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Wheat Yield and Important Traits Influenced by Interaction of Potassium and Irrigation Levels Evaluated at Number of Locations in the Country by AMMI Analysis and Non-Parametric Measures

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ABSTRACT

AMMI analysis of treatments consisted of levels of potassium with irrigations observed highly significant effects of locations, treatments, and T×L interactions for wheat yield. About 53.4% of the total variations in yield values was due to locations followed by 26.3% and 10.8% by treatments and interactions effects. Further analysis found 59.7% contributed by $AMMI_1$ while 17.2% and 9.4% by $AMMI_2$ and $AMMI_3$ components for thousands grain weight as total of first two components cumulative to 76.9% of the total variation. The sums of squares for G×E signal and noise were 56.7% and 43.3% of interaction effects for grains per spike as the sum of squares of T×L signal was 2.58 times of treatments effects and IPC1 alone was 3.54 times the treatments effects. Measures ASV and ASV1 recommended T_6, T_5, T_4 for wheat yield while measures utilized 81.6% of interaction sum of squares whereas MASV and $MASV^1$ measures based on 98.4% identified T_3, T_5, T_8, T_4 treatments. Maximum average for thousands grains weight; GAI selected T_8, T_9, T_6 whereas as per HM values treatments T_5, T_2, T_8 would be more desirable. Grains per spike found the measures RPGV and HMRPGV settled for T_8, T_9, T_5 treatments. Non parametric measures for yield observed Si^1 selected T_3, T_2, T_5 as opposed to T_6, T_4, T_1 by S_i^2 values. T_6, T_4, T_1 genotypes considered by S_i^3 Si^4 measure considered T_6, T_4, T_1 next Si^5 for T_6, T_3, T_4 and Si^6 pointed towards T_6, T_4, T_8 genotypes while Si^7 favored T_6, T_1, T_4 genotypes. Composite measures for thousands grains weight found NPi(1) for T_3,T_4,T_7 while as per NPi(2) for T_4,T_3,T_7, NPi(3) T_4,T_3,T_2, NPi (4) found T_4, T_5, T_7 as suitable treatment combinations. Multivariate hierarchical clustering as per Ward's method for wheat yield observed first irrigation level with three potassium levels formed a cluster and other irrigation levels with potassium application remained in other one. At the first node of demarcation for thousands grains weight IPC5 exhibited MASV with MASV1, ASV1, IPC4, ASV, Si^1 Si^2 Si^3 Si^4 Si^5 Si^6 Si^7 $NPi^{(1)}$, CV in one side and mean, GAI, PRVG, IPC1, HM, IPC1, $NPi^{(2)}$ $NPi^{(3)}$ $NPi^{(4)}$ on other side. The performance of treatments based on AMMI and non-parametric measures would be more meaningful for identification of suitable irrigation and potassium levels for wheat sustainable production.

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Keywords AMMI, ASV, MASV, RPGV, HMRPGV, Ward's method.

INTRODUCTION

An increased world population demands the harnessing of all the available technologies for more production per unit of land to sustain the food availability (Liu *et al.* 2021). Cereal crop wheat has been considered as a big source of calories owing to the great percentage of starch in flour and in whole grain (Azmat *et al.* 2022). Good numbers of ingredients have been derived from wheat crop that are used in many food items for population consumptions (Kadkol *et al.* 2020). The limitations on the water availability for irrigation would be stringent under the changed scenario of the rainfall and its erratic distribution pattern due to climate change to meet the full requirement of the crop (Wang *et al.* 2018, Wang *et al.* 2021). Potassium availability in soils known to possess the desirable effects for good harvest of crop yield as well as for the quality produces (Wang *et al*. 2013, Lv *et al.* 2017)). Because K has a dominant role in the opening and closing of the stomata for water transpiration from the leaves and inhaling of carbon dioxide to the leaves (Zörb *et al.* 2014) thus K relieves water, salt and drought stresses of the crop. In case of inadequacy of potassium, the stomatal activity of leaves becomes slow and water losses are high (Zhang *et al.* 2022). The presence of optimum and adequate potassium availability to plants increase plant uptake of water as well as improving water use efficiency (Singh *et al.* 2018, Dhillon *et al.* 2019). The present study was conducted to investigate the effect of potassium fertilization and irrigation schedule to improve the yield and important traits of wheat crop at major locations under the coordinated wheat improvement program of the country.

