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Understanding the *chapatti making* attributes of the Indian wheats – II: The rheological basis

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Abstract
The concept of good *chapati* varies from individual to individual and depends mainly on the rheological properties of the dough used to prepare the *chapaties.* The research project was largely built around two type of plant meterials, the tall traditional cultivars of the pre-dwarfing era, and three backcross recombinant populations (BC_1F_5 generation) C 273/PBW 343//PBW 343 (70 lines), C 306/PBW 534//PBW 534 (70 lines) and C 518/ PBW 343//PBW 343 (80 lines). Association of traits studied with *chapati* score in set of cultivars and genetic stocks Starch pasting characteristics showed mild negative correlation with *chapati* quality, which is again contrasting, to the requirements of bread making. The correlations were not consistent over years possibly due to environmental factor (temperature, rainfall, fertilizer and irrigations etc.) and due to change in the constitution of the set. Similarly mixographic traits showed negative association *chapati* making quality. The correlations which prevail in the populations carry much greater weight as these have persisted over several rounds of recombination and are likely to reflect under lying causes of superior *chapati* quality. As various components of *chapati* quality would be disassembled, the relative levels of correlations for individual traits would be uncovered. Among the starch pasting characteristics, final viscosity and setback were consistently negatively associated with the *chapati* making quality. In case of the mixographic traits, mixing tolerance index is negatively associated whereas rate of dough development has consistent positive correlation with *chapati* quality.

Keywords: Chapati making quality, Mixograph, Rheological properties, Starch pasting, Wheat

INTRODUCTION

Wheat is the leading cereal grain produced, consumed and traded in the world. It is the second most important crop after rice in India and grown on around 30 mha area. In India, the annual wheat production was 98.37 million tonnes (2016-17) whereas global wheat production was estimated at 735.3 million tonnes during 2015-16, (Anonymous, 2016). Since there are large differences in grain quality requirements for major baked food types such as bread, pastries, noodles, and cookies etc., the grain quality required to produce flat bread, like Indian *chapati* is different from that required to make a pan type bread. The technological interventions for processing of wheat floor depend mainly on the reheological properties of the dough used to prepare the *chapaties.*

Sinha and Singh (1974) studied the rheological characteristics of 25 varieties from the four wheat growing states on the farinograph and categorized those for different purposes. Studies on the rheological aspects of improved wheat varieties were conducted by Austin and Hanslas (1983). The authors observed that for *chapati* making medium strong dough is the ideal choice. Rao *et al* (1989) studied the effect of damaged starch on the functional quality characteristics of whole meal flour used for *chapati*-making. Damaged starch in the flour was positively correlated to the diastatic activity and flour water absorption.

Saxena *et al* (1997) tried to correlate the physico-chemical and rheological characteristics of wheat flour with the *tandoori roti* quality, using eight commercial wheat cultivars (PBW 154, PBW 175, PBW 229, PBW 138, WL 1562, CPAN 3004, GW 180 and K 8804) grown at one location. Varieties with high water absorption capacity gave *roties* with better quality. Rheological properties were improved upon adding isolated arabinoxylans of good *chapati* making varieties to flours. Interestingly, addition of isolated arabinoxylans of good *chapati* making varieties to poor *chapati* making varieties had significantly improved the chapati quality (Das *et al,* 2006; Hemalatha *et al,* 2006). Sensory studies showed that *chapatis* prepared from flour added with arabinoxylans of good *chapati* varieties had soft texture and high overall quality scores. (Hemalatha *et al* 2013) reported that due to their high water binding capacity water soluble arabinoxylans are known to play an important role in rheological properties of dough, retrogradation of starch and breadmaking quality. Addition of water soluble arabinoxylans to refined wheat flour significantly increased the farinograph water absorption and dough development time and also increased bread quality parameters like loaf volume, crumb structure and de- creased staling characteristics. Sasaki *et al* (2008) determined visco-elastic properties of wheat flours, starch and gluten-starch mixture with varying amylose content and reported that the amylase content strongly affected rheological properties of flour gels. Seib (2000) reported that the elastic response of starch gels increased with increase in amylose content in the continuous phase, the volume fraction of swollen granules, rigidity of dispersed granules and adhesion between dispersed and continuous phases. Wheat cultivars with high-amylose have been used to increase resistant starch in breads (Hung *et al* 2005) and to improve the texture of noodles (Morita *et al* 2003). In addition, Blazek and Copeland (2008) and Singh *et al* (2011) reported that non-starch constituents, e.g. proteins, lipids and non-starch polysaccharides also influence rheological/viscoelastic properties of wheat flours.

The present study was taken up with the aim to understand the reheological characteristics of wheat dough and their correlation with *chapati-making* properties. Genotypes known to have good *chapati-making* characteristics are known to be grown under different production conditions. Since the growing environment plays an important role for the expression of multigenic traits such as *chapati* quality, studies in one environment with the genotypes known to have good quality will be helpful in understanding this trait and its association with end use quality.

MATERIALS AND METHODS

Plant material used in study: The research project was largely built around the tall traditional cultivars of the pre-dwarfing era, which were known to excel for *chapati* quality. These included C 306, C 518 and C 273. The few cultivars that had emanated from crosses of these superior *chapati* quality wheats with dwarf wheats formed another important component of this set and included WG 357, PBW 175, PBW 154, PBW 226. Lok 1 and others as mentioned in the table 2 & 3. All the plant material was sown in a randomized complete block design in three replications with a plot size of 2 m length and four rows per plot. To represent the second set of materials, three backcross recombinant populations (BC_1F_5 generation) derived from C 273/PBW 343//PBW 343 (70 lines), C 306/PBW 534//PBW 534 (70 lines) and C 518/PBW 343//PBW 343 (80 lines) were studied (details discussed in part I).

Observations recorded:

Rheological properties based on mixographic studies: The mixograph was operated using AACC (1990) approved method with 35 g flour (14% moisture basis) The mixer was run for exactly 7min using 63 percent absorption. The spring tension was kept at No.9. The curves were interpreted for different parameters as follows: -

Mixing time: The Time taken by the curve from the start of the mixing to reach the peak consistency

Dough Strength: It is measured as the height of the curve in cm. measured from the center of the curve at peak to the base line.

Dough development area (cm^2): It is the area under the curve measured from the center of the curve upto the base line, from start of mixing upto the peak is reached. It was measured using a planimeter.

Area under curve: It is taken from the center of recorded curve to base line, from beginning of mixing until. The mixing of 7 mins has elapsed. It was measured using "Planimeter" and is termed as the baking strength.

Rate of dough development: It is the measure of angle formed by the line through the center of the ascending curve with the one drawn through the center of the curve at the peak and parallel to the base line.

Rate of dough weakening: It is the angle formed by the line through the centre of the descending curve with one as above.

Mixing tolerance: It is the angle enclosed by the lines drawn through the ascending and descending curve at peak point.

Starch pasting characteristics: The starch pasting characteristics were estimated with Starch Master using the following procedure: Allow the instrument to warm up for 30 min prior to the experiment. Weigh 4.0 (14% moisture basis) of wholemeal in a consister and add 25.0 ml distilled water into the consister. Place the paddle into the consister and vigorously jog the blade through the sample up and down 10 times or until it mixes uniformly. Insert the consister into the pre-adjusted instrument using the standard profile given below (Table 1):

The measurement cycle was initiated by depressing the motor tower of the instrument. The canister on completion of test was removed and discarded. The gelatinization temperature, peak viscosity, breaks down value, hold viscosity, setback value and final viscosity from the instrument were recorded.

Chapati-making characteristics: For baking *chapaties* the method used in the quality laboratory Department of Plant Breeding and Genetics was employed (Kumar *et al*, 2018). The chapati score was calculated using the parameters Dough stickiness (5), Puffing of *chapatti* (5), Texture of *chapati* (5), Color of *chapati* (5), Taste of *chapati* (5), Flavor of *chapati* (5) and Texture of *chapati* after 2 hrs (5). The total score was finally calculated out of a maximum of ten.

Data analysis

Analysis of variance: The material had been planted in a randomized complete block design. The analysis of variance for different traits was done as per the following model:

Equation I: $Y_{ij} = m + t_i + b_j + e_{ij}$

Y_{ij} = observation obtained from the i-th treatment and j-th block.

m = general mean

t_i = the effect of i-th treatment

b_j = the effect of j-th block

e_{ij} = error associated with i-th treatment and j-th block

The analysis of variance based on the above model takes the following form:

Critical Difference (CD) to compare two genotypes was computed as follows:

Equation II:

$$CD = \sqrt{\frac{2MSE}{r}} \times t_a \,(r-1)\,(g-1)$$

Where, a = level of significance

Correlation coefficients: The correlation coefficient (r) between two different observations (say X and Y) was calculated using the following formula:

Equation III:

$$r_{xy} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y}$$

Where: x and y = means of variables

s_x and s_y = standard deviations of x and y

n = population size.

Table 1. The profile of the method used for determining the starch pasting characteristics.

Time	Temp	Values
00:00:00	Speed	960 rpm
00:00:10	Speed	160 rpm
00:00:10	Temp	50̊° C
00:01:00	Temp	50°C
00:04:42	Temp	95°C
00:07:12	Temp	95°C
00:11:00	Temp	50°C
Idle Temperature		: 50 ± 1°C
End of Test		: 13 min
Time between readings		: 4 sec

RESULTS AND DISCUSSION

Genetic variation for *Chapati* score: *Chapati* score is a composite trait and is based on dough handling (stickiness of the dough), puffing of *chapati*, texture, taste, flavour and colour of the *chapati.* Conventionally, a *chapati* score above 8 (out of 10) represents excellent *chapati* quality. Significant genotypic differences were observed for *chapati* score of the genotypes in both the years (Table 3a and b). The *chapati* score showed variation between the groups of genotypes, with the tall wheats of pre dwarfing era excelling over other groups. The tall varieties not only established themselves as a distinct group with highest *chapati* score (Table 4 and 5). The genetic stocks, on the other hand again failed to give good *chapaties* thus emphasizing the fact that good *chapati* quality resulted from a combination of different component traits and not because of one or two traits. The advanced breeding lines in this season again showed an intermediate *chapati* score.

Similarly, significant genotypic differences (5% level of significance) were observed for *chapati* score in all the three populations *viz:* 'A' (C273/PBW343//PBW343), 'B' (C306/PBW534//PBW534) and 'C' (C518/PBW343//PBW343) (Table 6a, b and c). Details of variation in *chapati* score have already been discussed in the part I.

Genetic variation for mixographic characteristics: The mixograph was initially developed to determine precisely the mixing requirements of dough. But in addition the mixograms are interpreted for other parameters like strength of dough, mixing tolerance and baking strength etc. Ideally a good baking wheat variety should have a shorter mixing time and high dough strength, baking strength and mixing tolerance values. The set of genotypes exhibited highly significant variation for the mixographic characteristics during both sea-

Table 2. Analysis of variance for randomized block design.

