significant at 5 and 1 per cent level of probability, respectively

Table 2. Stability parameters of different rice genotypes (Eberhart and Russell model, 1966).

Sr. No.	Genotype	Mean Yield (kg plot^{-1})	Rank	bi-Eber	Rank	S^2_{di}	Rank
G1	NWGR-3026	4.165	17	1.085*	5	0.210+	14
G2	NWGR-3113	4.017	18	0.906*	8	0.067	7
G3	NWGR-3215	3.288	21	0.754*	16	0.170	12
G4	NWGR-3132	4.534	7	1.182*	11	0.249+	15
G5	NWGR-3199	4.265	16	0.912*	6	0.386+	17
G6	NWGR-3213	4.334	11	0.809*@	12	-0.059	4
G7	NWGR-3006	4.470	8	1.083*	4	-0.046	3
G8	NWGR-2018	4.410	10	0.732*	17	0.480+	20
G9	NWGR-2032	3.910	19	0.976*	1	0.427+	19
G10	IET19140	5.426	1	1.231*	15	0.039	2
G11	IET19148	4.278	15	1.216*	14	0.137	10
G12	IET19123	5.351	2	1.131*	9	0.109	9
G13	IET19147	4.634	3	0.909*	7	-0.060	5
G14	IET19160	4.579	4	1.081*	3	0.164	11
G15	IET19132	4.327	12	0.071@	21	0.191	13
G16	IET19114	4.322	13	1.028*	2	-0.003	1
G17	IET19143	4.574	5	1.636*@	20	0.638+	21
G18	IET19189	4.565	6	1.197*	13	0.376+	16
G19	IET19117	4.292	14	1.136*	10	0.421+	18
G20	IET19146	4.424	9	1.297*@	18	-0.064	6
G21	GR-103	3.515	20	0.631*@	19	-0.093	8
	Overall mean	4.366					

*significant for β = 0 and @ significant for β = 1 at (P=0.05)

+ Significant at (P=0.05), bi-Eber = Eberhart and Russell Regression coefficient

therefore, it is well adaptable to favorable environment. NWGR 3213, IET 19132 and GR 103 were found suitable for poor environment with lower yield. Genotypes NWGR-3132, NWGR-3199, NWGR-2018, NWGR-2032, IET19189 and IET1917 were found unstable due to their significant S^2_{di} values (Akcura *et al*. 2005 and Laghari *et al*. 2003).

Wricke's ecovalence (W_i^2)

The ecovalence values (W_i^2) were worked out for rice genotypes over four locations and are presented in Table 3 and Fig. 1. The results indicated that the genotypes IET19147, NWGR-3006, IET19114, NWGR-3113 and NWGR-3213 had the lowest ecovalence values and therefore, would be considered to be the most stable. The ranks of these genotypes for yield were 3, 8, 13, 18 and 11, respectively. Genotype IET19132 had higher ecovalence values and lower mean yield, whereas IET19143 had higher ecovalence and higher mean yield and considered as most unstable genotypes (Fig. 1). These results are in partial agreement with those obtained by Eberhart and Russell (1966) (Chandrasiri *et al*. 2002; Mekbib 2003;

Bhargava *et al*. 2005).

Shukla's stability variance (Sh-σ_i^2)

This approach is considered of practical importance because it identifies environmental factors that contribute to the heterogeneity in the GEI. According to Shukla's stability variance (1972), stable genotypes are those having minimum stability variance (Sh-σ_i^2). Results for stability variance and overall means are summarized in Table 3 for grain yield of rice with their ranking order. Results obtained for W_i^2 and Sh-σ_i^2 stability methods were at par for measuring stability and their ranks were similar.

Tai's α and λ

In Tai's (1971) stability analysis, the interaction term is partitioned into two components: the linear response to environmental effects, which is measured by statistics α and the deviation from the linear response, which is measured by another statistics λ. A variety with α = 0, λ = 1 and α < 0, λ = 1 or α > 0, λ = 1 have been defined as having average, above average or below average stability, respectively (Tai 1971). The latter two types