MATERIALS AND METHODS

Nine treatment combinations comprised of three irrigation levels with three doses of Potassium were evaluated in research field trials at nine major centers (Dhanduk, Durgapura, Jabalpur, Pune, Kanpur, Dharwad, Shilongani, Vijapur, Jammu) of All India Coordinated Research Project on Wheat across north eastern plains zone of the country during 2020-21 cropping season. The cluster analysis, pattern analysis, and principal component analysis have been advocated to decipher the interactions patterns for multi-location studies. Moreover the good number of AMMI as well as non-parametric measures had shown their effectiveness for meaningful interpretations. The recent measures had been mentioned below for completeness (Pupin *et al.* 2018, Olivoto *et al.* 2019) as :

ASV $\quad ASV = \left[\left(\frac{SSIPC\,1}{SSIPC\,2}\,PC1\right)^2 + (PC^2)\right]^{1/2}$

ASV1 $\quad ASV1 = \left[\frac{SSIPC\,1}{SSIPC\,2}\,(PC\,1)^2 + (PC2)^2\right]1/2$

Modified AMMI stability value $\quad SSIPCn$

$$MASV = \sqrt{\sum_{n=1}^{N-1} \frac{SSIPCn}{SSIPCn\text{-}1}\,(PCn) + \;(PC\,n{+}1)}$$

$$MASV1 = \sqrt{\sum_{n=1}^{n-1} \left(\frac{SSIPCn}{SSIPC_{n+1}}PC_n\right)^2 + (PC_{n+1})^2}$$

HM = Number of environments / $\sum_{j=1}^{k} \frac{1}{GVij}$

GVij genetic value of ith genotype in jth environments

Relative performance of genotypic values across environments $\quad RPGVij = \sum GVij \,/\, \sum GVj$

Harmonic mean of Relative performance of genotypic values HMRPGV$_{i}$. = Number of environments/

$$\sum_{j=1}^{k} \frac{1}{RPGVij}$$

Geometric adaptability index

$$GAI = \sqrt[n]{\prod_{k=1}^{n} \bar{X}_k}$$

Seven nonparametric methods for assessing G×E interaction and stability analysis were observed in literature (Pour-Aboughadareh *et al.* 2019). X_{ij} denotes the yield of ith genotype in jth environment where i=1,2, ...k, , j =, 1,2 ,..., n and rank of the ith genotype in the jth environment by r_{ij} and as the mean of ith genotype the correction for yield of ith genotype in jth environment as ($\bar{X}^*ij = \bar{X}ij - .+ \quad$) as $\bar{X}^*ij$, was the corrected phenotypic value was the mean of ith genotype in all environments and was the grand mean. Generally used seven statistics based on ranks of genotypes yield and corrected yield were expressed as follows :

$$S_i^{(1)} = \frac{2\sum_{j}^{n-1} \sum_{j'=j+1}^{n} [r_{ij} - r_{ij'}]}{[n(n-1)]}$$

$$S_i^{(2)} = \frac{\sum_{j=1}^{n} (r_{ij} - \bar{r}_{i})^2}{n-1}, \quad \bar{r}_i = \frac{1}{n} \sum_{j=1}^{n} r_{ijo}$$

$$S_i^{(3)} = \frac{\sum_{j=1}^{n} (r_{ij} - \bar{r}_i)^2}{\bar{r}i_o}$$

$$S_i^{(4)} = \sqrt{\frac{\sum_{j=1}^{n} (\bar{r}_{ij} - r_i)^2}{n}}$$

$$S_i^{(5)} = \frac{\sum_{j=1}^{n} (r_{ij} - \underline{r}_i)}{n}$$

$$S_i^{(6)} = \frac{\sum_{j=1}^{n} (r_{ij} - r_i)}{\bar{r}_i}$$

$$S_i^{(7)} = \frac{\sum_{j=1}^{n} (r_{ij} - \underline{r}_i)^2}{\sum_{j=1}^{n} (r_{ij} - \underline{r}_i)}$$

$$Z_i^{(v)} = \frac{[S_i^{(v)} - E\{S_i^{(v)}\}]}{Var\{S_i^{(v)}\}}, \quad V = 1, 2$$

Non parametric measures as NPi(1), NPi(2), NPi(3) and NPi(4) based on ranks of corrected means of genotypes. Ranks of genotypes as per corrected yield X*ij denoted by r*ij with average of ranks and median by r_i* and M*di.

$$NP_i^{(1)} = \frac{1}{n} \sum_{j=1}^{n} (r^*_{ij} - M^*_{di})$$

$$NP_i^{(2)} = \frac{1}{n} \left(\frac{\sum_{j=1}^{n} [r_{ij} - M_{di}]}{M_{di}} \right)$$

$$NP_i^{(3)} = \frac{\sqrt{\sum (r^*_{ij} - \bar{r}_i)^2 / n}}{\bar{r}_{i_o}}$$

$$NP_i^{(4)} = \frac{2}{n(n-1)} \left[\sum_{j=1}^{n-1} \sum_{jl=j+1}^{m} \frac{(r^*_{ij} - r^*_{ij})}{\bar{r}_{io}} \right]$$

AMMISOFT version 1.0 software utilized for AMMI analysis of data sets and SAS software version 9.3 for further analysis.

RESULTS AND DISCUSSION

Significance of effects based on AMMI analysis

Yield

Table 1 expressed the highly significant variations due to locations, treatments and T×L interactions were observed by AMMI analysis (George and Lundy 2019)). This analysis also showed that about 53.4% of the total sum square of variation for yield was due to locations followed by 26.3% of treatments, whereas interactions accounted only 10.8%. Further interaction effects portioned into five interactions principal components which accounted for 98.4% of interactions sum of square variations. AMMI1 explained a total variation of 65.9%, followed by 15.6% for AMMI2, 10.5% for AMMI3, AMMI4 accounted for 3.7% and followed by 2.4% by AMMI5. The first two AMMI components in total showed 81.6% of the total variation (Golkar *et al.* 2020). The sums of squares for T×L signal and noise were 70.3% and 29.7% of total interaction respectively. Nearly 0.29 times of the treatments effects was of T×L-signal sum of squares.