Source	d. f.	Sum of Squares	Mean sum of squares	F-ratio
Replications	r-1	RSS	MSR	MSR/MSE
Treatments	g-1	GSS	MST	MST/MSE
Error	(r-1) (g-1)	SSE	MSE	

Where, r = no. of replications, g = no. of genotypes sons (Table 3a and b). The mean performance of the set of genotypes is given in table 4 and 5. The mixographic characteristics of the three recombinant populations ‘A’, ‘B’ and ‘C’ are given in table 7, table 8 and table 9 respectively. The detailed results are explained below.

Mixing time is the time in minutes required by the wheat flour produce optimally developed dough when mixed with water and this is indicated by the peak in dough consistency. In first year the genotypes in the tall varieties group took less time to attain the peak than the genotypes in other groups. The tall wheat C 273 however gave a high value of 2.27 min, which is significantly higher than the group average of 1.70 min. The lowest value of mixing time for first year was recorded in the tall varieties group for C 518 (1.27 min). The genetic stocks, advanced lines and the commercially grown varieties showed a mixing time which was significantly higher than tall wheats. Numerically the genetic stocks and the advanced lines gave higher values than the commercial wheats, with the stock DI 9 (a derivative of C 306) recording the highest value of 3.13 min for the season. PBW 343, the commercially grown wheat, also gave lowest value of mixing time i.e., 1.27 min. The trends for mixing time, however, got reversed in second year. The commercially grown wheats along with released varieties known for quality gave low values as compared with other groups. Variety PBW 502 of commercial group gave a value as low as 1.05 min of mixing time. However the lowest value of mixing time was recorded to be 1.0 min for Lok 1 from the released varieties known for quality group. The genetic stocks again gave high values of mixing time with WH 1003 (3.03 min) recording the highest value for the season. The tall wheats group, however, followed the trend from last season giving similar values of mixing time. This is indicative of the fact that mixing time in tall wheats was stable and was not affected by the seasonal changes. The lower mixing requirements registered by the tall varieties indicate a weaker gluten type which did not change with environmental changes that occurred over the two years of the study. The mixing time was found to be normally distributed in all the recombinant populations. The distribution was skewed towards higher side in population ‘B’ and towards lower side in population ‘C’. The variation in mixing time was found to be higher than the parents in all the populations. The population means for mixing time were found to be non-overlapping. In population ‘A’ 68 genotypes out of 70 were found to have a mixing time more than that of the parent C 273 (2.15 min) and 2 genotypes were observed in the parental range. However none of the genotypes were found to be inferior to PBW 343 (1.25 min). In population ‘B’ all the 70 genotypes gave values higher than that of

Table 3a. Analysis of variance of cultivars and genetic stocks for Mixographic and Starch pasting characteristics during first year.

Source of Variation	Degree of freedom	Mean squares												
		MTi	DS	RDD	RDW	MTo	DDA	BS	PT	PV	HV	FV	Sb	Bd
Replication	2	0.20*	0.08**	6.89*	11.26**	6.92*	6.29*	11.51**	0.81	85472	18845.33	233066.7*	16393.33	6368.00
Genotypes	23	1.04**	1.59**	295.30**	104.65**	295.30**	74.41**	75.77**	1.60**	760760.6**	418350.1**	738291.1**	78935.07**	118197.00**
Error	46	0.06	0.01	1.79	1.45	1.79	1.29	1.93	0.51	33740.04	25385.4	55592.8	13624.06	4895.19

* Significant at 5% level, ** Significant at 1% level, MTi = mixing time (min), DS = Dough strength (cm), RDD = rate of dough development (°), RDW = Rate of dough weakening (°), MTo = Mixing tolerance (°), DDA = Dough development area (cm^2), BS = Baking strength (cm^2), PT = Paste temperature (°c), PV = Peak Viscosity (rpm), HV = Hold viscosity (rpm), FV = Final Viscosity (rpm), Bd = Breakdown (rpm), Sb = Setback (rpm)

Table 3b. Analysis of variance of cultivars and genetic stocks for Mixographic and Starch pasting characteristics during second year.

Source of Variation	Degree of freedom	Mean squares												
		MTi	DS	RDD	RDW	MTo	DDA	BS	PT	PV	HV	FV	Sb	Bd
Replication	2	0.04	0.02	2.72	4.87	2.77	5.93	6.01	4.92*	109472	44576.00	3818.67	573.33	2433.33
Genotypes	23	0.82**	0.47**	72.71**	68.28**	72.71**	58.55**	56.14**	1.73*	289245.7**	300207.30**	398363.80**	51196.98**	100462.70**
Error	46	0.02	0.07	5.53	4.82	5.53	1.96	6.12	1.24	106152.8	41931.82	122588.80	55.45.62	1516.93

* Significant at 5% level, ** Significant at 1% level, MTi = mixing time (min), DS = Dough strength (cm), RDD = rate of dough development (°), RDW = Rate of dough weakening (°), MTo = Mixing tolerance (°), DDA = Dough development area (cm^2), BS = Baking strength (cm^2), PT = Paste temperature (°c), PV = Peak Viscosity (rpm), HV = Hold viscosity (rpm), FV = Final Viscosity (rpm), Bd = Breakdown (rpm), Sb = Setback (rpm)

Table 4. Mean performance of cultivars and genetic stocks evaluated for mixographic and starch pasting characteristics during first year.

Genotype	MTi	DS	RDD	RDW	MTo	DDA	BS	PT	PV	HV	FV	Bd	Sb	CS
C 273	2.27	6.40	39.33	33.33	140.67	18.67	42.67	68.27	2575.33	1606.33	2788.00	969.00	1181.67	7.9
C 306	1.67	6.33	40.67	28.00	139.33	15.00	43.33	68.47	2588.00	1679.67	3132.00	908.33	1452.33	8.1
C 518	1.27	6.33	46.67	27.33	133.33	9.00	39.00	68.67	2049.67	1227.67	2414.67	822.00	1187.00	8.0
C 591	1.77	5.60	37.33	15.33	142.67	13.00	41.33	68.90	3021.33	1911.67	3214.33	1109.66	1302.66	8.0
WG 357	1.53	7.23	50.33	34.00	129.67	13.00	48.67	68.00	2965.00	1777.67	2858.33	1187.33	1080.66	7.6
PBW 343	1.27	6.07	51.67	21.67	128.33	10.00	40.00	68.60	2866.33	1874.33	3240.67	992.00	1366.34	7.6
PBW 550	2.60	6.30	26.00	18.33	154.00	21.00	49.67	67.07	3193.00	2090.33	3375.33	1102.67	1285.00	7.4
PBW 502	1.40	5.53	34.67	33.00	145.33	9.33	39.00	69.03	2434.67	1730.67	2560.67	704.00	830.00	7.4
PBW 509	2.83	5.73	37.33	30.33	142.67	20.33	42.00	68.60	3208.00	1836.67	3059.00	1371.33	1222.33	7.6
PBW 554	2.10	7.03	41.67	28.33	138.33	17.33	48.00	68.33	2946.33	1720.33	2819.67	1226.00	1099.34	7.6
PBW 531	1.93	6.70	39.00	32.33	141.00	16.33	49.33	67.20	2698.00	1606.00	2553.33	1092.00	947.33	7.6
PBW 534	2.19	5.83	19.67	23.67	160.33	20.67	50.33	69.90	3580.00	2528.33	4154.00	1051.67	1625.67	7.5
Pusa 5-3	1.93	6.00	35.33	26.33	144.67	14.00	41.67	68.63	2609.33	1734.67	3131.00	874.66	1396.33	7.2
DI 105	1.70	5.70	46.33	18.67	133.67	11.67	44.33	69.03	2932.33	1868.00	3252.67	1064.33	1384.67	7.8
DI 9	3.13	4.97	16.67	13.33	163.33	18.00	42.00	67.63	2775.67	1585.33	3195.00	1190.34	1609.67	7.8
WH 423	2.07	5.90	28.00	23.33	152.00	12.33	40.33	68.13	1609.67	919.67	1827.67	690.00	908.00	7.7
WH 595	1.80	5.93	31.00	29.00	149.00	12.67	43.00	68.30	3455.00	2251.33	3409.67	1203.67	1158.34	7.6
WH 712	2.67	5.80	25.33	20.33	154.67	19.33	44.67	68.10	3317.33	2014.00	3247.33	1303.33	1233.33	7.5
KO 123	1.40	6.53	48.33	29.33	131.67	11.00	43.67	68.27	2380.00	1519.00	2805.33	861.00	1286.33	7.4
KYZ K2K 13	1.30	6.03	48.33	30.33	131.67	10.33	39.33	67.80	2194.00	1284.00	2292.00	910.00	1008.00	7.5
HD 2793	2.40	5.53	28.33	20.33	151.67	18.67	44.00	68.37	3042.33	2177.00	3525.00	865.33	1348.00	7.5
WH 800	1.63	5.87	42.00	24.67	138.00	11.67	51.33	66.70	3172.00	2133.67	3287.33	1038.33	1153.66	7.5
WH 1003	2.80	6.40	35.33	21.33	144.67	21.33	51.67	67.80	3266.67	2143.33	3431.33	1123.34	1288.00	7.4
Glupro	3.10	8.67	51.00	19.67	129.00	29.33	59.00	69.47	1861.33	1188.00	2348.33	673.33	1160.33	5.3
CD (5%)	**0.14**	**0.19**	**2.19**	**1.98**	**2.19**	**1.87**	**2.28**	**1.17**	**301.83**	**261.80**	**387.43**	**191.79**	**114.96**	**0.41**

MTi = mixing time (min), DS = Dough strength (cm), RDD = rate of dough development (°), RDW = Rate of dough weakening (°), MTo = Mixing tolerance (°), DDA = Dough development area (cm^2), BS = Baking strength (cm^2), PT = Paste temperature (°c), PV = Peak Viscosity (rpm), HV = Hold viscosity (rpm), FV = Final Viscosity (rpm), Bd = Breakdown (rpm), Sb = Setback (rpm), CS = *chapati* score

Table 5. Mean performance of cultivars and genetic stocks evaluated for mixographic and starch pasting characteristics during second year.

