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The Variation and Stability Analysis of Starch Pasting Properties among New Plant Type (NPT) Wheat Derivatives

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ABSTRACT

Pasting is one of the most important properties of wheat starch determining the flour quality and functionality. Twenty three New Plant Type (NPT) wheat derivatives along with three checks (PBW 343, HD 2329, and Raj 3765) have been studied in multi-location trials to assess the variation and environment induced fluctuations for their starch pasting properties. Although all flour pasting characteristics varied, Breakdown Viscosity (BV) and Setback Viscosity (SV) exhibited greater variability across environments. Additive Main effects and Multiplicative Interaction (AMMI) analysis indicated significant interactions between Genotypes and Environments Interaction (GEI) in starch pasting properties. Genotypes accounted largest proportion (39.78%) of the Sum of squares (SQ) for peak viscosity (PV) followed by environments (33.30%) and GEI (33.30%). Trough Viscosity (TV), GEI accounted for the largest proportion (40.44%) of the SQ followed by environments (31.76%) and genotypes (27.80%). Genotypes accounted for the largest proportion (44.0%) of the SQ for (BV) followed by environments (33.30%) and GEI (21.59%). With respect to FV, environments accounted for the largest proportion (43.07%) of the SQ followed by GEI (30.84%) and genotypes (26.09%). Environments accounted for the largest proportion (52.48%) of the SQ followed by genotypes (23.89%) and GEI (23.65%) for SV. The interactions between genotype and locations differed greatly; however, some genotypes apparently found to be specifically adaptable to growth location. Correlation among starch pasting characteristics revealed that significant positive correlations were found between PV and BV, FV and TV, as well as SV and FV in all the individual environments tested that can be utilized in selection and simultaneous improvement in for starch quality improvement.

Keywords: AMMI-biplot analysis, Environment, Quality, *Triticum aestivum* L., Viscosity.

INTRODUCTION

Wheat is a major source of nutrition and, in this upcoming age of food industries, it is still the most important crop due to its multifarious end products. Starch and protein are the major constituents of the wheat endosperm and their properties are important for the quality of the final wheat products. Starch is composed of linear amylose (22-35%) and a highly branched amylopectin (65–78%). The functional properties of starch, particularly the ability of starch or flour to take up water and form a paste in the presence of heat, are affected by variations in the proportions of amylose to amylopectin (Dengate,1984) and, thereby, influencing the

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end-use of the wheat variety more importantly in appearance, structure, and quality of food products. The pasting properties of starch have been identified as major quality attribute for certain types of noodles. Research related to the relationship between pasting properties of starch and noodle (Yun *et al*., 1996; Liu *et al* 2003a, b; Song *et al*., 2004), steamed bread (Huang *et al*., 1996; Sun *et al*., 2009) have been investigated. It was proved that starch pasting properties not only affect noodle appearance quality (colour and appearance) but the texture (stickiness and elasticity) and taste (smoothness) as well (He *et al*., 2004). Therefore, pasting properties of wheat flour (or starch) could be used as an index to evaluate noodle quality.

Rapid Visco Analyzer (RVA) has been proposed as a selection tool for starch viscosity and functionality of flour in certain types of noodles (Panozzo and McCormick, 1993). Starch pasting properties are mainly determined by such characteristics of starch granule (A-granule, B-granule), content of amylose content, ratio of amylose/amylopectin as well as influenced by other components such as protein (Maningat and Seib, 2010.). The functional properties of wheat starches with different particle size have been investigated (Zeng *et al.,* 2014). The viscosity parameters decreased with the increase of the ratio of B granule and the retrogradation of mixed starches increased with the ratio of B granule (Zeng *et al.,* 2014). Protein per cent showed significant positive correlation with TV and negative correlation with BV; SV and FV were negatively correlated with gluten content (Sarkar *et al.,* 2014; Suneetha unpublished). Many studies related to the relationship between the gluten or starch and processing quality (Ottenhof and Farhat, 2004; Ragaee and Abdel-Aal, 2006) and interaction between gluten and starch has been carried out (Kaldy *et al*., 1993; Petrofsky and Hoseney, 1995), but there is limited information available on pasting properties of wheat starch and its mechanism and influence are still unclear (Champenois *et al*., 1998). In addition, growth environment has significant influence on starch pasting properties of wheat (Crosbie *et al*., 1992; Morris *et al*., 1997, Bao *et al*., 2004; Geera *et al*., 2006; Brennan *et al.,* 2012; Siebenmorgen *et al.,* 2013; Sarkar *et al.,* 2014; Beckles and Thitisaksakul, 2014). Numerous methods for multi environment trials data have been developed to expose patterns of Genotype Environment Interaction (GEI), namely, joint regression (Finlay and Wilkinson, 1963, Eberhart and Russel, 1966) and AMMI (Gauch, 1992). AMMI, which stands for the additive main effect and multiplicative interaction, is widely used for Genotype×Environment (GE) investigation in multi-environment cultivar trait (Crossa *et al.,* 1990). AMMI model combines the analysis of variance of genotypes and the environment main effects with principal component analysis of the GEI into a unified approach (Gauch and Zobel, 1996). This method has been shown to be effective because it captures large portion of the GE sum of squares as well as clearly separates main and interaction effect (Ebdon and Gauch, 2002).

In addition to yield, the breeders would be required sooner than later to tailor their breeding strategies to meet the requirements of the rapidly emerging food industries. To achieve significant improvement in yield potential, Indian Agricultural Research Institute (IARI), New Delhi, initiated a strategic research in designing New Plant Type (NPT) wheat by combining grain weight, grain number per spike, and intermediate to high tiller per plant through hybridization between Sirsa Farm Wheat (SFW) which has very long spike with high spikelet number and genetic stocks and/or released varieties. Some of these lines have given 15-22% higher yield than the leading commercial varieties and are being used in wheat breeding programmes as donors of desirable genes (Singh *et al*., 2001). Knowledge on quality traits in these genotypes was not known. Attempts were made to identify the predominant starch characteristics within these genotypes which will help to focus research on improvement

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of wheat quality for end use. In India, focused research on starch quality is insignificant. Hence, there is vast potential for the identification and development of genotypes with desirable starch pasting properties better suited for various uses. The objective of the present study was to characterize the NPT wheat derivatives for starch pasting properties across environments and to identify stable genotypes for starch pasting properties in these environments.