Thousand grains weight

Highly significant variations due to locations, T×L interactions and treatments were 53.3% , 21.1% and 12% respectively (Table 1). AMMI1 accounted for 59.7% by followed by 17.2% for AMMI2, 9.4% for AMMI3, AMMI4 accounted for 6.6% respectively. Nearly 76.9% of the total variation had been accounted by the first two AMMI components. Approximately 66.7% and 33.3% of interactions sums of squares

Table 1. AMMI analysis of potassium and irrigation on yield and important traits.

Source of variations	Degree of freedom mean sum of squares			% Share of corresponding factors			Contributions to interaction Sum of squares (%)		
	Yield	Thousands grains weight	Grains per spike	Yield	Thousands grains weight	Grains per spike	Yield	Thousands grains weight	Grains per spike
Treatments (T) 8	470.68	33.36	23.47	26.32	0.73	0.44			
Locations (L) 8	955.20	4332.86	4890.77	53.42	95.35	91.04			
T×L interactions 64	24.13	12.08	27.33	10.80	2.13	4.07			
IPC1 15	67.95	21.62	44.34				65.99	41.94	38.03
IPC2 13	18.56	20.14	41.93				15.62	33.86	31.17
IPC3 11	14.78	11.50	34.07				10.52	16.37	21.43
IPC4 9	6.36	4.38	9.91				3.70	5.10	5.10
IPC5 7	5.61	2.37	7.31						
IPC 6	3.80	0.60	4.35						
IPC7 3	1.89	0.51	0.61						
Residual 1	0.40	0.00	0.03						
Error 162	8.36	4.03	11.82						
Total 242	59.12	150.23	177.60						

accounted by T×L signal and noise. More over the sum of squares for T×L -signal is 1.93 times that for treatments main effects. While noise of interaction was 0.97 times only.

Grains per spike

Highly significant variations due to locations, T×L interactions and treatments were observed by AMMI analysis (Table 1). This analysis also revealed about 91% of the total sum square of variation for trait was due to locations followed by interactions 4% whereas treatments accounted only very marginally. Further analysis observed 38% by AMMI1 followed by 31.2% for AMMI2, 21.4% for AMMI3, AMMI4 accounted for 5.1% respectively. Nearly 69.2% of the total variation contributed by first two AMMI components. The sums of squares for G×E signal and noise were 56.7% and 43.3% of total interaction effects respectively while the sum of squares for T×L-signal was 2.58 times of treatments main effects.

Performance of treatments as per AMMI analysis measures

Yield

Table 2 found the absolute IPCA-1 scores pointed for T_5, T_6, T_4 as per IPCA-2, T_1, T_6, and T_8 treatments would be of choice (Koundinya *et al.* 2019). Values of IPCA-3 favored T_9, T_4, T_7 treatments. As per IPCA-4, T_3, T_5, T_8 would be of stable performance. IPCA-5 identified T_8, T_4 ,T_1 as IPCA-6 selected T_7, T_5, T_2 while as per IPCA-7 treatments T_2,T_6,T_7. First two

Table 2. AMMI based and analytic measures for yield.

Yield	IPC1	IPC2	IPC3	IPC4	IPC5	IPC6	IPC7	ASV1	ASV	MA-SVI	MA-SV	Mean	Stdev	CV	GAI	HM
T_1	-0.8894	-0.2928	-1.2904	1.3164	0.3105	-0.4394	-0.3278	3.77	1.85	6.15	3.93	27.62	5.60	20.27	27.19	26.77
T_2	-2.6950	0.8276	-0.7649	-0.8389	-0.7668	0.1750	0.0319	11.42	5.60	11.95	6.19	30.86	9.03	29.25	29.81	28.75
T_3	-1.7196	-1.3894	0.9223	-0.1828	0.9688	0.2541	0.3509	7.40	3.80	8.52	4.89	32.04	7.48	23.34	31.40	30.83
T_4	0.8332	0.5949	-0.1679	0.8278	-0.1326	1.1090	0.2974	3.57	1.81	5.58	3.33	33.83	6.21	18.37	33.39	32.98
T_5	0.0629	1.2413	0.8474	-0.3288	0.7176	-0.1047	-0.6758	1.27	1.25	3.89	2.99	36.06	7.68	21.29	35.45	34.88
T_6	0.0925	0.3378	1.6778	0.6396	-0.9137	-0.5419	0.1738	0.52	0.39	5.94	4.00	37.40	7.73	20.66	36.82	36.27
T_7	1.9638	0.9809	-0.4879	-0.5472	0.4733	-0.0723	0.2708	8.35	4.15	8.74	4.60	36.05	6.66	18.47	35.56	35.06
T_8	0.9604	-0.5801	-0.6757	-0.4052	-0.0233	-0.7452	0.4334	4.10	2.06	5.40	3.08	39.41	5.48	13.91	39.12	38.82
T_9	1.3913	-1.7202	-0.0607	-0.4808	-0.6338	0.3654	-0.5546	6.12	3.34	6.99	4.27	40.51	5.62	13.87	40.18	39.84

Table 3. AMMI based and analytic measures for thousands grain weigh.