Genotype	MTi	DS	RDD	RDW	MTo	DDA	BS	PT	PV	HV	FV	Bd	Sb	CS
8A	1.69	5.23	23.00	22.67	149.33	12.67	43.00	68.57	3218.00	2452.67	4063.00	765.33	1610.33	7.9
9D	2.02	5.17	22.33	23.67	150.22	15.67	44.33	68.97	3508.67	2680.67	4427.33	828.00	1746.66	7.8
C 273	2.01	5.80	25.00	21.33	146.67	18.67	47.33	69.53	3190.00	2388.67	3914.67	801.33	1526.00	8.0
C 306	1.61	5.63	27.33	25.00	143.56	15.00	44.00	69.87	2927.00	2257.33	3956.33	669.67	1699.00	8.1
C 518	1.29	6.27	34.67	28.33	133.78	13.33	46.00	69.60	2694.33	2033.33	3750.00	661.00	1716.67	8.1
C 591	1.64	5.63	25.33	18.67	146.22	18.33	45.00	68.97	3493.67	2555.00	4252.33	938.67	1697.33	8.0
WG 357	1.43	5.97	32.00	30.33	137.33	11.00	43.00	69.00	2963.67	1924.67	3513.67	1039.00	1589.00	7.9
PBW 343	1.13	5.53	32.00	23.00	137.33	11.00	38.67	71.07	3399.00	2828.67	4396.67	570.33	1568.00	7.6
PBW 502	1.05	5.30	30.00	22.67	140.00	9.00	37.33	71.23	3128.00	2712.00	4126.00	416.00	1414.00	7.1
PBW 550	2.14	6.03	22.67	17.33	149.78	18.67	53.33	69.80	3536.67	2544.67	4162.67	992.00	1618.00	7.4
DBW 16	1.49	4.87	22.33	23.33	150.22	11.33	38.33	70.23	2973.00	2666.33	4255.00	306.67	1588.67	7.4
PBW 533	1.18	5.77	33.33	27.33	135.56	9.67	43.67	70.27	3010.33	2234.33	3579.33	776.00	1345.00	7.4
PBW 534	2.19	5.77	20.33	23.67	152.89	20.67	51.00	69.90	3580.00	2528.33	4154.00	1051.67	1625.67	7.3
PBW 554	1.87	4.90	22.00	21.00	150.67	17.33	51.00	70.63	3376.33	2482.33	4192.00	894.00	1709.67	7.6
HI 1418	1.17	5.77	33.00	24.00	136.00	10.00	41.67	71.13	2623.00	1891.33	3351.00	731.67	1459.67	7.8
HI 1479	1.47	5.40	25.00	16.33	146.67	12.33	41.67	69.67	3305.00	2319.00	3918.00	986.00	1599.00	7.5
PBW 154	1.69	5.60	25.67	21.00	145.78	13.00	47.00	69.63	3256.00	2374.00	4000.67	882.00	1626.67	7.2
PBW 175	1.53	5.77	27.67	26.33	143.11	13.00	48.33	69.13	3662.00	2738.00	4409.00	924.00	1671.00	7.3
PBW 226	1.36	6.00	26.67	27.00	144.44	12.33	44.00	69.93	2979.00	2006.33	3408.67	972.67	1402.34	7.3
LOK 1	1.00	5.97	30.67	27.33	139.11	14.00	41.33	68.90	3583.67	2612.67	4169.00	971.00	1556.33	7.9
KO 123	1.63	5.13	26.00	16.67	145.33	12.67	44.00	70.30	3336.33	2682.67	4658.33	653.66	1975.66	7.5
HD 2793	2.65	4.87	20.67	11.00	152.44	21.00	47.67	70.50	3340.33	2347.00	4569.33	993.33	2222.33	7.6
WH 712	1.95	5.83	24.33	13.33	147.56	18.67	51.33	70.87	3644.67	2695.00	4391.67	949.67	1696.67	7.3
WH 1003	3.03	5.20	14.33	21.67	160.89	27.33	50.33	69.67	3800.33	2941.67	4552.67	858.66	1611.00	7.4
CD (5%)	**0.23**	**0.43**	**3.86**	**3.61**	**3.86**	**2.30**	**4.06**	**1.32**	**535.36**	**336.47**	**575.32**	**95.04**	**63.99**	**0.31**

MTi = mixing time (min), DS = Dough strength (cm), RDD = rate of dough development (°), RDW = Rate of dough weakening (°), MTo = Mixing tolerance (°), DDA = Dough development area (cm^2), BS = Baking strength (cm^2), PT = Paste temperature (°c), PV = Peak Viscosity (rpm), HV = Hold viscosity (rpm), FV = Final Viscosity (rpm), Bd = Breakdown (rpm), Sb = Setback (rpm), CS = *chapati* score

Table 6a. Analysis of variance for starch pasting characters evaluated for C 273/PBW 343//PBW 343 population

Source of Variation	Degree of freedom	Paste Temperature	Peak Viscosity	Hold viscosity	Final Viscosity	Breakdown	Setback
Replication	2	0.33	140856.90	5781.33	212650.70	40017.78	19960.89
Treatment	71	3.41**	875789.30**	589117.90**	1544928.00**	147150.40**	455927.00**
Error	142	0.34	288621.80	156992.30	293514.20	37847.86	60351.20

* Significant at 5% level, ** Significant at 1% level

Table 6b. Analysis of variance for starch pasting characters evaluated for C 306/PBW 534//PBW 534 population

Source of Variation	Degree of freedom	Paste Temperature	Peak Viscosity	Hold viscosity	Final Viscosity	Breakdown	Setback
Replication	2	17.34	111459.60	171552.00	354133.30	69672.89	160981.30
Treatment	71	22.32	757208.30**	388919.00**	1468623.00**	312885.00**	505253.80**
Error	142	20.87	384099.60	101622.00	298525.30	200303.70	94611.53

*Significant at 5% level, ** Significant at 1% level

Table 6c. Analysis of variance for starch pasting characters evaluated for C 518/PBW 343//PBW 343 population

Source of Variation	Degree of freedom	Paste Temperature	Peak Viscosity	Hold viscosity	Final Viscosity	Breakdown	Setback
Replication	2	46.98	250713.00	48327.80	103189.90	101414.40	291960.20
Treatment	81	44.63	622589.40**	490051.40**	1582614.00**	107376.70**	464224.40**
Error	162	44.89	138114.60	116916.70	454510.40	67139.94	135035.40

*Significant at 5% level, ** Significant at 1% level

PBW 534 which gave a mixing time of 2.18 min. The other parent, C 306, gave a mixing time of 1.6 min. In case of population ‘C’ the parental values of mixing time were observed to be 1.3 min and 1.4 min for C 518 and PBW 343 respectively. Out of 80 genotypes in this population, 78 were found to range between the parental values whereas 2 genotypes gave mixing time values higher than PBW 343.

Dough strength is the ability of wheat flour to offer resistance to the stretching pressure and is measured as the height of the mixographic curve at the peak in cms. The set of genotypes showed marked differences for dough strength in first year. The advanced lines group showed high values for dough strength followed by tall wheats. However the highest value of dough strength was recorded for WG 357 (7.23 cm) from tall wheats group. These two groups were followed by commercial varieties and than by genetic stocks. The lowest value of dough strength was recorded to be 4.97 cm for DI 9. C 306 from which DI 9 is derived gave a higher value of 6.33 cm, whereas C 591 (5.60 cm) and its derivative DI 105 (5.70 cm) gave equivalent values of dough strength. The winter wheat, Glupro having high protein content, gave high value of dough strength recorded at 8.67 cm. In second year, the released varieties known for quality group gave high values of dough strength followed by tall wheats group. The tall wheat C 518 gave highest value of 6.27 cm for the season. The commercially grown wheats and the advanced lines gave comparable value but lower than the above two groups. The genetic stocks however gave lowest values in this season with HD 2793 giving lowest value of 4.87 cm in the group and comparable to the commercially grown wheat DBW 16. PBW 554, an advanced line which gave a high value of above 7 cm in first year however failed to give high value of dough strength in second year, recording a value of 4.90 cm only. In general also the dough strength values recorded were lower for the second year samples as compared to the first year. The variation in the values of dough strength was normally distributed in populations ‘A’ and ‘C’, where as in population ‘B’ the variation was almost equally distributed in to different classes. The transgressive segregants on higher side were observed in all the three cases. In population ‘A’ all the 70 genotypes gave dough strength value higher than that of C 273 (5.6 cm) whereas the other parent, PBW 343, gave a value of 5.4 cm. In population ‘B’ the parents C 306 and PBW 534 gave dough strength values of 6.4 cm and 6.0 cm respectively. 44 genotypes out of 70 genotypes in this population gave dough strength values higher than that of C 306, 8 genotypes were found to have values in the parental range whereas 18 genotypes yielded values lower than that of PBW 534. In population ‘C’ the parents C 518 and PBW 343 gave values of 6.2 cm and 5.9 cm respectively. 5 genotypes out of 80 gave values in the parental range whereas 70 were having higher values than those of C 518. 5 genotypes gave values lower to PBW 343.

Rate of dough development is the rate at which dough is developed on mixing flour with water and is represented by the angle which the mixing curve forms with the longitudinal line passing through the centre of the peak. Rate of dough development was found to be significantly higher for tall wheats in comparison to other groups of genotypes in first year. Commercial wheat PBW 343 with lowest mixing time, however, showed highest rate of dough development i.e., 51.67°. The lowest rate of dough development, as a consequence of

Table 7. Performance of 'A' population for mixographic and starch pasting characteristics