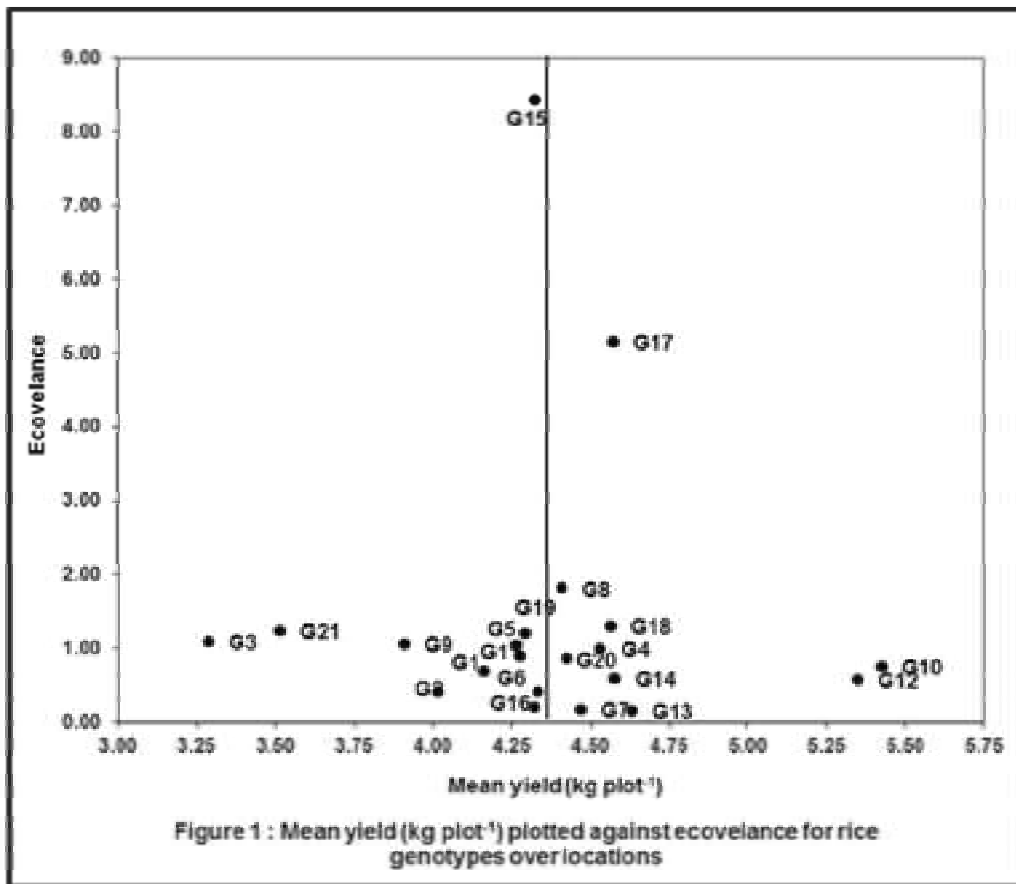Figure 1 : Mean yield (kg plot^{-1}) plotted against ecovelance for rice genotypes over locations

Table 3. Mean yield, Wricke's ecovalence, Shukla's stability variance (Sh- σ^2), Tai á and ë with their ranks for different rice genotypes

Sr. No.	Mean Yield (kg plot^{-1})	Rank	W^2_i	Rank	Sh-σ^2_i	Rank	(α_i)	Rank	(λ_i)	Rank
G1	4.165	17	0.676	8	0.224	8	0.085	5	2.386	10
G2	4.017	18	0.406	4	0.124	4	-0.094	8	1.381	5
G3	3.288	21	1.081	15	0.373	15	-0.246	16	3.272	14
G4	4.534	7	0.990	12	0.340	12	0.182	11	3.246	13
G5	4.265	16	1.033	13	0.355	13	-0.088	6	3.683	15
G6	4.334	11	0.406	5	0.124	5	-0.191	12	1.076	4
G7	4.470	8	0.163	2	0.035	2	0.083	4	0.517	2
G8	4.410	10	1.806	19	0.640	19	-0.269	17	5.788	19
G9	3.910	19	1.052	14	0.362	14	-0.024	1	3.827	16
G10	5.426	1	0.754	9	0.253	9	0.231	15	2.162	8
G11	4.278	15	0.889	11	0.302	11	0.216	14	2.728	11
G12	5.351	2	0.566	6	0.183	6	0.131	9	1.873	6
G13	4.634	3	0.148	1	0.029	1	-0.092	7	0.447	1
G14	4.579	4	0.579	7	0.188	7	0.081	3	2.039	7
G15	4.327	12	8.424	21	3.078	21	-0.930	21	21.164	21
G16	4.322	13	0.192	3	0.046	3	0.028	2	0.693	3
G17	4.574	5	5.142	20	1.869	20	0.636	20	14.277	20
G18	4.565	6	1.295	18	0.452	18	0.197	13	4.293	18
G19	4.292	14	1.202	16	0.418	16	0.136	10	4.179	17
G20	4.424	9	0.866	10	0.294	10	0.297	18	2.183	9
G21	3.515	20	1.239	17	0.431	17	-0.369	19	3.017	12

show a predictable favoring of 'poor' or 'good' environment, respectively. Tai's analysis also provides prediction interval for α = 0 and a confidence interval for λ values, so that the results can be depicted graphically called Tai's plot. The results are given in Table 3 and depicted in Fig. 2. The genotypes NWGR-3113, NWGR-3006, IET19147 and IET19114 were located in the average stability region and NWGR-3213 into the above average stability region. IET19132 and IET19143 were highly unstable. IET19140, IET19148 and IET19146 gave positive á values significantly different from á=0 (P=0.05). Similarly, á value of NWGR-3215 and GR-103 were found negative and significantly different from α=0 (Thillainathan and Fernandez 2001 and Carvalho *et al*. 1983).