TGW	IPC1	IPC2	IPC3	IPC4	IPC5	IPC6	IPC7	ASV1	ASV	MAS-VI	MA-SV	Mean	Stdev	CV	GAI	HM
T_1	-1.94	-1.11	0.2898	0.5998	-0.0882	-0.2560	-0.3860	2.64	2.42	4.04	3.22	34.75	13.37	38.48	29.68	19.11
T_2	-1.07	0.22	-0.0671	0.0933	-0.7620	0.5938	0.3368	1.34	1.21	4.71	2.56	36.13	13.27	36.72	31.32	21.25
T_3	-1.06	1.77	-0.9469	0.1010	0.6608	-0.1230	0.1017	2.21	2.13	6.50	4.21	35.92	13.46	37.46	30.61	19.27
T_4	0.28	-0.57	0.6586	-0.5380	0.9089	0.5430	-0.1816	0.67	0.65	6.00	3.19	35.70	13.32	37.32	30.47	19.30
T_5	-0.04	0.85	0.5540	-1.3279	-0.4144	-0.3613	-0.0929	0.85	0.85	5.01	3.32	36.85	13.34	36.19	31.93	21.49
T_6	1.46	1.21	0.9813	0.8758	-0.3163	0.0566	-0.2467	2.17	2.02	5.50	3.81	38.04	14.50	38.13	32.21	19.79
T_7	0.36	-0.94	0.9381	0.2315	0.2845	-0.3609	0.5706	1.04	1.03	4.32	2.83	36.78	13.97	37.98	31.20	19.28
T_8	0.83	-1.20	-1.0871	-0.4501	-0.3707	0.0055	-0.1099	1.58	1.52	5.26	3.44	37.57	13.79	36.70	32.32	21.10
T_9	1.17	-0.23	-1.3207	0.4147	0.0973	-0.0977	0.0081	1.47	1.32	4.85	3.14	37.97	14.13	37.21	32.28	19.99

IPCAs in ASV and ASV1 measures utilized 81.6% of T×L interaction sum of squares. ASV1 measures recommended (T_6, T_5, T_4) and ASV pointed towards (T_6, T_5, T_4) as of stable performance. Adaptability measures MASV and MASV1considered all significant IPCAs of the AMMI analysis using 98.4% of T×L interactions sum of squares. Values of MASV1 identified T_3, T_8, T_4 would express stable performance whereas T_5, T_8, T_4 be of stable performance by MASV respectively. Since the yield expressed highly significant variations among treatment, mean yield was considered as an important measure to assess the potential of treatments. Mean yield selected T_9, T_8 with lowest yield of T_1 (Table 2). This measure is simple, but not fully exploiting all information contained in the dataset. Consistent yield of T_8, T_1, T_9 as per least values of standard deviation more over the values of CV identified T_9, T_8, T_4 genotypes for the consistent performance. More over the values of GAI selected T_9, T_8, T_6. The simultaneous selection measure HM identified T_9, T_8, T_6 while values of other measures RPGV and HMRPGV also settled for T_9, T_8, T_6 treatments. The estimates of GAI, HM, RPGV and HMRPGV had the same rankings of treatments for wheat yield.

Thousand grains weight

Treatments T_5, T_4, T_3 were pointed by IPCA-1 values and IPCA-2 was settled for T_2, T_9, T_4 treatments (Table 3). Values of IPCA-3 favored T_2, T_1, T_5 treatments. As per IPCA-4, T_2, T_3, T_7 would be of stable performance. IPCA-5 identified T_1, T_9 ,T_7 whereas IPCA-6 selected T_8, T_6, T_9 while as per IPCA-7 treatments T_9, T_5, T_8. First two IPCAs in ASV and ASV1 measures utilized 75.8% of T×L interaction sum of squares. ASV1 measures recommended (T_4, T_5, T_7) and ASV pointed towards (T_4, T_5, T_7) as of stable performance. Adaptability measures MASV and MASV1 considered all significant IPCAs of the AMMI analysis using 97.3% of interactions sum of squares. Values of MASV1 identified T_1, T_7, T_2 would express stable performance whereas T_2, T_7 ,T_9 be of stable performance by MASV respectively. Higher

Table 4. AMMI based and analytic measures for grains per spike.