MATERIALS AND METHODS

Twenty three NPT wheat derivatives of *Triticum aestivum* along with three outstanding checks (PBW 343, HD 2329 and Raj 3765) have been studied in multi-location trials to assess their starch pasting properties. Some of the genotypes with similar pedigree (half-sibs) were included to know the differences in quality traits as these genotypes differed in morphological and yield components. The experiment was laid out at two locations *viz*., New Delhi (IARI research farm) and IARI Regional Research Station, Pusa (Bihar). The Indo-Gangetic plains form the most important wheat area in India. The cool winters and the hot summers are very conducive to a good crop of wheat. Based on agroclimatic conditions, the country is broadly divided into six wheat zones. The location New Delhi comes under North-western Plains Zone while Pusa (Bihar) comes under North-eastern Plains Zone. New Delhi possesses three major seasons, i.e. an extremely hot summer, a monsoon season, and a fairly cold winter. The summer months, from March till June, remains hot and humid with the average high of 37ºC where the average high climbs to 42ºC. The winter, on the other hand, remains fairly cold with the average of 18.8ºC with as low as 5ºC. The average annual rainfall is about 617 mm with August being the wettest month of the year with more than 300 mm of precipitation. The soils textures are sandy loam to clay loam and pH varies from 7.4 to 8.4. Pusa (Bihar) is characterized by three distinct seasons, *i.e.* cool-day winter, hot-day summer, and warm wet rainy season. Cool-day season extends from October to February, with fairly low temperature varying between 7 and 16ºC. Hot dry season spreads over March to mid June with temperatures rising up to 45ºC with low humidity. Warm-wet season is the period of monsoon from mid-June to September where temperatures range from 24 to 35ºC. The average annual rainfall is about 1192 mm. The soils are very deep, calcareous fine loamy, fine silty with soil pH varying from 6.5 to 8.4. A description of the environments, namely, weather parameters and soil conditions at these two locations are given in Table 1. At New Delhi, the experiment was carried out for two successive years (2006-2007 and 2007-2008) in two environments *i.e.,* Timely Sown Irrigated (TSI) and Late Sown Irrigated (LSI) conditions. At Pusa (Bihar), the experiment was carried out for one year (2007-2008). The period between sowing under TSI and LSI was about 30 days. At both locations, the experiment was laid out in randomized block design with three replications. Each entry was

Table 1. Details of Environments (ENV) under study.

Location	Latitude/ longitude	Soil characteristics	Normal rain (mm)	Average annual temperature (°C) Min	Max
New Delhi, India	28.63°N/ 77.15°E	Sandy laom to clay loam soil with pH varying from 7.4 to 8.4	617	18.6	37
Pusa (Bihar), India	25.98°N/ 35.65°E	Very deep, calcareous fine loamy, fine silty with soil pH varying from 6.5 to 8.4	1192	18.8	35

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plotted in four rows of five meters length. The standard cultivation practices prescribed for wheat under irrigated conditions were followed precisely. Quality traits were analyzed at grain quality lab, genetics division, IARI, New Delhi, after the crop harvest.

The wheat representing each genotype/crop year/growing location/environment combination was cleaned, tempered and milled according to American Association of Cereal Chemists (AACC, 2000). Milling (AACC-21A) of the grain samples to obtain flour for starch pasting properties was done by using Quadrumat Senior mill, (Brabender, Germany) and the moisture content of the flour was determined (AACC 46-12). Starch pasting properties (AACC 76-21) was measured using Rapid Visco-Analyser (RVA) super3 model (Newport Scientific, Australia). Each sample was analyzed in duplicate. A programmed heating and cooling cycle of standard 1 profile was used. The sample was dispersed in water (25.0 mL) and stirred in an RVA canister initially at 960 rpm for 10 seconds and finally at 160 rpm for the remaining test. The temperature profile started from 50°C for 1 minute followed by ramping the temperature linearly to 95°C in 3 minutes and 20 seconds, holding for 2 minutes 92 seconds cooling the system to 50°C in 3 minutes and 88 seconds and the temperature remained constant at 50°C and the test process ended in 13 minutes. The pasting curves obtained were analyzed using RVA Starch Master Software Setup Tool (SMST) to obtain the characteristic parameters *viz.,* Peak Viscosity (PV, maximum paste viscosity achieved in the heating stage of the profile, also known as the maximum Hot Paste Viscosity), Trough Viscosity (TV, minimum viscosity at 95°C, i.e., holding strength at the minimum Hot Paste Viscosity, also called HPV) Breakdown Viscosity (BV, PV-TV), Final Viscosity (FV, viscosity at the end of the test at 50°C) and Setback Viscosity (SV, FV-PV). All these genotypes were also tested for falling number which measures the alpha-amylase enzyme activity in flour before analyzing starch pasting properties.

The data obtained from the study was statistically evaluated by SAS 9.2 software. The six environments in the present study were designated as Env1: TSI-New Delhi 2006/2007, Env2: LSI-New Delhi 2006/2007, Env3: TSI-New Delhi 2007/2008, Env4: LSI-New Delhi 2007/2008, Env5: TSI-Bihar 2007/2008, and Env6: LSI-Bihar 2007/2008. Separate Analysis Of Variance (ANOVA) was performed for starch pasting properties for each test location. Bartlett's test of homogeneity was used for difference estimation between test locations. Combined ANOVA was performed for starch pasting properties. The mean squares of GEI starch pasting properties were used to test the effect of genotypes. Multivariate analysis through AMMI analysis was carried out (Gauch, 1992). The AMMI model separates the additive main effects from interaction, which is analyzed as multiplicative component using principal component analysis by which the interaction patterns can be analyzed and the results of AMMI analysis are shown in common graphs called biplots (Gauch and Zobel, 1997). Pearson correlation coefficients among the starch pasting properties were calculated for each environment separately.

RESULTS

Considerable differences were observed among the genotypes across locations with respect to starch pasting properties. The mean values for starch pasting properties for each genotype and for each of the six growing environments as well as the extent of variation observed for each starch attributes are depicted in Tables 2 and 3, respectively.