Entry	MTi	DS	RDD	RDW	MTo	DDA	BS	PT	PV	HV	FV	Sb	Bd	CS
1	3.3	6.1	23	17	140	28	50	68.70	2476.33	1490.00	3440.00	986.33	1950.00	7.6
2	3.1	6.4	26	21	133	24	46	68.10	3038.00	1799.33	3877.67	1238.67	2078.33	7.7
3	2.8	6	22	18	140	20	47	69.10	3165.33	1909.00	4574.00	1258.33	2667.00	7.6
4	2.8	7.8	33	26	121	29	59	67.80	3130.00	1784.00	3752.00	1346.00	1968.00	7.7
5	2.9	6.5	25	22	133	25	50	68.27	3080.33	1827.67	3954.67	1252.67	2127.00	7.7
6	3	6.5	29	26	125	25	49	68.53	2856.00	1798.00	4137.67	1058.00	2339.67	7.6
7	3.5	6.3	22	29	129	28	47	67.83	4234.33	2043.33	4456.67	1191.00	2413.67	7.5
8	2.6	6.7	31	31	118	22	45	69.53	3582.33	2179.33	4297.00	1403.00	2117.67	7.7
9	3.3	6	21	25	134	28	47	68.97	3429.67	1938.33	4027.67	1491.33	2089.33	7.6
10	2.8	7.7	32	34	114	27	58	67.10	2645.00	1340.67	3117.33	1304.33	1776.67	7.2
11	2.8	7	31	23	126	25	49	67.97	3522.00	2391.00	4085.67	1786.33	2627.33	7.6
12	2.5	7.1	33	32	115	24	50	68.83	2977.67	1714.00	3910.00	1326.33	2267.00	7.8
13	3.2	6.7	26	31	123	27	51	68.83	2548.67	1406.00	3458.00	1142.67	2052.00	7.6
14	3.5	7.2	24	29	127	35	52	62.83	2330.00	1573.33	3855.67	775.33	2366.00	7.3
15	2.9	7.8	27	30	123	32	62	69.37	2427.67	1511.33	3836.67	916.33	2325.33	7.6
16	2.9	8.4	35	41	104	31	62	67.13	3245.33	2023.33	4366.00	1223.33	2365.67	7.5
17	3.1	7	26	25	129	30	57	69.13	2838.67	1733.00	4115.67	1105.67	2382.67	7.6
18	3	7.7	34	38	108	31	57	69.13	2845.67	1733.67	3807.67	1112.00	2074.00	7.7
19	3.7	7.5	26	31	123	38	63	68.27	3466.33	2177.33	4814.67	1289.00	2637.33	7.4
20	3.2	8.8	35	40	105	36	65	68.93	3185.67	1900.00	4181.33	1285.67	2281.33	7.5
21	4.8	7.9	22	26	132	47	75	61.60	2273.33	1053.67	2415.33	1219.67	1361.67	7.7
22	4.6	7.6	23	32	125	41	63	67.07	2716.33	1430.00	3335.33	1276.33	1893.67	7.7
23	4.3	7.6	24	30	126	43	67	68.83	2308.33	1108.00	2772.00	1200.33	1730.67	7.9
24	4.9	7.1	24	21	135	45	64	68.13	3531.00	1704.00	4682.67	1527.00	2678.67	7.5
25	3.8	7.9	20	26	134	44	90	68.70	2939.67	1529.33	3747.00	1410.33	2217.67	7.6
26	2.5	6.9	23	34	123	25	53	67.07	3595.33	2366.33	4612.67	1229.00	2246.33	7.6
27	3.7	6.3	22	28	130	24	44	67.43	3192.00	2123.67	4428.67	1068.33	2305.00	7.7
28	3.3	6.7	25	35	120	28	53	61.67	3445.33	2270.67	4545.33	1174.67	2274.67	7.5
29	3.1	6.5	21	34	125	26	52	67.87	3162.67	2093.33	4435.33	1069.33	2342.00	7.7
30	3.1	6.9	26	32	122	28	53	68.13	2875.67	1748.67	4224.00	1127.00	2475.33	7.5
31	3.7	6.5	23	30	127	32	56	69.27	3557.00	2304.67	5009.33	1252.33	2704.00	7.6
32	3.3	7.5	28	37	115	31	58	68.10	3571.67	2359.67	5181.67	1212.00	2822.00	7.6
33	3.1	7.2	32	34	114	26	59	68.37	3490.33	2337.67	4987.00	1152.67	2649.33	7.5
34	2.7	6.5	25	36	119	24	46	67.67	4066.00	2399.00	4419.67	1667.00	2020.67	7.4
35	3.4	6.7	21	32	127	32	55	68.53	3200.67	1965.00	4432.00	1235.67	2467.00	7.5
36	4.5	7.3	18	34	128	44	66	69.53	3669.67	2318.33	4809.67	1349.33	2491.33	7.4
37	4.8	6.9	19	30	131	42	65	69.67	3591.67	2150.67	4895.00	1441.00	2744.33	7.5
38	4	6.5	24	35	121	33	55	68.83	3804.33	2160.00	4388.67	1644.33	2228.67	7.4
39	3.3	6.2	18	29	133	27	56	67.70	4052.00	2606.67	5082.67	1445.33	2476.00	7.5
40	3.6	7	26	37	117	33	54	69.37	3357.33	2164.00	4986.00	860.00	2822.00	7.6
41	3.2	6.3	20	26	134	28	52	69.10	2990.67	1862.33	4595.67	1128.33	2733.33	7.6
42	3	6.7	23	36	121	25	51	68.83	2964.33	1807.00	4110.33	1157.33	2303.33	7.6
43	2.9	6.4	24	30	126	27	49	67.23	4394.33	3006.33	5728.00	1388.00	2721.67	7.5
44	3.5	6.5	20	27	133	30	54	68.70	4143.67	3091.33	5951.67	1052.67	2860.33	7.5
45	2.7	6.7	30	33	117	22	45	68.40	2927.00	1775.00	3837.67	1153.33	2084.00	7.8
46	3.9	6.2	15	18	147	37	60	69.33	3818.00	2173.67	4753.67	1641.00	2580.00	7.4
47	4.2	5.6	13	21	146	33	49	69.50	3674.67	2083.00	4609.33	1591.67	2526.33	7.1
48	3.4	6.7	19	21	140	32	62	68.80	3597.00	2312.00	5159.67	1285.00	2847.67	7.7
49	3.5	6.4	17	26	137	32	55	68.40	3982.00	2290.33	4227.67	1691.67	1937.33	7.5
50	3.7	6.4	16	29	135	34	54	61.77	4154.33	2731.67	5432.00	1422.67	2700.33	7.3
51	2.7	6.8	19	24	137	27	58	69.67	3988.33	2761.67	5434.67	1226.67	2673.00	7.5
52	4.6	6.7	18	23	139	41	64	69.40	3639.67	2426.00	5714.33	1213.67	3288.33	7.6
53	4.3	5.8	14	20	146	37	58	69.67	3691.67	2549.67	5881.67	1142.00	3332.00	7.3
54	3.2	6.6	17	23	140	29	58	69.87	3453.67	2240.33	5050.33	1222.33	2894.00	7.1
55	3.2	5.6	18	30	132	25	45	66.67	4477.67	3211.33	6023.67	1265.00	2812.33	7.3
56	4.6	6.5	20	16	144	37	60	69.53	3632.67	2331.67	5405.67	1302.33	3074.00	7.0
57	3	7.2	22	28	130	26	57	66.53	3155.33	1928.67	4272.67	1226.67	2344.00	7.2
58	3.2	6.9	24	39	117	26	56	67.57	3050.33	1901.00	4132.00	1149.33	2231.00	7.3
59	4	6.7	23	25	132	33	56	67.70	3530.33	2109.33	4613.67	1427.67	2512.33	7.5
60	3.7	6.7	19	42	119	32	52	67.27	3753.67	2341.67	4676.33	1412.00	2334.67	7.6
61	3.4	7.8	29	35	116	33	61	65.80	3810.33	2349.33	4715.00	1461.00	2365.67	7.5
62	4	6.9	26	39	115	36	56	66.13	3013.67	1798.33	4071.00	1215.33	2274.67	7.4
63	3.3	6.7	29	39	112	28	55	66.53	2168.00	1279.33	3240.33	889.33	1964.33	7.7
64	3.2	6.7	23	44	113	28	52	66.40	2893.67	1696.33	3715.33	1197.33	2019.00	7.5
65	3.5	6.8	22	37	121	29	49	67.30	2960.67	1729.67	3927.00	1229.67	2197.33	7.6
66	3.3	6	16	30	134	29	48	66.70	3904.33	2398.67	4883.00	1505.67	2484.33	7.5
67	3.2	6	22	31	127	26	47	66.23	3650.33	2314.33	4632.00	1336.00	2317.67	7.5

Contd…..

68	4.5	7.1	22	36	122	42	59	66.67	2251.33	1357.67	3796.00	893.67	2105.00	7.3
69	3.1	6.9	23	30	127	31	56	66.80	4067.67	2511.33	4938.67	1556.33	2427.33	7.5
70	3.7	6.8	25	36	119	30	54	66.70	3497.67	2247.00	4660.00	1250.67	2446.33	7.5
C 273	2.15	5.6	22	22	136	18	49	69.53	3190.00	2388.67	3914.67	801.33	1526.00	8.2
PBW 343	1.25	5.4	31	20	129	9	36	71.07	3399.00	2828.67	4396.67	570.33	1568.00	7.7
								ns	**879.26**	**647.1**	**892.73**	**304.92**	**390.92**	

MTi = mixing time (min), DS = Dough strength (cm), RDD = rate of dough development (^{o}), RDW = Rate of dough weakening (^{o}), MTo = Mixing tolerance (^{o}), DDA = Dough development area (cm^2), BS = Baking strength (cm^2), PT = Paste temperature (^{o}c), PV = Peak Viscosity (rpm), HV = Hold viscosity (rpm), FV = Final Viscosity (rpm), Bd = Breakdown (rpm), Sb = Setback (rpm), CS = *Chapati* score

highest mixing time, was recorded for DI 9 (16.67^o). The trend observed was that the genotypes with high mixing time showed low rate of dough development. The winter wheat Glupro however had a high rate of dough development (51^o) in spite of a higher mixing time (3.10 min). In second year, the commercially grown varieties gave comparatively higher values of rate of dough development than other groups of genotypes. Highest value of rate of dough development in this season was recorded to be 34.67^o for 'C 518'. WH 1003 with highest mixing time (3.03 min) gave lowest value of rate of dough development i.e., 14.33^o. Lok 1 (mixing time 1.00 min) and PBW 502 (mixing time 1.05 min) gave high values of 30.67^o and 30.00^o respectively. The advanced lines gave low values for rate of dough development. In this season also the rate of dough development was found to be inversely related to the mixing time. On the whole rate of dough development was lower during second year. Ideally the wheat variety with a higher rate of dough development, which implies that the energy requirements of such wheat will be lower for developing satisfactory dough, is preferred for baking. But practically the stronger wheat varieties are having lower rates of dough development due to a slower rate of water absorption by their flour. The rate of dough development was found to be normally distributed for populations 'A' and 'C'. In population 'B' however, the distribution was skewed towards lower side. The population 'C' was found to have higher mean value for this trait than other two populations. In population 'A' the rate of dough development values of the parents were observed to be 22^0 and 31^0 for C 273 and PBW 343 respectively. 35 genotypes out of 70 were found to be in between the parental values; whereas 30 genotypes were found to give values lower than that of C 273. 5 genotypes gave values higher than that of PBW 343. In population 'B' 40 genotypes out of 70 gave rate of dough development values in between the parental range. 30 genotypes gave lower values than that of PBW 534 (19^0) whereas none of the genotypes gave values higher than that of C 306 (51^0). In population 'C' the parental values of rate of dough development were observed to be 56^0 and 43^0 for C 518 and PBW 343 respectively. 7 genotypes out of 80 were found to give values in the parental range whereas 71 genotypes gave values lower than that of PBW 343 and 2 genotypes gave higher values than that of C 518.

The rate of dough weakening is the rate at which the dough breakdown occurs when mixing is continued beyond optimum and is measured as the angle formed by the descending curve with the perpendicular line drawn from the apex to the base line. It is indicative of breakdown of dough strength when dough is over mixed and was found to be low for genetic stocks in first year. Entry DI 9 (13.33^o) gave lowest values of rate of dough weakening. In tall wheats the rate of dough weakening was some what high with C 518 being an exception with a rate of 15.33^o. The highest value of rate of dough weakening was recorded to be 34.00^o for WG 357, which also had the highest dough strength (7.23 min). The advanced lines group gave high values followed by tall wheats and commercial varieties. A low rate of dough weakening was observed for Glupro (19.67^o). In second year the genetic stocks again showed low values for rate of dough weakening with a group average of 15.67^o. HD 2793 with lowest dough strength (4.87 cm) gave low value of 11.00^o. The released varieties with known quality, in comparison with other groups, yielded high values of the rate of dough weakening, but the highest value in this season was again recorded for WG 357 (30.33^o). The commercial varieties and the advanced lines gave intermediate values of the rate of dough weakening. The lower values of dough weakening are preferred which means that the dough losses on its strength slowly when over mixed and in general the stronger wheats with higher baking strength exhibit lower values for dough weakening. On the whole the rate of dough weakening was lower during second year. The intermediary values recorded for the tall varieties confirm to the general belief that moderately strong wheats are better suited for baking *chapaties.* The rate of dough weakening was observed to be normally distributed in all the three populations. Both inferior and superior transgressive segregants were observed in all the three cases, with population 'B' having high number of inferior and population 'C' having high number of superior segregants. In population 'A' 57 genotypes out of 70 gave rate of dough weakening values higher than that of C 273 (22^0) whereas 5 genotypes gave

Table 8. Performance of 'B' population for mixographic and starch pasting characteristics.