	IPC1	IPC2	IPC3	IPC4	IPC5	IPC6	IPC7	ASV1	ASV	MAS-VI	MA-SV	Mean	Stdev	CV	GAI	HM
T_1	-0.0358	-0.3810	-2.6134	-0.0252	-0.5333	0.6293	-0.0862	0.3835	0.3831	13.66	6.48	35.81	13.33	37.23	33.81	32.10
T_2	-0.2558	-2.2234	-0.2820	-1.0301	0.0470	-0.6508	0.0707	2.2452	2.2413	9.07	4.59	35.98	15.26	42.41	33.38	31.11
T_3	1.7631	1.9636	-0.6382	-0.3894	0.4461	-0.3789	0.4195	2.9128	2.7656	6.85	4.30	37.72	13.07	34.66	35.71	33.92
T_4	0.9112	-0.1461	0.7069	1.2132	-1.3579	-0.3812	0.0305	1.1214	1.0171	7.04	3.97	36.44	14.22	39.03	34.51	32.99
T_5	2.0110	-0.5317	0.9985	-0.4275	0.3788	0.1172	-0.4656	2.5108	2.2842	5.42	3.49	38.72	15.18	39.20	36.49	34.66
T_6	-0.7576	0.2177	-0.5011	1.3082	1.1337	-0.1820	-0.2794	0.9497	0.8647	5.08	3.41	37.42	13.15	35.16	35.65	34.16
T_7	-0.3118	-1.0885	1.1224	0.3568	0.4104	0.9128	0.4855	1.1531	1.1417	12.21	4.64	36.76	14.62	39.76	34.62	32.86
T_8	-2.2296	0.5462	0.3534	-0.1564	-0.0828	-0.6252	0.0598	2.7749	2.5228	8.19	3.55	36.90	12.50	33.86	35.17	33.65
T_9	-1.0946	1.6433	0.8535	-0.8497	-0.4421	0.5587	-0.2348	2.1176	2.0402	8.54	4.31	37.70	11.85	31.42	36.12	34.75

Table 5. Assessment of treatments combinations for yield as per non-parametric measures.

Yield		PRVG	HMP-RVG	Rme	Rmed	Si^1	Si^2	Si^3	Si^4	Si^5	Si^6	Si^7	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$
T_1	I1 K_0	0.7916	0.7874	4.88	5.00	3.03	5.36	1.10	2.32	1.89	3.49	2.52	1.89	0.2099	0.2608	0.3412
T_2	I1 K_2	0.8764	0.8539	4.00	3.00	1.75	7.75	1.94	2.78	2.00	4.50	3.44	2.00	0.2667	0.3977	0.2500
T_3	I1 K_4	0.9162	0.9072	4.25	4.00	1.44	5.44	1.28	2.33	1.61	3.41	3.00	1.56	0.2393	0.3520	0.2180
T_4	I2 K_0	0.9707	0.9689	5.50	5.00	2.75	5.00	0.91	2.24	1.67	2.73	2.67	1.56	0.2593	0.3578	0.4400
T_5	I2 K_2	1.0305	1.0286	5.50	5.00	1.81	6.00	1.09	2.45	1.89	3.09	2.82	1.78	0.4444	0.6124	0.4514
T_6	I2 K_4	1.0699	1.0684	5.25	6.00	2.67	4.19	0.80	2.05	1.50	2.57	2.48	1.33	0.4444	0.5847	0.7619
T_7	I3 K_0	1.0363	1.0292	5.88	7.00	2.61	6.36	1.08	2.52	1.92	2.94	2.95	1.89	0.3778	0.5309	0.5497
T_8	I3 K_2	1.1375	1.1344	4.88	6.00	2.39	5.61	1.15	2.37	1.92	3.54	2.60	1.67	0.8333	1.1145	1.1242
T_9	I3 K_4	1.1708	1.1632	4.88	4.00	2.61	11.36	2.33	3.37	2.75	5.08	3.67	2.56	1.7037	2.0741	1.6068

mean values selected T_6, T_9, T_8 with lowest of T_1 treatment (Table 3). Consistent value of T_5, T_2, T_8 as per least values of standard deviation more over the values of CV identified T_{15}, T_{13}, T_6 treatments for the consistent performance. More over the values of GAI selected T_8, T_9, T_6. The simultaneous selection measure HM identified T_5, T_2, T_8 while values of other analytic measures RPGV and HMRPGV settled for same T_8, T_9, T_6 treatments.

Grains per spike

IPCA-1 pointed for T_1, T_2, T_7 treatments for grains per spike whereas IPCA-2 settled for T_4, T_6 and T_1 treatments (Table 4). Values of IPCA-3 favored T_2, T_8, T_6 treatments. As per IPCA-4, T_1, T_8, T_3 would be of stable performance. IPCA-5 identified T_8, T_2 ,T_5 IPCA-6 selected T_5, T_6, T_3 while as per IPCA-7 treatments T_4, T_8, T_1. First two IPCAs in ASV and ASV1 measures utilized 69.2% of T×L interaction sum of squares. ASV1 measures recommended (T_1, T_6, T_4) and ASV pointed towards (T_1, T_6, T_4) as of stable performance. MASV and MASV1 using 95.7% of interactions sum of squares identified T_6, T_5, T_3 and T_6, T_5 ,T_8 be of stable performance respectively. More grains per spike values selected T_5, T_3, T_6 with lowest value corresponding to T_1. Consistent performance of T_9, T_8, T_3 as judged by least values of standard deviation more over the values of CV identified T_9, T_8, T_3 for the consistent performance. More over the values of GAI selected T_5, T_9, T_6. The measure HM identified T_9, T_5, T_6 while values of other measures RPGV and HMRPGV also settled for T_8, T_9, T_5 treatments.