The Analysis Of Variance (ANOVA) of individual environments and pooled over six environments tested for starch pasting properties of 26 wheat genotypes showed that genotypes, environments, and GEI were highly significant. Variability existed among the genotypes for all the starch pasting properties (Table 4). Further, the GEI was partitioned into Interaction Principal Component Analysis (IPCA) axes through AMMI analysis (Table 4) for all the traits

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Table 2. Mean performance of NPT wheat derivatives for starch pasting properties across locations**.**

	PV		TV		BV		FV		SV	
Genotypes	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
DL880	211.56	18.67	147.64	21.51	64.39	7.13	258.20	26.50	110.73	11.96
DL882	225.33	21.31	159.78	18.41	65.94	10.08	276.41	30.43	115.36	18.86
DL886	245.96	18.07	173.69	11.07	72.25	18.43	299.29	20.37	132.30	14.43
DL892	272.34	14.97	167.13	9.60	100.81	21.82	277.82	18.57	106.46	15.64
DL893	253.73	21.66	159.19	20.72	89.86	16.62	269.30	31.59	107.05	19.33
DL898	274.45	11.57	175.17	10.24	103.12	15.17	282.69	10.64	105.62	10.49
DL899	247.30	17.12	148.21	15.40	103.11	20.83	248.75	24.08	104.48	17.51
DL901	256.88	17.61	156.43	17.22	97.73	16.19	255.85	18.16	97.96	11.16
DL902	254.62	24.23	172.30	13.14	80.09	10.99	302.73	34.58	129.06	18.42
DL903	260.83	25.74	158.35	15.32	100.61	18.60	262.02	26.60	106.06	16.54
DL908	242.63	11.38	167.15	12.21	75.19	15.56	281.39	20.03	113.76	17.40
DL910	272.14	18.69	169.41	8.48	99.54	19.76	267.93	15.00	104.69	15.60
DL919	256.02	23.58	166.49	7.61	82.89	19.38	285.78	24.97	118.79	21.03
DL924	272.49	27.36	160.38	9.97	104.19	19.45	286.51	29.45	117.78	22.00
DL927	272.01	29.21	155.87	16.99	114.96	21.45	256.92	34.23	112.00	20.65
DL935	243.37	28.22	159.33	25.98	81.91	14.25	271.16	37.92	128.95	28.98
DL940	246.03	16.03	168.21	8.67	76.75	12.95	285.68	19.43	120.50	17.56
DL954	239.49	31.34	169.36	13.46	77.01	23.95	274.11	38.47	137.81	28.84
DL960	239.09	18.50	166.10	16.62	73.07	12.79	283.14	30.56	117.16	20.65
DL966	249.24	12.40	170.45	8.58	80.16	9.21	286.35	8.23	121.59	17.97
DL973	227.59	19.25	161.69	14.39	66.72	7.66	277.75	28.57	116.36	19.01
DL974	252.07	15.63	161.43	11.21	88.45	18.96	276.76	22.66	113.41	16.09
DL976	267.04	17.67	178.82	11.17	87.52	11.44	305.51	23.53	124.00	18.75
HD2329	269.67	15.43	166.47	5.60	102.58	13.08	276.63	13.74	108.20	15.17
PBW343	257.99	21.84	182.97	9.09	75.55	17.31	304.45	24.62	131.37	20.74
RAJ3765	237.85	22.02	157.84	19.27	86.44	16.09	268.87	32.78	109.00	17.22
Mean	251.84		164.61		86.57		277.77		115.79	
LSD (5%)	11.36		8.89		8.40		13.82		8.53	
CV (%)	5.61		6.72		12.07		6.19		9.16	
Max	274.45 (DL898)		182.97 (PBW343)		114.96 (DL927)		305.51 (DL976)		137.81 (DL954)	
Min	211.56 (DL880)		147.64 (DL880)		64.39 (DL880)		248.75 (DL899)		97.96 (DL901)	

characterized. Biplot mean *versus* IPCA1 (biplot I) and IPCA 1 *versus* IPCA 2 (biplot II) were utilized for identifying stable genotypes for starch pasting properties. The representative pasting curves of genotypes are presented in Figures 1-a to 1-d; the AMMI biplot between mean versus IPCA I are presented in Figures 2-a to 2-e and the AMMI biplot II between interaction principal components for starch pasting properties are presented in Figures 3-a to 3-e. The results are described below for the characters one by one.

Peak Viscosity (PV)

The average PV was 251.84 RVU and it ranged from 211.56 (DL 880) to 274.45 (DL898) (Table 2). Across locations, minimum average PV of 226.85 was observed for Env5 and maximum average

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Table 3. Mean and range among genotypes for starch pasting properties in RVU in six environments.

	PV		TV		BV		FV		SV	
Environments	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Env1	259.90	25.00	165.92	14.55	97.02	21.93	292.73	21.02	130.74	13.12
Env2	270.78	21.06	164.42	10.46	105.37	20.61	298.71	21.95	134.07	14.67
Env3	245.85	19.93	172.99	9.17	68.79	15.23	283.69	20.40	117.22	17.89
Env4	263.26	15.05	173.19	8.71	88.82	11.97	284.26	15.45	119.35	16.76
Env5	226.85	26.46	146.40	17.10	80.88	15.06	242.90	27.15	96.38	11.38
Env6	244.38	15.98	164.75	18.08	78.53	15.59	264.32	25.14	96.96	10.37
Mean	251.84		164.61		86.57		277.77		115.79	
LSD (5%)	5.46		4.27		4.03		6.64		4.10	
CV (%)	5.61		6.72		12.07		6.19		9.16	
Max	270.78 (II)		173.19 (IV)		105.37 (II)		298.71 (II)		134.07 (II)	
Min	226.85 (V)		146.40 (V)		68.79 (III)		242.90 (V)		96.38 (V)	

Table 4. AMMI analysis of variance for grain yield and yield components of NPT wheat derivatives across six environments during 2006-2007 to 2007-2008.[a]