Entry	MTi	DS	RDD	RDW	MTo	DDA	BS	PT	PV	HV	FV	Sb	Bd	CS
1	4.7	7.4	20	29	131	48	71	71.37	2828.67	1557.00	3724.67	1271.67	2167.67	7.7
2	3.1	7.2	21	31	128	31	58	69.83	2813.00	1852.33	4168.00	960.67	2315.67	8.0
3	4.8	6.7	17	20	143	43	59	70.67	3652.33	2166.67	4738.33	1485.67	2505.00	7.9
4	2.9	7.2	24	35	121	28	54	65.47	2618.67	1718.00	3946.00	900.67	2228.00	7.9
5	2.6	8	29	35	116	21	53	70.50	3421.67	2346.00	4628.00	1078.67	2272.00	7.9
6	3.6	7.3	20	27	133	41	63	69.53	2332.33	830.00	1957.33	1502.33	1126.33	7.9
7	4.4	8.1	25	31	124	46	71	69.53	3450.33	2326.33	5379.00	1124.00	3052.67	7.4
8	4.4	7.4	19	32	129	46	65	62.77	3056.67	1930.00	4832.67	968.33	2944.00	7.7
9	3.8	7.8	22	27	131	43	72	68.50	3300.00	2124.33	5003.67	1149.67	2797.33	7.6
10	3.1	7.9	32	34	114	32	58	70.77	4919.67	1969.67	4284.67	1082.67	2315.00	7.8
11	3.8	8.6	30	40	110	45	71	70.23	3260.33	2152.00	4645.00	1108.33	2493.00	7.9
12	3.2	8.7	28	34	118	40	75	70.00	3320.00	1931.67	4312.00	1388.33	2390.33	7.7
13	4.7	7.9	25	26	129	50	74	71.47	3527.00	2216.33	4861.00	1310.67	2644.67	7.9
14	4.1	7.8	20	29	131	46	70	70.53	3136.00	1959.33	4332.33	1176.67	2373.00	7.8
15	4.7	7.8	20	17	143	52	76	69.53	3454.33	2141.33	4579.67	1438.33	2429.67	7.9
16	4.9	7.1	17	17	146	50	68	70.37	3728.33	2552.33	5365.00	1176.00	2812.67	7.9
17	4.9	7.9	19	34	127	49	71	71.20	2923.67	1721.67	4190.00	1202.00	2301.67	7.9
18	3.2	8.1	30	32	118	38	61	69.93	3003.00	1730.33	3796.00	1272.67	2065.67	7.8
19	5.3	6.5	21	26	133	50	62	70.10	3665.67	2534.00	5295.67	1131.67	2761.67	7.7
20	3.4	8.1	24	28	128	38	71	70.20	2538.00	1467.33	3737.67	1070.67	2270.33	8.0
21	4	6.9	22	26	132	39	59	64.33	2883.33	1716.67	3892.67	1166.67	2176.00	7.6
22	4.6	7.6	23	29	128	44	62	63.67	3117.67	1856.67	4051.33	1261.00	2194.67	7.5
23	4.1	7.9	30	35	115	39	70	69.80	3440.00	2010.00	4078.00	1430.00	2068.00	7.4
24	4.1	6.8	24	43	113	34	54	70.10	2806.67	1548.33	3448.67	1258.33	1900.33	7.0
25	4	7.3	23	37	120	40	61	70.00	3430.33	1923.67	4039.67	1464.33	2159.00	7.2
26	4	7.6	30	33	117	38	62	70.27	3500.67	2325.33	5253.00	1177.00	2929.33	7.0
27	4.6	7	20	29	131	42	65	70.10	3430.00	2257.33	5155.67	1172.67	2898.33	7.2
28	3.8	7.5	21	33	126	36	62	69.53	3316.33	2272.33	5235.33	1044.00	2963.00	7.2
29	3.3	5.6	17	22	141	25	46	72.10	2392.33	1623.00	3769.00	769.33	2146.00	7.0
30	4.2	6	20	27	133	37	55	70.87	3330.00	2373.33	5228.33	956.67	2851.67	6.9
31	5	8	18	26	136	51	72	64.93	3468.67	2084.00	4669.67	1385.33	2585.67	7.0
32	4.9	8.1	28	23	129	50	67	70.67	3755.00	2450.00	5379.67	1305.00	2941.67	7.3
33	4.9	6.7	17	16	147	45	62	71.90	4041.67	2637.00	5128.33	1404.67	2491.33	7.2
34	4.8	7.2	26	31	123	42	60	71.20	3586.00	2094.67	4695.33	1491.33	2600.67	7.2
35	5.6	6.8	25	22	133	46	58	70.60	3862.00	2504.67	5772.67	1357.33	3268.00	7.1
36	5.1	7.6	24	25	131	52	69	72.77	2865.00	1767.00	4163.67	1098.00	2396.67	7.3
37	4.9	7.4	25	25	130	40	62	71.27	3129.00	1969.00	4557.33	1160.00	2421.67	6.9
38	5.2	7.2	20	28	132	50	66	69.50	3063.67	1860.67	4140.00	1223.33	2278.67	6.9
39	5.3	7.6	18	27	135	50	73	71.60	2866.00	1860.33	4313.00	1005.67	2451.33	6.9
40	5.6	7.8	23	28	129	47	66	70.10	3596.67	2193.67	4954.33	1403.00	2760.67	7.1
41	5.4	7.4	18	30	132	45	66	72.03	3038.33	2007.33	4464.67	1031.00	2457.33	7.3
42	5.4	7.1	20	21	139	37	64	72.33	2368.00	1503.00	3598.33	865.00	2095.33	7.2
43	5.5	7	17	23	140	42	63	72.60	2799.00	1743.33	4120.00	1072.33	2376.67	7.0
44	4.9	6.7	22	25	133	36	59	71.63	3146.33	1959.67	4497.00	1186.67	2537.33	7.2
45	5.4	6.2	18	22	140	41	56	71.17	2981.00	2119.67	4680.00	861.33	2560.33	7.0
46	5.5	6.1	17	22	141	42	54	72.37	2624.00	1753.00	4376.00	871.00	2623.00	7.3
47	5.4	5.9	20	24	136	38	50	71.20	3185.67	2222.33	5145.00	963.33	2922.67	7.1
48	5.7	5.5	18	32	130	35	44	71.33	3040.33	2080.67	4700.33	943.00	2601.67	7.4
49	4.7	6.7	24	25	131	36	58	69.93	3554.67	2327.67	5480.33	1227.00	3152.67	7.3
50	5.1	6.2	24	22	134	35	57	69.97	3454.00	2326.00	5380.00	1128.00	3054.00	7.5
51	5.5	6	19	20	141	38	54	72.73	2955.67	1945.33	4470.00	1009.33	2523.67	7.1
52	4.9	6.1	18	16	146	40	59	72.60	2685.67	1783.67	4124.33	902.00	2340.67	7.0
53	4.9	6.1	19	34	127	36	55	72.03	3184.00	2249.33	5097.00	934.67	2847.67	7.4
54	5	4.9	16	22	142	38	56	66.40	3122.00	2077.00	4347.00	1045.00	2270.00	7.0
55	4.2	5.5	18	24	138	30	51	71.37	3265.33	2199.67	4459.00	1065.67	2259.33	7.2
56	2.3	5.7	22	29	129	18	37	63.90	3392.00	2306.00	4798.33	1086.00	2492.33	7.2
57	2.7	5.4	25	20	135	18	39	69.70	3830.00	2519.33	4944.67	1510.67	2425.33	7.1
58	5.4	6.5	23	25	132	41	61	65.73	2624.00	2091.67	4460.00	899.00	2368.33	7.1
59	5.3	5.4	16	25	139	41	60	63.20	3348.33	2389.67	5160.33	958.67	2770.67	7.0
60	5.2	5.5	18	26	136	30	52	62.60	2311.67	2637.33	4234.67	1056.00	1952.33	7.0
61	5.6	69	22	26	132	50	66	71.33	2651.67	1696.33	4156.67	955.33	2460.33	7.2
62	4.9	5.8	18	18	144	35	59	71.77	2924.33	1926.33	4369.00	998.00	2442.67	7.0
63	4.9	5.8	19	24	137	41	55	71.07	3583.67	2249.00	4592.00	1334.67	2343.00	7.0
64	5.3	6.9	23	18	139	46	61	70.37	3450.00	2046.67	4551.00	1403.33	2504.33	6.9
65	5.2	5.7	19	23	138	40	61	70.23	3009.00	1743.33	3832.67	1265.67	2089.33	7.1

Contd..…..

66	5.6	5.2	21	27	132	43	59	73.60	2470.67	1773.00	4162.33	697.67	2389.33	7.2
67	4.9	4.9	22	31	127	46	65	72.07	2653.33	1857.33	4593.00	794.33	2735.33	7.2
68	4.8	5.8	23	28	129	41	55	65.03	2333.33	1499.67	3871.67	833.67	2372.00	7.2
69	2.7	5.5	21	30	121	39	56	62.20	1649.67	791.67	2022.33	858.00	1214.00	7.0
70	4.1	6.4	18	23	139	36	63	69.17	2502.00	1583.33	3695.33	874.33	2190.00	7.2
C 306	1.6	6.4	51	29	100	11	42	68.47	2588.00	1679.67	3132.00	953.67	1385.67	8.2
PBW 534	2.18	6	19	24	137	22	50	69.90	3580.00	2528.33	4154.00	1019.67	1606.00	7.4
								ns	**1007.89**	**520.22**	**895.89**	**370.28**	**491.71**	

MTi = mixing time (min), DS = Dough strength (cm), RDD = rate of dough development (°), RDW = Rate of dough weakening (°), MTo = Mixing tolerance (°), DDA = Dough development area (cm^2), BS = Baking strength (cm^2), PT = Paste temperature (°c), PV = Peak Viscosity (rpm), HV = Hold viscosity (rpm), FV = Final Viscosity (rpm), Bd = Breakdown (rpm), Sb = Setback (rpm), CS = *Chapati* score

values lower than that of PBW 343 (20^0). 8 genotypes were observed to have values in the parental range. In population 'B' the parents were observed to have values of 29^0 and 24^0 for C 306 and PBW 534 respectively. Out of 70 genotypes in this population, 23 were found to be in the parental range whereas 23 genotypes gave values higher than that of C 306 and 24 genotypes gave values lower than that of PBW 534. In population 'C' the rate of dough weakening values for the parents were observed to be 28^0 and 30^0 for C 518 and PBW 343 respectively. 11 genotypes out of 80 were observed to have values in the parental range whereas 25 genotypes gave values lower than that of C 518 and 44 genotypes gave values higher than that of PBW 343.