Behavior of treatments based on non-parametric measures

Yield

Average and median of ranks were calculated as per ranks based on yield values of treatments over the considered locations. Rme and Rmed identified T_7, T_4, T_5 and, T_7, T_6, T_5 treatments respectively (Table 5). Measure S_i1 selected T_3, T_2, T_5 as opposed to T_6, T_4, T_1 treatments by Si^2 values. T_6, T_4, T_1 genotypes considered by S_i^3 measure and Si^4 measure considered

Table 6. Assessment of treatments combinations for thousands grain weight as per non-parametric measures.

	PRVG	HMPRVG	Rme	Rmed	Si^1	Si^2	Si^3	Si^4	Si^5	Si^6	Si^7	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$
T_1	0.9477	0.9444	5.00	5.50	3.33	11.75	2.35	3.43	2.89	5.20	3.62	2.89	0.3852	0.5078	0.4938
T_2	0.9997	0.9971	4.63	4.50	2.14	4.48	0.97	2.12	1.67	3.24	2.39	1.67	0.3333	0.4579	0.4625
T_3	0.9772	0.9741	4.25	4.00	1.78	4.19	0.99	2.05	1.22	2.59	3.05	1.11	0.1852	0.3483	0.3026
T_4	0.9717	0.9710	5.00	5.00	1.83	3.75	0.75	1.94	1.33	2.40	2.50	1.33	0.1778	0.2671	0.2529
T_5	1.0189	1.0167	5.00	5.50	2.06	4.25	0.85	2.06	1.56	2.80	2.43	1.56	0.3457	0.4581	0.4568
T_6	1.0283	1.0251	5.88	7.00	3.08	10.11	1.72	3.18	2.58	3.96	3.48	2.56	0.6389	0.8205	0.7957
T_7	0.9952	0.9936	5.13	5.50	2.03	4.36	0.85	2.09	1.44	2.54	2.68	1.44	0.3210	0.4396	0.4269
T_8	1.0313	1.0292	4.88	5.50	2.47	6.36	1.30	2.52	2.11	3.90	2.68	2.11	0.6032	0.6304	0.6181
T_9	1.0300	1.0279	5.25	6.00	3.00	9.19	1.75	3.03	2.44	4.19	3.34	2.44	0.8148	0.9699	0.9600

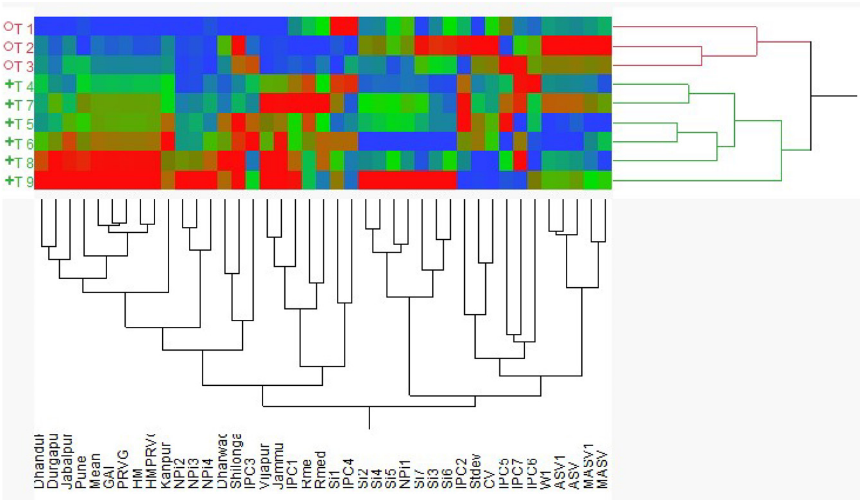

Fig. 1. Multivariate hierarchical cluster analysis of treatments and measures for yield.

T_6, T_4, T_1 next measure Si^5 settled for T_6, T_3, T_4 and Si^6 pointed towards T_6, T_4, T_8 genotypes while Si^7 favored T_6, T_1, T_4 genotypes (Hameed *et al.* 2020). No parametric composite measures, consider the ranks of as per treatments yield and corrected yield simultaneously as values of NPi(1) found suitability of T_6,T_3,T_4 while by , NPi(2) measure T_1, T_3, T_4, while T_1, T_3, T_4 mentioned by NPi(3) and last measure NPi (4) found T_3, T_2, T_1 as suitable treatments (Vaezi *et al.* 2018).

Thousand grains weight

Rme identified for T_6, T_9, T_7 and Rmed settled for T_6, T_9, T_8 respectively (Table 6). Measure Si^1 selected T_3, T_4, T_7 as opposed to T_4, T_3, T_5 by Si^2 values. T_6, T_4, T_1 considered by Si^3 considered T_4, T_5, T_7 and Si^4 measure settled for T_4, T_3, T_5 next measure Si^5 settled for T_3, T_4, T_7 and values of Si^6 pointed towards T_4, T_7, T_3 while Si^7 favoured T_2, T_5, T_4 treatments. Values of composite measure $NPi^{(1)}$ identified T_3,T_4,T_7 and values of $NPi^{(2)}$ for T_4,T_3,T_7, whereas measure $NPi^{(3)}$ pointed for T_4,T_3,T_2, and values of measure $NPi^{(4)}$ found T_4, T_5, T_7 as suitable treatment combinations.