Source	*df*	PV (RVU)	TV (RVU)	BV (RVU)	FV (RVU)	SV (RVU)
Sum of squares						
Model	155	99164.5**	39044.5**	66594.3**	128957.7**	64596.6**
Genotypes	25	39449.6** (39.78)	10853.9** (27.80)	29304.3** (44.0)	33645.2** (26.09)	15433.2** (23.89)
Environments	5	33023.5** (33.30)	12402.7** (31.76)	22912.9** (33.33)	55545.4 ** (43.07)	33889.1** (52.48)
G×E Interaction	125	26691.3** (33.30)	15787.7** (40.44)	14377.0 ** (21.59)	39767.1 ** (30.84)	15274.2 ** (23.65)
PCA I	29	9718.62** (36.41)	7451.3** (47.20)	5519.4 ** (38.39)	15171.0 ** (38.15)	7267.8** (47.58)
PCA II	27	5614.8 (21.04)	4270.4** (27.05)	2969.77 (20.66)	12236.0 ** (30.77)	3300.5* (21.61)
PCA III	25	5445.7 (20.40)	2095.2* (13.27)	2378.2 (16.54)	6297.7* (15.84)	1819.9 (11.91)
Residual	44	5912.0	1970.7	3509.6	6062.2	2885.9

[a] Figures in the parenthesis are percentage contribution to the sum of squares. PV= Peak Viscosity in RVU; TV= Trough Viscosity in RVU; BV= Breakdown Viscosity in RVU; FV= Final Viscosity in RVU; SV= Setback Viscosity in RVU.
**: Significant at probability level of less than 0.01, *: Significant at probability level of less than 0.05.

PV of 270.78 for Env2 (Table 3). The mean PV under late sown conditions was more than the timely sown condition at both the locations. AMMI analysis revealed that genotypes accounted for the largest proportion (39.78%) of the SQ for PV followed by environments (33.30%) and GEI (33.30%). Further, partitioning of GEI component into principal component axes revealed that PCA I covered 36.41% of the GEI sum of squares while the second and third principal component axes (PCA II and PCA III) explained further 21.04 and 20.4% of the SQ of this interaction. Biplot presentation of mean PV and IPCA 1 (Figure 2-a.) indicated that the genotypes DL 924, DL 966, DL 927, DL 898, PBW 343, DL 919 and DL 974 recorded high PV

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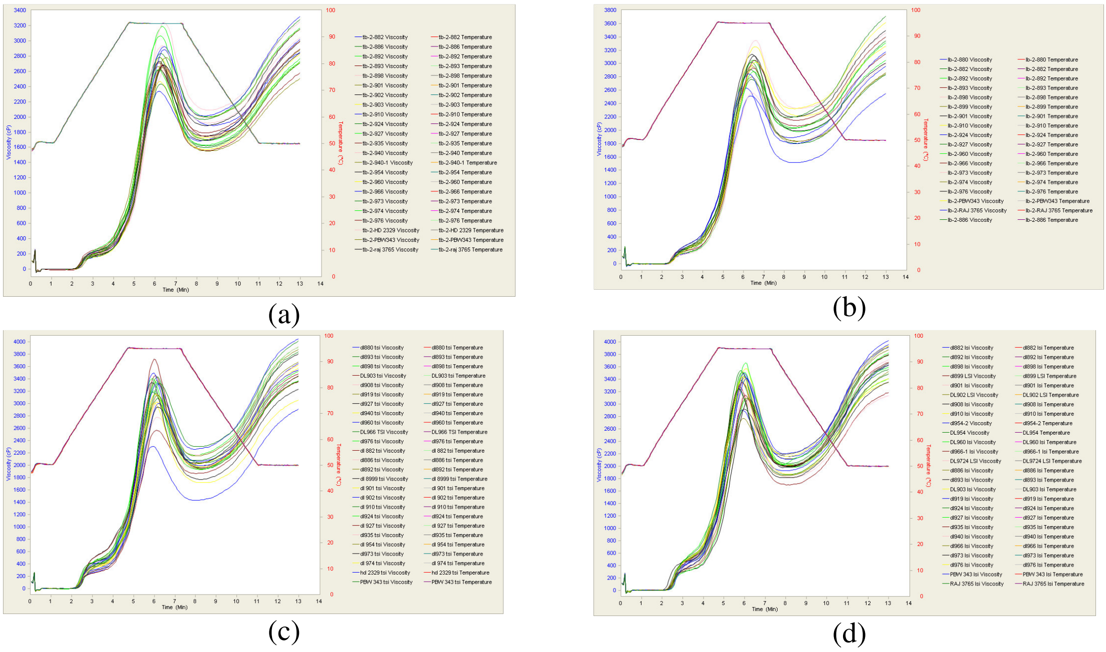


Figure 1. RVA profile of some wheat genotypes grown under: (a) timely sown irrigated environment at Pusa (Bihar), (b) late sown irrigated environment at Pusa (Bihar), (c) timely sown irrigated environment at New Delhi. (d) late sown irrigated environment at New Delhi.