Mixing tolerance refers to the ability of wheat dough to resist breakdown when extra energy is applied to the system. It is measured by the angle enclosed by the ascending and descending portions of the mixographic curve. It is another measure of dough weakening. In first year the mixing tolerance was found to be high in the advanced lines with PBW 534 showing a high value of 160.33°. The genetic stock DI 9, however, recorded the highest value of 163.33° mixing time. The genetic stocks showed a lot of variation for mixing tolerance with values ranging from 131.67° for K 0123 and KYZ K2K-13 to 163.33° for DI 9. The commercially grown wheat PBW 343 (128.33°) recorded lowest value of mixing tolerance in this season. The tall wheats showed intermediate values of mixing tolerance. Glupro also yielded a low value of 129° mixing tolerance. In second year, the genetic stocks gave high values for mixing tolerance with WH 1003 recording a value of 160.89°. The advanced lines followed the genetic stocks with PBW 534 and PBW 554 showing values above 150°. The tall wheats group and the released varieties with known quality gave intermediate values for mixing tolerance, with C 518 being an exception recording lowest value of 133.78° for the season. In commercially grown varieties group, DBW 16 and PBW 550 gave higher values of 150.22° and 149.78° respectively. The values for the mixing tolerance are almost similar for both the years of study which shows that the character is stable and can be employed for screening of the breeding materials. The variation for mixing tolerance was observed to be normally distributed in all the three populations with most of the individuals falling in between the parental ranges. However transgressive segregants on both the sides were identified in all the populations. In population 'A' the mixing tolerance of the parents was observed to be 136^0 and 129^0 for C 273 and PBW 343 respectively. 19 genotypes out of 70 gave mixing tolerance values in between the parental range, whereas 40 genotypes gave values lower than that of PBW 343 and 11 genotypes were having values higher than that of C 273. In population 'B' none of the genotypes out of 70 were observed to have mixing tolerance values lower than that of C 306 (100^0), whereas 20 genotypes gave values higher than that of PBW 534 (137^0). Remaining 50 genotypes gave values in the parental range. In population 'C' the parental values of mixing tolerance were observed to be 96^0 and 107^0 for C 518 and PBW 343 respectively. Out of 80 genotypes in this population 71 were found to have mixing tolerance values more than that of PBW 343 whereas 3 genotypes gave values lower than that of C 518. 6 genotypes were observed to have mixing tolerance values in the parental range.

Dough development area is the area enclosed by the developing curve upto the peak is reached and it relates to the energy requirements for dough development. In first year the values of dough development area were found to be high for advanced lines. C 518, the tall wheat variety, gave lowest value of 9 cm^2 dough development area. The highest value of 21.33 cm^2 was recorded for the genetic stock WH 1003. Other genetic stocks gave values ranging from 10.33 cm^2 for K 0123 to 21.33 cm^2 (WH 1003). In commercially grown wheats group PBW 343 and PBW 502 gave low values of 10.00 cm^2 and 9.31 cm^2 respectively, whereas PBW 550 (21.00 cm^2) and PBW 509 (20.33 cm^2) recorded high values. The tall wheats barring C 518 gave intermediate values of dough development area in the season though the mean value was lowest for the group. Glupro gave a high value of 19.33 cm^2. In second year the commercial wheats group gave low values with PBW 502 and PBW 533 recording values

Table 9. Performance of 'C' population for mixographic and starch pasting characteristics .

Entry	MTi	DS	RDD	RDW	MTo	DDA	BS	PT	PV	HV	FV	Sb	Bd	CS
1	2.1	7.4	36	44	100	23	50	75.43	2423.33	1526.33	3625.33	897.00	2099.00	7.6
2	2.6	7.2	31	38	111	23	50	60.93	2497.00	1625.00	3777.67	872.00	2152.67	7.5
3	2.1	7.2	41	41	98	20	46	57.07	2167.33	1363.67	3365.00	788.67	2001.33	7.2
4	2.9	6.8	29	36	115	21	49	65.17	3266.67	2020.33	3759.33	1247.67	1739.00	7.4
5	1.7	7.4	43	39	98	18	52	64.07	2632.67	1774.00	3921.33	858.67	2147.33	7.2
6	3.4	7.1	27	33	120	32	54	57.60	3309.00	2298.33	4890.67	1010.67	2592.33	7.5
7	3.4	6.7	22	35	123	30	53	63.80	2996.67	2069.00	4388.33	927.67	2319.33	7.7
8	3.3	6.8	25	27	128	29	54	69.53	2666.33	1675.67	3656.67	990.67	1981.00	7.8
9	4.7	7.4	23	39	118	46	63	71.53	3406.33	2385.00	4839.00	1021.33	2452.67	7.4
10	4.4	6.8	23	33	124	40	60	63.77	3315.33	2298.00	4806.67	1017.33	2508.67	7.4
11	2.7	6.5	25	32	123	24	50	70.60	2941.00	2252.67	4745.00	729.67	2534.67	7.4
12	3.5	6.8	28	35	117	28	53	63.83	3033.33	2210.00	4741.00	823.33	2531.00	7.5
13	3.4	7.9	35	38	107	33	61	63.87	2596.00	1615.33	4269.00	980.67	2653.67	7.4
14	2.9	7.4	35	35	110	27	54	64.47	2999.00	1325.67	2816.33	1673.33	1490.67	7.4
15	3	6.9	26	29	125	29	53	70.50	2972.00	1941.00	4088.00	1031.00	2146.67	7.5
16	2.5	6.6	28	30	122	21	49	71.50	3181.33	2241.67	4341.00	939.67	2099.33	7.6
17	2.2	6.8	31	26	123	21	51	71.33	2835.67	1887.67	4184.33	948.00	2296.67	7.4
18	2.3	6.1	20	27	133	21	46	70.80	2490.67	1678.33	3601.00	812.33	1922.67	7.4
19	3.5	5.3	18	19	143	27	44	71.50	3097.33	2103.67	4506.67	1027.00	2403.00	7.5
20	2.3	7.1	33	32	115	22	52	70.90	3088.67	2024.00	4339.33	1064.67	2315.33	7.6
21	2	7.7	42	39	99	21	63	69.07	949.33	187.33	609.67	762.00	422.33	7.5
22	2.3	8.5	41	45	94	26	62	70.63	2702.33	1505.67	3217.00	1196.67	1711.33	7.7
23	2.9	7.2	34	33	113	26	54	70.37	3030.67	1730.67	3401.67	1300.00	1671.00	7.6
24	2.6	6.7	28	26	126	25	53	69.97	2184.33	1409.33	3352.67	775.00	1943.33	7.6
25	2.9	7.5	33	38	109	28	56	64.60	2600.33	1763.67	3858.00	816.67	2091.00	7.4
26	2.6	7	29	34	117	27	54	70.80	3301.33	2341.33	4608.67	930.00	2237.33	7.7
27	4	7	24	31	125	37	56	64.77	2237.33	1196.67	2751.00	1040.67	1554.33	7.5
28	3.1	7.3	25	40	115	31	26	62.93	3151.00	2173.67	4211.33	977.33	2037.67	7.7
29	2.5	6.5	33	30	117	24	47	64.93	2611.00	1568.33	3325.67	1042.67	1757.33	7.4
30	3.6	5.4	15	20	145	27	45	70.63	2987.67	1993.33	4150.33	1016.00	2046.33	7.4
31	2.5	5.8	19	25	136	22	43	70.37	3194.33	2084.00	4172.00	1110.33	2088.00	7.8
32	2	6.9	41	35	104	17	48	70.07	2696.33	1954.33	4017.33	1078.67	2063.00	7.6
33	3.3	5.5	21	25	134	24	47	63.37	3242.00	2211.33	4424.67	1067.33	2292.00	7.8
34	2.9	5.6	26	25	129	19	41	70.50	3052.67	2034.67	4176.67	1018.00	2142.00	7.8
35	4.6	6.7	18	25	137	43	64	71.03	2467.00	1752.00	4301.00	715.00	2499.00	7.3
36	3.8	6.7	20	28	132	36	58	70.23	2997.33	1766.67	3890.33	1230.67	2157.00	7.6
37	3.9	7.2	29	30	121	32	58	63.23	1988.67	982.33	2514.33	1007.00	1532.00	7.7
38	4.1	7.7	28	28	124	46	74	61.67	1918.67	986.00	2357.67	933.00	1372.00	7.5
39	2.8	6	20	25	135	24	48	64.70	2319.00	1390.00	3146.33	929.00	1756.33	7.5
40	3.3	6.6	19	28	133	28	54	71.37	2341.67	1458.33	3643.00	883.33	2184.67	7.5
41	2	7.5	37	40	103	21	50	70.90	2593.33	1167.00	2641.33	1426.33	1474.33	7.6
42	1.4	7.4	41	31	108	12	45	64.73	1959.67	1081.67	3122.67	878.00	2040.00	7.5
43	1.4	6.2	35	28	117	15	46	70.53	3048.67	1941.67	4120.67	1107.00	2179.00	7.6
44	1.5	5.9	30	31	119	14	42	67.33	3281.33	2119.67	3936.00	1161.67	1816.33	7.6
45	2.6	6.3	28	22	130	22	49	70.63	3105.67	1962.00	3498.67	1144.67	2236.67	7.4
46	2.3	7	34	34	112	22	51	71.07	2271.33	1568.67	3719.33	1036.00	2150.67	7.4
47	2.1	7	34	39	107	20	46	70.23	2535.00	1466.67	3350.00	1068.33	1880.00	7.6
48	2	6.9	35	30	115	18	48	71.07	2331.33	1376.67	3238.67	954.67	1862.00	7.5
49	2.1	7.4	40	36	104	22	52	70.23	2717.00	1714.33	3695.67	1002.67	1981.33	7.5
50	2	7	43	36	100	21	55	69.17	3374.33	2308.00	4549.33	1124.67	2259.67	7.5
51	2.6	6.7	27	29	124	25	53	64.87	3387.33	1604.00	3248.33	1783.33	1644.33	7.4
52	2.3	6.7	31	29	120	22	49	69.73	2975.00	2037.00	4532.67	938.00	2495.67	7.2
53	3.8	5.5	13	21	146	32	51	65.03	2864.33	1915.00	4372.33	949.33	2457.33	7.2
54	3.1	6.2	24	25	131	26	48	70.77	3042.67	1879.67	4014.67	1163.00	2135.00	7
55	3.7	6.2	19	30	131	32	53	70.77	3804.00	2310.33	4462.33	1477.00	2152.00	7.3
56	3.7	7.2	29	25	126	36	61	70.93	2665.00	1606.00	3937.00	1057.33	2329.33	7.4
57	3	7.4	32	26	122	38	65	71.37	3572.67	2508.33	5359.00	1139.00	2875.67	7.5
58	3.2	7	31	29	120	39	63	70.93	3515.67	2462.00	5087.33	1053.67	2625.33	7.5
59	2.9	8.3	38	40	102	30	61	64.20	2644.00	1549.00	3865.67	1095.00	2316.67	7.2
60	2.3	7.1	33	28	119	23	52	60.37	2728.33	1743.33	3952.00	985.00	2208.67	7.2
61	2.4	6.8	32	23	125	35	56	65.60	2909.67	2053.33	4437.67	856.33	2384.33	7.5
62	2.5	7.2	32	34	114	24	49	64.27	2712.67	1928.33	4116.33	785.33	2189.00	7.3
63	2.7	6.8	29	31	120	27	50	70.80	3149.00	2195.33	4477.33	951.00	2279.33	7.3
64	3.3	7	24	32	124	31	54	71.60	3200.33	2297.33	4820.00	903.00	2522.67	7.1
65	2.6	6.4	23	34	123	23	46	64.87	2656.00	1756.67	3799.67	899.33	2043.00	7.4
66	2.1	7.3	32	41	107	22	47	68.37	3053.67	2309.00	4522.00	841.00	2242.67	7.3
67	2.2	6.8	34	39	107	22	44	65.30	3026.33	2165.00	4403.67	861.33	2038.67	7.4