Grains per spike

Treatments T_4, T_5, T_3 and, T_5, T_3, T_4 identified by mean and median of ranks as per treatments combinations over the locations of this study (Table 7). Measure Si^1 selected T_4, T_6, T_7 as opposed to T_4, T_6, T_2 by Si^2 values. Treatments T_4, T_3, T_1 considered by Si^3 measure and Si^4 measure considered T_4, T_6, T_2 treatments whereas Si^5 settled for T_4, T_6, T_2 while values of Si^6 pointed towards T_4, T_3, T_1 and measure Si^7 favoured T_4, T_6, T_3 treatments. Non parametric composite

Table 7. Assessment of treatments combinations for grains per spike as per non-parametric measures.

	PRVG	HMPRVG	Rme	Rmed	Si^1	Si^2	Si^3	Si^4	Si^5	Si^6	Si^7	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$
T_1	0.9646	0.9583	5.13	5.50	2.31	5.36	1.05	2.32	1.67	2.93	2.86	1.67	0.2083	0.3367	0.3354
T_2	0.9546	0.9428	4.25	4.00	2.17	5.19	1.22	2.28	1.61	3.41	2.86	1.56	0.2074	0.3644	0.3467
T_3	1.0222	1.0097	5.63	6.50	2.25	5.48	0.98	2.34	1.75	2.80	2.79	1.67	0.3030	0.5204	0.5000
T_4	0.9834	0.9795	6.13	6.00	1.69	2.86	0.47	1.69	1.25	1.84	2.03	1.22	0.1746	0.2552	0.2558
T_5	1.0397	1.0355	6.13	7.00	2.69	8.11	1.32	2.85	2.08	3.06	3.46	1.89	0.7556	0.9113	0.8622
T_6	1.0147	1.0129	4.13	4.00	2.14	4.86	1.18	2.20	1.47	3.21	2.93	1.44	0.3611	0.6081	0.5900
T_7	0.9867	0.9823	4.25	3.00	2.17	5.44	1.28	2.33	1.83	3.88	2.64	1.56	0.3889	0.4783	0.4444
T_8	1.0037	0.9965	4.13	4.00	2.69	7.36	1.78	2.71	2.11	4.61	3.10	2.11	0.5278	0.6201	0.6159
T_9	1.0304	1.0240	5.25	5.00	3.06	9.69	1.85	3.11	2.67	4.57	3.23	2.67	0.5926	0.7323	0.7190

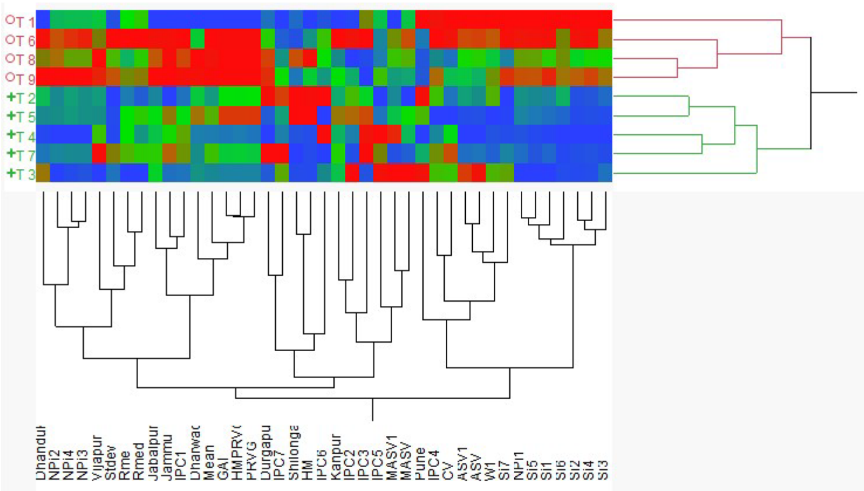

Fig. 2. Multivariate hierarchical cluster analysis of treatments and measures for thousand grains weight.

measure $NPi^{(1)}$ values found suitability of T_4,T_6,T_7, more over measure $NPi^{(2)}$ identified T_4,T_2,T_1, and next measure $NPi^{(3)}$ favoured for T_4,T_1,T_2 and last measure $NPi^{(4)}$ found T_4, T_1, T_2 as suitable treatment combinations.