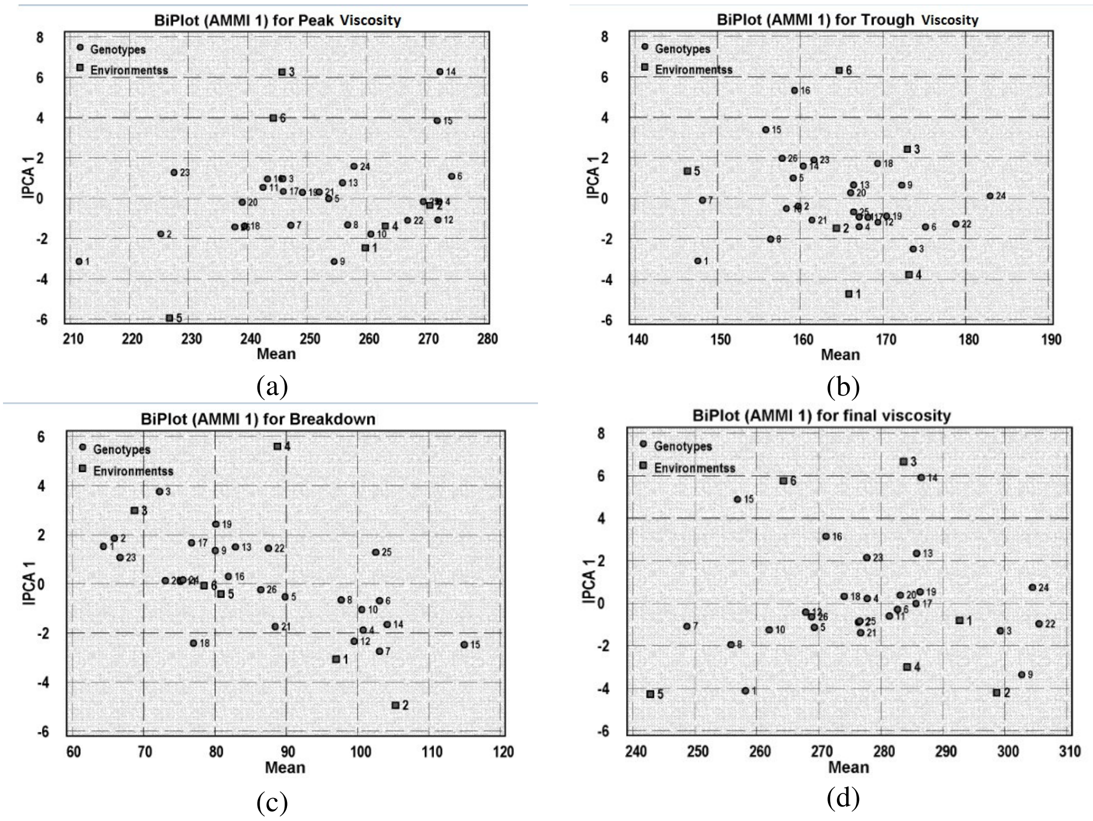
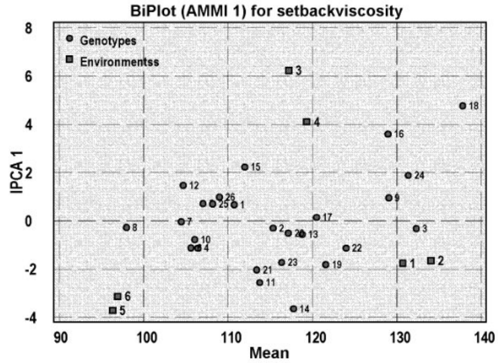
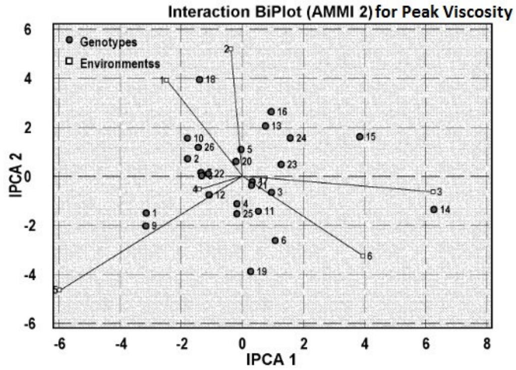


Figure 2. AMMI Biplot I for: (a) Peak Viscosity, (b) Trough Viscosity, (c) Breakdown Viscosity, (d) Final Viscosity and (e) Setback Viscosity. the genotypes are labelled as 1-DL880,2-DL882,3-DL886,4-DL892,5-DL893,6-DL898,7-DL899,8-DL901,9-DL902,10-DL903,11-DL908,12-DL910,13-DL919,14-DL924,15-DL927,16-DL935,17-DL940,18-DL954,19-DL966,20-DL960,21-DL974,22-DL976,23-DL973,24-PBW343, 25-HD2329 and 26-RAJ3765. **Figure 2 continued…**



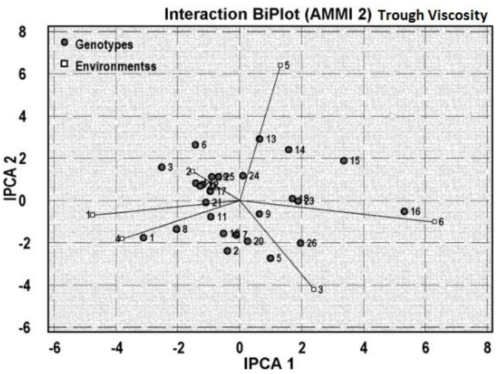
(e)

Continued of Figure 2.



(a)

Figure3



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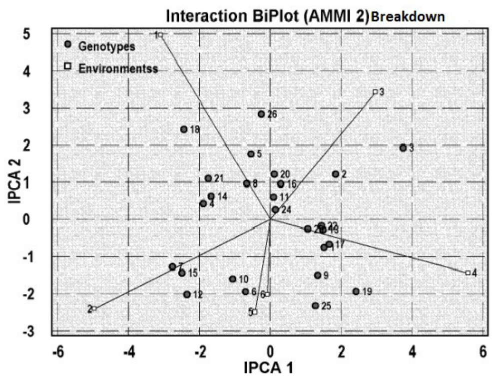

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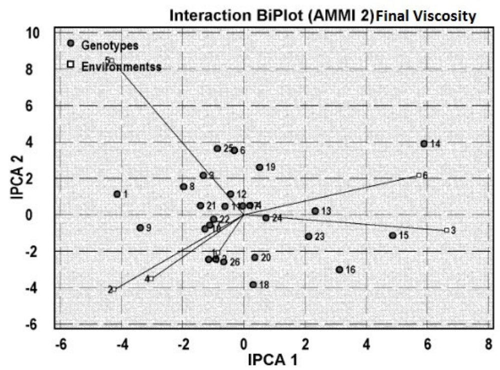

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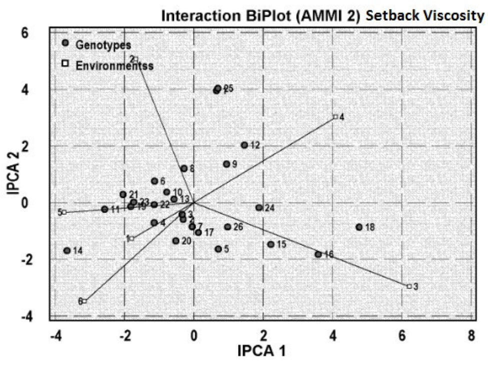

(e)

Figure 3. Interaction Biplot (AMMI II) for: (a) peak viscosity, Trough Viscosity, (c) Breakdown Viscosity, (d) Final Viscosity and (e) Setback Viscosity. Interaction BIPLOT (AMMI II) for starch pasting characteristics across environments. the genotypes are labelled as 1-DL880,2-DL882,3-DL886,4-DL892,5-DL893,6-DL898,7-DL899,8-DL901,9-DL902,10-DL903,11-DL908,12-DL910,13-DL919,14-DL924,15-DL927,16-DL935,17-DL940,18-DL954,19-DL966,20-DL960,21-DL974,22-DL976,23-DL973,24-PBW343, 25-HD2329 and 26-RAJ3765.