Spearman's rank correlation

Spearman's rank correlation coefficients were worked

out between ranks of all possible pairs of different stability estimates to identify agreement between different methods of stability and selection of genotypes based on yield and stability estimates. The results are presented in Table 4. The rank correlation coefficient between bi in Eberhart & Russel model and α in Tai's model, which provided a greater similarity in the stability. Similarly, positive perfect correlation was observed between Wi^2 and Sh-σ². Wi^2 and Sh-σ² had near positive perfect correlation with Tai's λ. Deviations from regression sum of square (S^2_{di}) had positive and high rank correlation with Wi^2, Sh-σ² and Tai λ(Carvalho *et al*. 1983; Mekbib 2003).

By looking to the rank correlation, it can be concluded that the stability estimates Wi^2, Sh-σ², Tai's á and Tai's λ could be used in place of Eberhart and Russel model. According to all stability estimates,

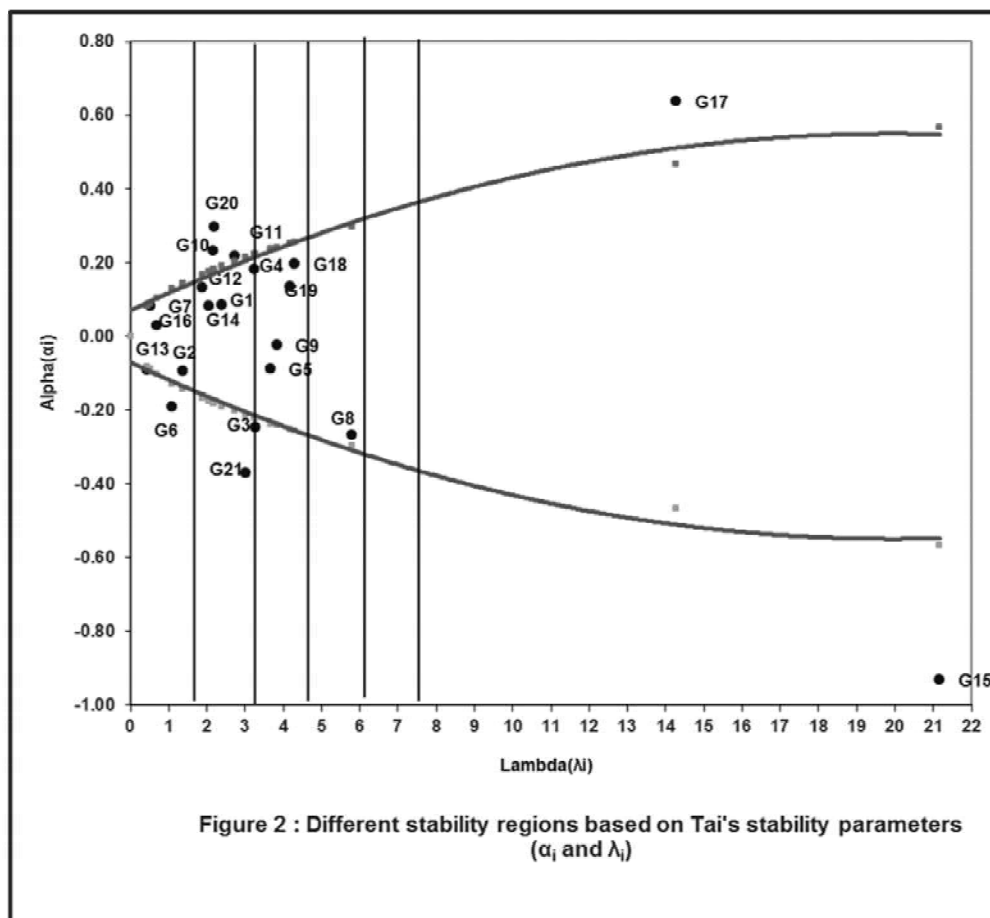Figure 2 : Different stability regions based on Tai's stability parameters
($α_i$ and $λ_i$)

Table 4. Spearman's rank correlation between ranks of mean yield and stability estimates

	M_rank	bi-rank	S^2_{di}_rank	W^2_rank	Sh-σ^2_i-rank	α_rank	λ_rank
M_rank	1.000						
bi-rank	-0.047	1.000					
S^2_{di}_rank	0.190	0.162	1.000				
W^2_rank	0.222	0.651**	0.758**	1.000			
Sh-σ^2_i-rank	0.222	0.651**	0.758**	1.000**	1.000		
α_rank	-0.047	1.000**	0.162	0.651**	0.651**	1.000	
λ_rank	0.223	0.517*	0.857**	0.971**	0.971**	0.517*	1.000

* and ** significant at 5 and 1 per cent level of probability, respectively

genotypes IET19147 and NWGR-3006 were identified as high yielding and stable genotypes by almost all methods.

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