Multivariate hierarchical clustering

Yield

Cluster analysis is exploited to classify treatments based on a studied variables into a number of different groups keeping alike objects in the similar group. Multivariate clustering of treatments based on studied traits had been carried out as per guidelines of popular Ward's method. First irrigation level with three potassium levels formed a cluster. Remaining irrigation levels with potassium application remained together in second one (Fig. 1). Si^2 expressed as point of dissection of considered measures at first node as AMMI based and non parametric measures except of Si1, IPC3, IPC4 categorized in one side and composite non parametric measures with location wise yield measures on other side. Stdev further sep-

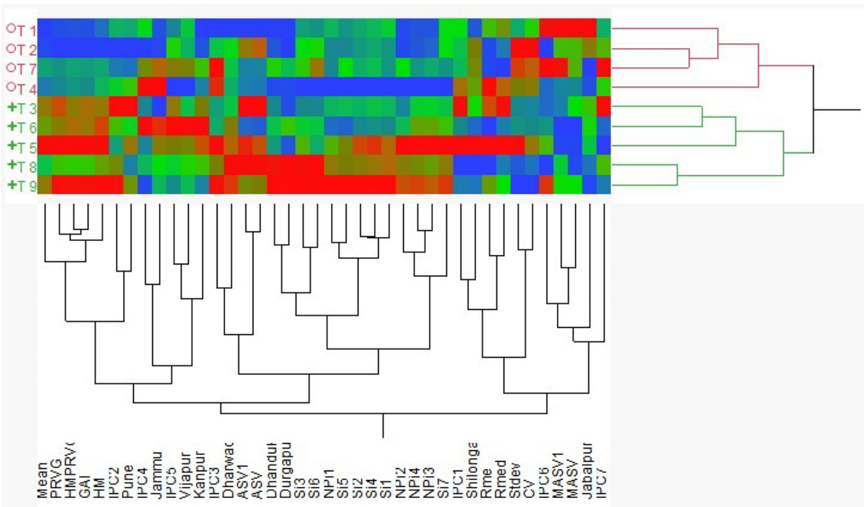

Fig. 3. Multivariate hierarchical cluster analysis of treatments and measures for grains per spike.

arated AMMI based measures from non parametric measures at second node. Moreover yield at Vijapur center placed Jammu yield, IPC1, Rme, Rmed, Si1, IPC4 from yield at other centers, composite non parametric measures.

Thousand grains weight

Nine treatment combinations were divided into two different clusters with respective membership of 04 and 05 treatments (Fig. 2). Second and third phosphorus levels with different levels of irrigation formed a first cluster. Remaining irrigation levels and phosphorus doses remained together in second one. IPC5 expressed as point of demarcation of considered measures as MASV categorized with MASV1, ASV1, IPC_4, ASV, Si^2 ,Si^3 ,Si^4 ,Si^5, Si^6 ,Si_7 , $NPi^{(1)}$, CV in one side and mean, GAI, PRVG, IPC1, HM, IPC1, $NPi^{(2)}$ $NPi^{(3)}$) $NPi^{(4)}$ on other side at first node. Si^7 partitioned the classified measures at second node with $NPi^{(1)}$, Si1 ,Si2 ,Si^3 ,Si^4 ,Si^5 ,Si^6 in latter and CV, ASV, ASV1in former one. Measure HMPRVG had separated out PRVG, Durgapura, IPC7, Shillongani, HM from in one group at second node of bifurcation of measures.

Grains per spike

Considered nine combinations were divided into two different clusters based on important morphological traits with respective membership of 04 and 05 treatments (Fig. 3). First irrigation level with five considered genotypes formed a cluster. Remaining irrigation levels with genotypes remained together in second one. Measure Si1expressed as point of dissection as non parametric composite measures along with MASV1, MASV, IPC6, IPC7, CV, Jabalpur for first group and ASV, ASV1, IPC3, IPC5, IPC4, IPC2, PRVG, HMPRVG, GAI, HM on other side at the first node.

CONCLUSION

AMMI analysis of treatments observed highly significant effects of locations, treatments, and their interaction effects for wheat yield. More than fifty per cent of the total variations in yield values were due to locations followed by treatments and their interactions effects. First component of AMMI analysis contributed more than half of the variations while first two components cumulative to 76.9% of the total variation for thousands grain weight. The sums of squares for T×L signal were more as compared to noise for grains per spike. ASV and ASV1 recommended T_6, T_5, T_4 treatments whereas MASV and MASV1 found suitability of T_3, T_5, T_8, T_4 treatments. Maximum value for thousands grains weight; GAI selected T8, T9, T6 whereas as per HM values treatments T_5, T_2, T_8 would be more desirable. RPGV and HMRPGV settled for T_8, T_9, T_5 treatments as far as grains per spike was concerned. Non parametric measures for yield favored T_3, T_2, T_5, T_6, T_4, T_8 treatments. Composite non parametric measures for thousands grains weight found T_3, T_4, T_5, T_7 treatments. Multivariate hierarchical clustering as per Ward's method for yield observed a first cluster of initial irrigation level with three potassium levels. The thousands grains weight expressed as IPC5 separated MASV with MASV1, ASV1, IPC4, ASV, Si^1 ,Si^2 ,Si^3 ,Si^4 Si^5, Si^6, Si^7 , $NPi^{(1)}$, CV in one side and mean, GAI, PRVG, IPC1, HM, IPC1, $NPi^{(2)}$, $NPi^{(3)}$, $NPi^{(4)}$ on other side at the first node of clustering. The performance of treatments based on AMMI and non-parametric measures would be more meaningful for identification of suitable irrigation and potassium levels for wheat sustainable production.

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