and positive IPCA1 scores, while the genotypes DL 901, DL 902, DL 903, DL 976, DL 892, DL 910 showed high PV and negative IPCA 1 scores. The genotypes DL 954, DL 899, DL 882, and DL 880 showed lower PV and negative IPCA1 scores. Genotypes DL 893, HD 2329, DL 892, DL 974, DL 966, DL 940 and DL 960 showed high mean PV and IPCA1 scores close to zero indicating their stability. These genotypes can be utilized in the improvement of starch pasting properties. Interaction biplot (AMMI II) revealed that genotypes DL 940, DL 974, DL 960 were found to be less sensitive to the environmental forces (Figure 3-a). The genotypes DL 924 showed favourable response to Env3, while the genotypes DL 898 and DL 960 were responsive to Env6. The genotypes DL 910, DL 892, DL 940, DL 908, PBW 343 and DL 902 were suitable for Env5 and 6 at Pusa (Bihar) and the genotypes DL 960, DL 976, DL 903, Raj 3765 showed favourable response under TSI and LSI environments at New Delhi with respect to PV.

Trough Viscosity (TV)

TV indicates the ability of flour to withstand heating (usually 95°C) and shear stress. Higher trough viscosity is desirable. The mean of TV for different genotypes across locations was 164.61 RVU with a range between 147.64 RVU (DL 880) and 182.97 RVU (PBW 343). Across locations, minimum average TV of 146.40 RVU was observed for Env5 and maximum average TV of 173.19 RVU for Env4 (Table 3). AMMI analysis showed that GEI accounted for the largest proportion (40.44%) of the SQ followed by environments (31.76%) and genotypes (27.80%). Further, partitioning of GEI component into principal component axes revealed that PCA I covered 47.20% of the GEI sum of squares, while the second and third principal component axes (PCA II and PCA III) explained further 27.07 and 13.27% of the SQ of this interaction. The genotypes DL 880, DL 899, DL 901, DL 903 and DL 882 recorded lower TV values across locations (Figure 2-b). Interaction biplot (AMMI II) for TV indicated that the environments were highly diverse and most of the genotypes showed specific adaptation (Figure 3-b). The genotypes DL 940, DL 974, DL 908 and DL 902 were plotted close to origin and were relatively insensitive to the environmental interactive forces. At New Delhi, the genotypes DL 974, DL 893, DL 960, and DL 899 were found suitable for TSI, while the genotypes DL 901, DL 899, DL 910, DL 978, and DL 892 were responsive to LSI environment. At Pusa (Bihar), the genotypes DL 919, PBW 343, DL 924, DL 927 under TSI and DL 901, DL 973 and DL 927 showed specific adaptation under LSI.

Breakdown Viscosity (BV)

Wide diversity in BV was observed with a mean of 86.57 RVU ranging between 64.39 RVU (DL 880) and 114.96 RVU (DL 927) across locations (Table 3). Differential response of genotypes to environments was observed. The genotypes DL 892, DL 898, DL 899, DL 903, DL 924, DL 927 and HD 2329 showed more than 100 RVU for BV across the locations and environments. Genotypes accounted for the largest proportion (44.0%) of the SQ for BV followed by environments (33.30%) and GEI (21.59%). Further, partitioning of GEI component into principal component axes revealed that PCA I covered 38.39% of the GEI sum of squares while the second and third principal component axes (PCA II and PCA III) explained further 20.66 and 16.54% of the SQ of this interaction. AMMI I biplot revealed that genotypes DL898, DL 902, DL 903, DL 924 and DL 927 showed high BV over locations and environments (Figure 2-c). Genotypes DL 899, DL 910, DL 927 and HD 2329 were found promising under TSI condition at both locations for BV. AMMI II biplot showed that genotypes PBW 343 and DL 908 were plotted close to the origin followed by DL 973 which were relatively stable across environments tested (Figure 3-c). The environments in which genotypes were specifically adapted were found to be highly divergent. The genotypes DL 960, DL 935, DL 901, DL 954, Raj 3765 and DL 893 were found to be suitable under TSI and the genotypes DL 899, DL 927, DL 910, DL 903, DL 919, DL 940, DL 966 were found to responsive under late sown

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condition at New Delhi. The genotypes DL 903, DL 898 and DL 910 were found suitable under TSI and LSI at Pusa (Bihar).

Final Viscosity (FV)

The FV of all the genotypes was higher than PV, except in DL 910 and DL 927 where there was decreased FV. Across locations, minimum average FV of 242.9 RVU was observed for Env5 and maximum average FV of 298.71 RVU for Env2 (Table 3). Environments accounted for the largest proportion (43.07%) of the SQ followed by GEI (30.84%) and genotypes (26.09%). Further, partitioning of GEI component into principal component axes revealed that PCA I covered 38.15% of the GEI sum of squares, while the second and third principal component axes (PCA II and PCA III) explained further 30.77 and 15.84% of the SQ of this interaction. AMMI I biplot showed that the genotypes DL 976, PBW 343, DL 902, DL 940, DL 966, DL 908 showed high FV (Figure 2-d). Interaction biplot (AMMI II) showed that the genotypes DL 908, DL 910, DL 892, DL 940, PBW 343, DL 974 and DL 976 were close to the origin and stable across environments (Figure 3-d). The genotypes DL 960, Raj 3765, DL 954, DL 882, DL 919, and DL 927 were found responsive to TSI, while the genotypes DL 954, DL 960, Raj 3765 and DL 902 were found suitable for LSI at New Delhi. At Pusa (Bihar) the genotypes HD 2329, DL 898, DL 966, and DL 901, DL 886 showed promise under TSI, while DL 919, DL 924, DL 898, DL 966 were found suitable for LSI.