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68	2.4	6.8	25	35	120	24	47	57.97	3257.00	2129.33	3968.67	1127.67	1839.33	7.1
69	2.4	6.7	27	31	122	23	48	65.13	2781.67	1825.33	3829.00	956.33	2003.67	6.8
70	2.7	6.6	25	30	125	24	47	62.27	2887.67	1822.67	4306.00	1065.00	1483.33	6.9
71	2.4	7.8	27	36	117	26	60	70.80	2445.00	1454.67	3555.33	1012.00	2592.67	7
72	2.5	7.1	21	32	127	26	54	71.23	2757.00	1854.00	4094.67	899.67	2337.33	7.3
73	3	6.2	18	25	137	27	49	72.20	2743.67	1797.00	4149.67	992.33	2266.33	7.3
74	2.4	6.7	26	39	115	23	45	70.03	2227.67	1473.67	3822.33	754.00	2348.67	7.1
75	2.7	7	25	32	123	26	53	70.90	2444.33	1494.33	3892.00	949.67	2397.67	7.4
76	3.9	7.9	17	36	127	43	69	70.93	2651.00	1811.33	4404.67	839.67	2593.33	7.3
77	3.6	6.4	18	32	130	31	52	65.27	3394.00	2371.33	4934.33	1042.67	2563.00	7.2
78	3.7	6.5	18	29	133	36	58	71.80	2394.00	1512.00	3807.33	889.33	2325.67	7.3
79	2.7	6.7	21	21	138	28	53	68.07	2560.67	1802.00	4078.00	888.33	2335.67	7.1
80	3.4	6.6	18	24	138	31	57	72.47	2920.00	1987.33	3797.00	939.33	2391.00	7.1
C 518	1.3	6.2	56	28	96	10	38	68.67	2049.67	1227.67	2414.67	837.67	1292.33	7.9
PBW 343	1.4	5.9	43	30	107	12	37	67.37	2686.00	1830.00	3110.00	889.00	1285.67	7.7
								ns	**603.25**	**555.14**	**1093.57**	**395.38**	**578.09**	

MTi = mixing time (min), DS = Dough strength (cm), RDD = rate of dough development (^{o}), RDW = Rate of dough weakening (^{o}), MTo = Mixing tolerance (^{o}), DDA = Dough development area (cm^2), BS = Baking strength (cm^2), PT = Paste temperature (^{o}c), PV = Peak Viscosity (rpm), HV = Hold viscosity (rpm), FV = Final Viscosity (rpm), Bd = Breakdown (rpm), Sb = Setback (rpm), CS = *Chapati* score

Table 10. Correlation matrix of the starch pasting characteristics evaluated for cultivars and genetic stocks during first year.

	Paste temperature	Peak viscosity	Hold viscosity	Final viscosity	Setback	Breakdown	Falling number
Peak viscosity	-0.10						
Hold viscosity	0.03	0.95*					
Final viscosity	0.15	0.90*	0.95*				
Setback	-0.35*	0.79*	0.57*	0.48*			
Breakdown	0.45*	0.46*	0.53*	0.76*	0.10		
Falling nmber	0.12	0.69*	0.82*	0.73*	0.21	0.25*	
Chapati Score	-0.33*	0.26*	0.17	0.18	0.36*	0.05	0.31*

* Significant at 5% level

Table 11. Correlation matrix of the starch pasting characteristics evaluated for cultivars and genetic stocks during second year.

	Paste temperature	Peak viscosity	Hold viscosity	Final viscosity	Setback	Breakdown	Falling number
Peak viscosity	-0.38*						
Hold viscosity	0.30*	0.78*					
Final viscosity	0.16	0.68*	0.98*				
Setback	-0.89*	0.47*	-0.20	-0.28*			
Breakdown	-0.53*	0.70*	0.92*	0.1	-0.10		
Falling nmber	-0.45*	0.47*	0.62*	0.52*	-0.08	0.78*	
***Chapati* Score**	-0.90*	-0.54*	-0.69*	-0.31*	-0.09	0.21	0.08

* Significant at 5% level

of 9.00 cm^2 and 9.67 cm^2 respectively. In this group only PBW 550 gave high value of 18.67 cm^2. The genetic stocks on the other hand gave high values with WH 1003 giving highest value of 27.33 cm^2 for the season. K 0123, however, gave a low value of 12.67 cm^2. The released varieties with known quality also gave low values of dough development area having a group average of 13.08 cm^2. Intermediate range of values was observed for the tall wheats, which gave best *chapati* scores. The advanced lines PBW 534 and PBW 554 gave higher values whereas HI 1418 and HI 1479 gave low values for dough development area. Overall examination of data for the two seasons showed that the tall varieties changed little over time for dough development area. In general the stronger wheats produce mixing curves with larger dough development area. Ideally the dough development area should be lower which corresponds with the lower energy requirements for developing satisfactory dough. This fact is of greater importance in case of varieties included for use in *chapati* making whereas mixing of dough is generally carried through manual kneading. The populations were found to be normally distributed for dough development area, with the population mean of 'B' population being higher than other two populations. Most of the lines in the populations were observed to give higher values than the better parent in all the three recombinant populations. In population 'A' the dough development area values observed for the parents were 18 cm^2 and 9 cm^2 for C 273 and PBW 343 respectively. Only 1 genotype out of 70 was found to

Table 12. Correlation matrix of the mixographic characteristics evaluated for cultivars and genetic stocks during first year.

	Mixing time	**Dough strength**	**Rate of dough development**	**Rate of dough weakening**	**Mixing tolerance index**	**Dough development area**	**Baking strength**
Dough strength	0.10						
Rate of dough development	-0.56*	0.58*					
Rate of dough weakening	-0.49*	0.25*	0.40*				
Mixing tolerance index	0.64*	-0.54*	-0.92*	-0.73*			
Dough development area	0.93*	0.42*	-0.31*	-0.32*	0.37*		
Baking strength	0.50*	0.67*	0.06	-0.16	0.03	0.71*	
***C*hapati Score**	-0.44*	-0.68*	-0.20	0.16	0.08	-0.61*	-0.68*

* Significant at 5% level

Table 13. Correlation matrix of the mixographic characteristics evaluated for cultivars and genetic stocks during second year.

	Mixing time	**Dough strength**	**Rate of dough development**	**Rate of dough weakening**	**Mixing tolerance index**	**Dough development area**	**Baking strength**
Dough strength	-0.37*						
Rate of dough development	-0.91*	0.58*					
Rate of dough weakening	-0.59*	0.50*	0.57*				
Mixing tolerance index	0.85*	-0.61*	-0.89*	-0.88*			
Dough development area	0.97*	-0.19	-0.82*	-0.48*	0.74*		
Baking strength	0.82*	0.14	-0.58*	-0.37*	0.54*	0.79*	
*C*hapati score	-0.14	0.23	0.33*	0.28*	-0.34*	-0.01	-0.20

* Significant at 5% level

have dough development area values to range between the parental values. 69 genotypes gave higher values than that of C 273 whereas no genotype was found to have value lower than that of PBW 343. In population ‘B’ the values of the parents, C 306 and PBW 534, observed were 11 cm^2 and 22 cm^2 respectively. Only 3 genotypes out of 70 were found to have values in the parental range whereas 67 genotypes gave values higher than that of PBW 534 and no genotype had values lower than that of C 306. In population ‘C’ 3 genotypes out of 80 were observed to have values of dough development area in the parental range of 10 cm^2 (C 518) and 12 cm^2 (PBW 343). 74 genotypes had values higher than that of PBW 343 whereas only 3 genotypes were having values lower than that of C 518.

Baking strength is the total area under the mixographic curve and determines the suitability of a wheat variety for its end use. Baking strength of the genotypes varied from 39.00 cm^2 for PBW 502 to 51.67 cm^2 for WH 1003 in first year. The genetic stocks showed a range of values for baking strength, with WH 1003 and WH 800 (51.33 cm^2) giving high values where as KYZ K2K-13 gave a low value of 39.33 cm^2. The advanced lines, however, gave high values whereas the tall wheats and the commercially grown varieties showed low to medium range of values for baking strength. Glupro was observed to have a high value of 59 cm^2. In second year the baking strength was found to vary from 37.33 cm^2 for PBW 502 to 53.33 cm^2 for PBW 550. The genetic stocks gave high values, whereas the commercial wheat varieties such as PBW 343 and DBW 16 gave baking strength values of less than 40 cm^2. The advanced lines PBW 534 and PBW 554 gave a high value of 51 cm^2, whereas, HI 1418 and HI 1479 gave a low value of 41.67 cm^2. The released varieties with known quality and the tall wheats were once again found to have low to medium values of baking strength in this season also. The variation

Table 14. Correlation coefficients of the mixographic and starch pasting characteristics with *chapati* score for recombinant populations

Starch pasting characters	Correlation coefficient			Mixographic characters	Correlation coefficient		
	A	B	C		A	B	C
Pasting temperature	0.16	-0.02	0.12	Mixing time	-0.31*	-0.45*	-0.17
Peak viscosity	-0.31*	0.10	-0.06	Strength	0.05	0.03	-0.17
Hold viscosity	-0.22	-0.11	-0.09	Rate of dough development	0.32*	0.40*	0.34*
Final viscosity	-0.38*	-0.13	-0.24*	Rate of dough weakening	0.00	0.28*	-0.04
Breakdown	-0.27*	0.14	0.05	Mixing tolerance	-0.17	-0.39*	-0.21
Setback	-0.44*	-0.16	-0.33	Dough development area	-0.23	-0.06	-0.23*
Falling number	-0.01	0.06	-0.03	Baking strength	-0.07	0.22	-0.23*

* Significant at 5% level

for the trait over the period of study was not much and the characteristic seems to be quite stable therefore it can be successfully utilized in screening of breeding materials. The baking strength of the lines in the recombinant populations was found to be normally distributed in all the three cases. Baking strength values higher than the better parent were recorded in most of the genotypes within population 'B' giving higher population mean than other two populations. In population 'A' the values of baking strength of the parents were observed to be 49 cm^2 and 36 cm^2 for C 273 and PBW 343 respectively. 17 genotypes out of 70 gave values in this parental range, whereas 53 genotypes gave values higher than that of C 273 and no genotypes was found to have value lower than that of PBW 343. In population 'B' the parental values of baking strength were observed to be 42 cm^2 and 50 cm^2 for C 306 and PBW 534 respectively. 3 genotypes out of 70 were found to range in between the parental values whereas 65 genotypes gave values of baking strength higher than that of PBW 534 and only 2 genotypes were found to have values lower than that of C 306. In population 'C' the parental range was observed to be narrow and the values of baking strength observed for C 518 and PBW 343 were 38 cm^2 and 37 cm^2 respectively. All the 80 genotypes in the population were found to have baking strength values higher than that of C 518.
Rheological studies are being utilised extensively for the evaluation of flour quality (Vizitiu *et al* 2012). Ahmed *et al.* (2015) studied physicochemical and rheological properties of soft wheat flours obtained from different wheat varieties grown in Pakistan, Ukraine and India. The rheological behaviour of Indian wheat flour showed high water absorption, high dough stability and less degree of softening. Our results are in line with the reports from literature.