Setback Viscosity (SV)

SV is a measure of recrystalization of gelatinized starch during cooling. Mean SV ranged from 97.96 RVU (DL 901) to 137.81 RVU (DL 954) with an average of 115.79 RVU. Across locations, minimum average SV of 96.38 RVU was observed for Env5 and maximum average SV of 134.07 RVU for Env2 (Table 3). Environments accounted for the largest proportion (52.48%) of the SQ followed by genotypes (23.89%) and GEI (23.65%) for SV. Further, partitioning of GEI component into principal component axes revealed that PCA I covered 47.58% of the GEI sum of squares while the second and third principal component axes (PCA II and PCA III) explained further 21.61 and 11.91% of the SQ of this interaction. AMMI I biplot showed that the genotypes DL 954, PBW 343, DL 935, DL 886, DL 902, DL 940, DL 976, DL 910, DL 966, DL 960 possessed higher SV (Figure 2-e). AMMI II interaction biplot revealed that the genotypes DL 892, DL 927, DL 935, DL 954, PBW 343, Raj 3765 were responsive to TSI, while the genotypes DL 902, DL 910, HD 2329 were favorable to LSI at New Delhi (Figure 3-e). The genotypes DL 974, DL 976, DL 973, DL 908, DL 919, DL 966 to TSI and DL 882, DL 886, DL 899, DL 940, DL 960 were responsive to LSI at Pusa (Bihar).

Correlation among Starch Pasting Characteristics

Correlation coefficients among starch pasting characteristics are presented in Table 5. Significant positive correlations were found between PV and BV (r= 0.74, 0.87, 0.75, 0.68, 0.74, 0.40 at Env 1, Env 2, Env 3, Env 4, Env 5, Env 6 respectively $P< 0.001$), FV and TV (r= 0.78, 0.82, 0.62, 0.74, 0.81, 0.89 at Env 1, Env 2, Env 3, Env 4, Env 5, Env 6, respectively, $P< 0.001$) and SV and FV (r= 0.58, 0.92, 0.33, 0.45, 0.72, 0.83 at Env 1, Env 2, Env 3, Env 4, Env 5, Env 6, respectively, $P< 0.001$) in all the individual environments tested, while negative correlations were observed between BV and SV.

DISCUSSION

Although all flour pasting characteristics varied, BV and SV exhibited greater

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Table 5. Correlation coefficients among the pasting characteristics in the six environments.

	Env1					Env2			
	PV	TV	BV	FV		PV	TV	BV	FV
TV	0.43**				TV	0.32*			
BV	0.74***	-0.16***			BV	0.87***	-0.17		
FV	0.31*	0.78***	-0.26		FV	0.15	0.82***	-0.23	
SV	0.053	0.47***	-0.40**	0.58***	SV	0	0.54***	-0.22	0.92***
	Env3					Env4			
	PV	TV	BV	FV		PV	TV	BV	FV
TV	0.32*				TV	0.27			
BV	0.75***	-0.05			BV	0.68***	-0.23*		
FV	0.34*	0.62***	-0.02		FV	0.31*	0.74***	-0.2	
SV	-0.09	-0.04	-0.28*	0.33*	SV	0.08	0.47***	-0.17	0.45**
	Env5					Env6			
	PV	TV	BV	FV		PV	TV	BV	FV
TV	0.67***				TV	0.55***			
BV	0.74***	0.09			BV	0.40***	-0.52***		
FV	0.75***	0.81***	0.17		FV	0.44*	0.89***	-0.57***	
SV	0.35*	0.45*	-0.04	0.72***	SV	0.15	0.65***	-0.54***	0.83***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

variability across environments relative to PV, TV and FV. Sarkar *et al.* (2014) also reported that association of SV viscosity with other quality parameters [Thousand Kernel Weight-TKW, KH- Kernel Hardness, Sedimentation Value (SV), Water Absorption Capacity (WAC), Dough Development Time (DDT), Dough Stability (DS) and Degree of Softening (DSo)] varied when grown over five locations, which might be related to the influence of growth environment, growing season, and year to year variations in weather. The mean PV under late sown conditions was more than the timely sown condition at both locations, indicating this trait being influenced by the time of sowing and environmental fluctuations. Tester and Karkalas (2001), Geera *et al.* (2006), Buresova *et al.* (2010), Thitisaksakul *et al.* (2012), Brennan *et al.* (2012), Rosicka-Kaczmarek *et al.* (2013) and Siebenmorgen *et al.* (2013) also reported that the genotypes, growth locations, and crop years have significant influence on starch pasting properties. PV is indicative of water binding capacity of the flour and the ease with which starch granules are disintegrated. The amylose component of the starch retrogrades more readily than amylopectin due its linear structure. It is well established that wheat samples with high breakdown impart the low chewiness and firmness to the noodles that are desirable (Miskelly and Moss 1985; Konik *et al*., 1994). High SV is also an indication of the amount of swelling power of the starch and is usually related to the amylose content of the starch. The joint use of HPV, CPV, breakdown and setback values along with the PV is recommended in wheat breeding to identify genotypes with desirable end use traits. In the present study, higher pasting characteristics were observed among the genotypes indicating the suitability of these genotypes for processing which is in agreement with Crosbie (1991). Sasaki and Matsuki (1998), Zhao *et al.* (1998), and Copeland *et al.* (2009) reported that lower amylose increases swelling volume and PV and decreases FV of the RVA profile. The increased amylopectin fraction of starch in the genotypes DL 910 and DL 927 might

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have resulted in the lower FV. In the present study, starch pasting properties serve as indirect selection for amylose and amylopectin proportions of the starch and will be further useful for predicting the end product quality. Wheat varieties/breeding lines with higher amylose contents and lower PV than FV were found suitable for noodles (Arachichige *et al*., 2005). Higher breakdown values were recorded in DL 924 and DL 927 and this probably was due to more amylose leaching out during mechanical shear stress. It is also evident from the BV values wherein during holding period of the test when the sample is subjected to constant high temperature and mechanical shear stress starch granules are disintegrated and amylose molecules will leach out into the solution. Morris *et al.* (1997) also reported that growth environment had significant impact on pasting properties. Bhattacharya *et al.* (1997) reported that genotypes with fairly high rate of breakdown are potentially useful for improving white salted noodles. Viscosity at the end of the test is known as FV and it is the most commonly used parameter to define sample quality as it indicates the ability of the material to form a viscous paste after cooking and cooling. After hot paste viscosity period, the sample is subsequently cooled and re-association between starch molecules especially amylose molecules occurs. This phase of the pasting curve is commonly referred to as the setback and involves retrogradation or reordering of the starch molecules. In most of the genotypes, the FV was higher than the PV, indicating that genotypes possess more amylopectin fraction. The genotypes DL 910 and DL 927 possessed PV higher than the FV indicating higher amount of amylose fraction of starch. The pasting characteristics, especially the PV and the rate of viscosity breakdown after gelatinization, have been widely used to predict the eating quality of Japanese white salted noodles (Blazeka and Copeland, 2008). Kim *et al*. (2003) reported that baking quality of wheat cannot be predicted by protein concentration and the interactions between protein and other fractions (amylose and amylopectin) of wheat flours is also important to explore the possibility of commercial use in novel applications. Selection for PV, SV and FV would also simultaneously improve BV, TV and SV, respectively, due to their positive correlations among themselves. Sarkar *et al.* (2014) reported that PV, TV and BV of the starch pasting characteristics showed significant and positive associations with grain quality parameters, namely, TKW, KH, SV, WAC, DDT, DS and DSo as well as among starch pasting properties, except SV which varied across locations. In the present study, the positive associations between the PV, BV, TV, and SV could serve as important selection tool that can be utilized in selection and simultaneous improvement in breeding programs for starch quality improvement.

It is evident from the study that quality traits are highly complex in nature and are highly influenced by the environment. Stability of genotypes for all traits measured varied among the genotypes. Some genotypes were more stable for one trait and unstable for others, suggesting that the genetic factors involved in G×E differed between traits. This is especially remarkable for the genotypes which have the same ancestors and are genetically very closely related. The promising genotypes which are consistently exhibiting superior performance can be recommended only for specific regions where they can attain high performance with regard to starch characteristics independent of the seasonal and location effects. The genotypes DL 886, DL 902 and PBW 343 possessed high SV under TSI and LSI condition at both locations. The genotypes DL 940, DL 974, DL 908 and DL 902 for TV, PBW 343 and DL 908 for BV, DL 908, DL 910, DL 892, DL 940, PBW 343, DL 974 and DL 976 for FV were found stable across the environments tested. In the present study, different effects of genotype and environment on starch viscosity characteristics and greater GEI were observed. Therefore, both proper cultivars and their most suitable growth locations should be selected to meet the requirements of the starch traits since the genotype has specific adaptability to growth location.

CONCLUSIONS

The present study has implications for wheat breeders and processors. The genotypes DL 940, DL 974, DL 908 and DL 902 for TV, PBW 343 and DL 908 for BV, DL 908, DL 910, DL 892, DL 940, PBW 343, DL 974 and DL 976 for FV were identified to be stable across the environments tested, which can be utilized in breeding for quality improvement programmes specific to starch pasting characteristics. However, wheat planted in different times will vary greatly in starch properties. It is apparent that even the same variety harvested during different seasons or from different locations does not result in the same starch quality. Hence, wheat breeders should carefully select the starch properties of breeding lines in suitable conditions as well as stable genotypes which are widely adaptable. So, for successful production of high quality wheat, both proper cultivar and its most suitable growth locations should be considered.

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تجزیه تغییرات و پایداری خاصیت های خمیری نشاسته بین تیپ های جدید گیاهی گندم اصلاح شده (NPT)

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چکیده

خاصیت خمیری یکی از مهمترین خاصیت های نشاسته گندم است که کیفیت و عملکرد آرد ژنوتیپ های گندم را تعیین می کند.در این پژوهش، ۲۳ تیپ جدید گیاهی (NPT) گندم اصلاح شده همراه با سه شاهد متمایز (PBW 343، HD 2329 و Raj 3765) در آزمون های چند منطقه ای بررسی شدند تا تغییرات در خاصیت خمیری نشاسته آن ها و نوسانات ناشی ازاثر محیط رشد ارزیابی شود.

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هرچند همه ویژگی های خاصیت خمیری تغییر نشان می داد، گرانروی(ویسکوزیته) نقطه شکست (breakdown viscosity) یا BV و گرانروی برگشتی (setback viscosity) یا SV در همه محیط های مطالعه شده تغییرات بیشتری در مقایسه با گرانروی در نقاط اوج(peak)، پست (trough) و نهایی (FV) نشان دادند. همچنین، در مورد خصوصیات خمیری نشاسته، تجزیه آثار اصلی جمع پذیر واثر متقابل ضرب پذیر (AMMI) حاکی از آن بود که بین ژنوتیپ و محیط (GEI) اثرات متقابل معنی داری وجود داشت. در مورد گرانروی نقطه اوج، ژنوتیپ ها بخش عمده (۳۹/۷۸٪) مجموع مربعات را توجیه می کرد و بعد از آن شرایط محیطی (۳۳/۳٪) و اثر متقابل ژنوتیپ و محیط (۳۳/۳٪) . در مورد گرانروی نقطه پست (TV)، اثر متقابل ژنوتیپ و محیط بیشترین بخش (۴۰/۴۴٪) مجموع مربعات را تبیین می کرد و بعد از آن شرایط محیط (۳۱/۷۶٪) و ژنوتیپ (۲۷/۸۰٪) . همچنین، ژنوتیپ ها بیشترین بخش (۴۴٪) مجموع مربعات مربوط به گرانروی نقطه شکست (BV) را تبیین می کرد و بعد از آن متغییر محیط (۳۳/۳٪) و GEI(۲۱/۵۹٪). در مورد FV، متغییر محیط بیشترین قسمت (۴۳/۰۷٪) مجموع مربعات را توجیه می کرد و به دنبال آن GEI(۳۰/۸۴٪) و ژنوتیپ (۲۶/۰۹٪). بر اساس نتایج، شرایط محیطی بیشترین بخش (۵۲/۴۸٪) ازمجموع مربعات SV را تبیین می کرد و بعد از آن ژنوتیپ (۲۳/۸۹٪) و GEI(۲۳/۶۵٪) قرار داشتند. هر چند اثر متقابل محیط و ژنوتیپ تفاوت زیادی نشان میداد، بعضی ژنوتیپ ها ظاهرا به طور ویژه ای با شرایط محل رشد سازگاری داشتند. همچنین، ضرایب همبستگی بین ویژگی های خمیری نشاسته آشکار ساخت که بین PVبا BV و FV و TVو نیز بین SVبا FVدر هر یک از محیط های اجرای آزمایش رابطه معنی دار و مثبتی وجود داشت. بر این اساس، گفتنی است که در برنامه بهنژادی برای بهبود کیفیت نشاسته، می تواند در بهگزینی همزمان با اصلاح بذر ابزار مهمی برای بهگزینی باشد.

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