Genetic variation for starch pasting characteristics: Starch pasting characteristics, studied using Rapid Visco™ Analyser (RVA), include different parameters used to understand the visco-elastic properties of starch granules when subjected to high temperatures and mechanical shear. The pasting temperature provides an indication of the minimum temperature required to cook a given sample. Peak viscosity indicates the water-binding capacity of the starch whereas final viscosity depicts the ability of starch to form a viscous paste after cooking and cooling. The hold viscosity indicates the ability of a sample to withstand the heating and shear stress. The higher peak and final viscosity values indicate the higher water holding capacity of starch which has a significant role in the baking quality. Breakdown and setback define the quality of the starch. The genotypes showed significant genotypic differences for all starch pasting characteristics studied during both seasons (Table 3 a and b). The mean performance of genotypes for various starch pasting characteristics is given in table 2 and 3. The starch pasting characteristics were also found to have significant genotypic differences in all the three populations (Table 6a, b and c). Whereas the mean performance of the genotypes for starch pasting characteristics is given respectively in table 7, table 8 and 8 for population 'A', 'B' and 'C'.
The pasting temperature for the wheat starch was observed to vary between 67.07^o for PBW 550 and 69.90^o for PBW 534 in first year. The tall wheats and the advanced lines recorded higher pasting temperature in comparison to genetic stocks and commercial wheats. In second year the pasting temperature showed more variation with the values ranging between 68.57^o for 8A and 71.23^o for PBW 502. The genetic stocks, the commercial varieties and the advanced lines gave higher values. The tall wheats and the released varieties with known quality recorded values on lower side. The pasting temperature was found to show a lot of variation within and between the populations. The populations 'A' and 'C' were somewhat normally distributed and slightly skewed towards lower side. These populations gave non overlapping means for pasting temperature, whereas population 'B' was found to be skewed towards both the extremes. In population 'A' the values of pasting temperature obtained for the parents are 69.53^{0C} and 71.07^{0C} for C 273 and PBW 343 respectively. 4 genotypes out of 70 gave values in this parental range whereas 66 genotypes gave values lower than that of C 273 and no genotypes with a value more than that of PBW 343 was obtained. In population 'B' 12 geno-

types out of 70 gave values in the parental range of 68.47^{0C} (C 306) and 69.90^{0C} (PBW 534). 13 genotypes gave values less than that of C 306 whereas 45 genotypes were found to have pasting temperature values of more than that of PBW 534. In population 'C' the parents C 518 and PBW 343 gave pasting temperature values of 68.67^{0C} and 67.37^{0C} respectively. Only 3 genotypes out of 80 gave values in the parental range, whereas 46 genotypes were observed to have values higher than that of C 518 and 31 genotypes gave values lower than that of PBW 343.

The values of peak viscosity observed in first year varied from 1609.67 cp for WH 423 to 3580.00 cp for PBW 534. Low values were observed for all the tall wheats except C 591 which gave a value of 3021.33 cp. The genetic stocks on the other hand gave high values with WH 595 (3455.00 cp), WH 712 (3317.33 cp), WH 800 (3172.00 cp), WH 1003 (3266.67 cp) and HD 2793 (3042.33 cp) all recording values above 3000 cp. However, low values of 1609.67 cp (WH 423) and 2194.00 cp (KYZ K2K-13) were also recorded in this group. The commercial varieties and the advanced lines gave medium to high values of the peak viscosity in this season. In second year the observed values of peak viscosity ranged between 2623.00 cp for HI 1418 and 3800.00 cp for WH 1003. The genetic stocks showed high values in this season and the tall wheats gave values on lower side for peak viscosity. In tall wheats group 9D (3508.67 cp) and C 591 (3493.67 cp), whereas in released varieties with known quality group Lok 1 (3583.67 cp) and PBW 175 (3662.00 cp) gave higher values of peak viscosity. All the advanced lines, barring HI 1418 which gave 2623.00 cp, gave high values as was the case with commercial wheat varieties. However DBW 16 gave a value on lower side (2973.00 cp). The populations were found to have a wide range of variation as far as peak viscosity is concerned. The parental extremes as well as transgressive segregants on both sides were obtained in all the three populations. The peak viscosity of the parents of population 'A' was observed to be 3190.00 cp and 3399.00 cp for C 273 and PBW 343 respectively. 16 genotypes out of 70 were found to have peak viscosity in this parental range, whereas 31 genotypes gave values higher to that of PBW 343 and 23 genotypes gave values lower to that of C 273. In population 'B' 45 genotypes out of 70 were found to have peak viscosity values in the parental range of 2588.00 cp (C 306) and 3580.00 cp (PBW 534). 18 genotypes gave values higher to that of PBW 534 and 7 genotypes gave values lower than that of C 306. In population 'C' the parents C 518 and PBW 343 were observed to have peak viscosity values of 20.49.67 cp and 2686.00 cp respectively. 49 genotypes out of 80 gave values in this parental range, whereas 26 genotypes were found to have values higher than that of PBW 343 and only 5 genotypes gave values lower than that of C 518.

The value of hold viscosity varied from 919.67 cp for WH 423 to 2528.33 cp for PBW 534 in first year. The tall wheats gave medium range of values with C 518 giving a value of 1227.67 cp. The genetic stocks gave values ranging from low for KYZ K2K-13 (1284.00 cp) to high for WH 595 (2251.33 cp). The commercial varieties and the advanced lines showed medium values with only PBW 534 giving high value for hold viscosity. The values of hold viscosity ranged between 1891.33 cp for HI 1418 and 2941.67 cp for WH 1003 in second year. The genetic stocks gave higher values with WH 1003 giving the highest value in the season. The commercial wheats also gave high values of hold viscosity; PBW 533 however, gave a medium value of 2234.33 cp. The tall wheats gave low to medium values except 9D (2680.67 cp) which gave a high value. The advanced lines (except HI 1418) gave medium values, whereas released varieties with known quality PBW 175 (2738.00 cp) and LOK 1 (2612.67 cp) gave high values. PBW 226, however, gave a low value of 2006.33 cp hold viscosity. All the three recombinant populations exhibited normal distribution for variation in hold viscosity. In population 'A' a large number of transgressive segregants were found to be on lower side where as their number was more on higher side in population 'C'. In population 'B' most of the variation for this trait was found to be lying in between the parental range with a few individuals being outside the range on both higher and lower sides. The parents of population 'A' C 273 and PBW 343 gave hold viscosity values of 2388.67 cp and 2828.67 cp respectively. 19 genotypes out of 70 gave values in this parental range, whereas 49 were observed to have lower value of hold viscosity than that of C 273. Only 2 genotypes were found to have values higher than that of PBW 343. In population 'B' the hold viscosity values of the parents were observed to be 1679.67 cp and 2528.33 cp for C 306 and PBW 534 respectively. 50 genotypes out of 70 gave values in this parental range with only 4 genotypes having higher values than that of PBW 534. 16 genotypes were observed to give hold viscosity values lower than that of C 306. In population 'C' the parental values for hold viscosity were observed to be 1227.67 cp and 1830.00 cp for C 518 and PBW 343 respectively. 40 genotypes out of 80 were observed to fall in this range whereas 34 gave higher values than PBW 343 and 6 genotypes gave values lower to that of C 518.

The final viscosity of the set of genotypes in first year ranged between 1827.67 cp for WH423 and 4154.00 cp for PBW 534. The tall wheats recorded medium range of values except C 518 which gave a low value of 2414.67 cp. The advanced lines PBW 554 (2819.67 cp) and PBW 531

(2553.33 cp) gave medium values in comparison to PBW 534 which gave highest value in the season. The commercial varieties gave high values except PBW 502 which gave a low value of 2560.67 cp for final viscosity. The genetic stocks showed a range of values from 1827.67 cp (WH 423) to 3525.00 cp (HD 2793). The values of final viscosity in second year, ranged from 3351.00 cp for HI 1418 to 4658.33 cp for K 0123. All the genetic stocks and the commercial wheat varieties except PBW 533 (3579.33 cp) gave high values of final viscosity whereas the tall wheats gave lower values in comparison. Low values were observed for PBW 226 (3408.67 cp) and WG 357 (3513.67 cp). The advanced lines also gave high values with an exception of HI 1418. On the whole the final viscosity values during second year were much higher showing thereby that this character is affected by the environment to a great extent. A wide range of variation was observed for final viscosity in all the populations. The variation was found to be normally distributed in all the three cases. In populations ‘A’ and ‘B’ more number of lines were observed above the better parent where as in population ‘C’ almost all the variation was found to be on higher side of the better parent. The final viscosity values of the parents of population ‘A’ were observed to be 3914.67 cp and 4396.67 cp for C 273 and PBW 343 respectively. 37 genotypes out of 70 were observed to have final viscosity values higher than that of PBW 343 and 15 genotypes gave values lower than that of C 273 whereas 18 genotypes fell in the parental range. In population ‘B’ 18 genotypes out of 70 fell in the parental range of 3132.00 cp (C 306) and 4154.00 cp (PBW 534). 50 genotypes were having a final viscosity higher than that of PBW 534 whereas only 2 genotypes were found inferior to C 306. In population ‘C’ the parental values of final viscosity for C 518 and PBW 343 were observed to be 2414.67 cp and 3110.00 cp respectively. 72 genotypes out of 80 gave values higher than that of PBW 343 and 3 genotypes were found to have final viscosity lower than that of C 518. 5 genotypes gave values in the parental range.

Breakdown values ranged from 844.00 cp for PBW 502 to 1606.00 cp for PBW 534 in first year. High values of breakdown were observed for all the tall wheats and the commercial wheat varieties except PBW 502 which gave lowest value in the season. The advanced lines also gave low to medium values with PBW 534 being an exception. The genetic stocks gave higher values with only WH 423 and KYZ K2K 13 showing low values of 954.33 cp and 1078.00 cp respectively. In second year the values of breakdown were found to range from 1126.33 cp for HI 1418 to 1976.00 cp for K 0123. The tall wheats and the genetic stocks gave high values in this season, whereas the commercial wheat varieties and the advanced lines gave low values of breakdown. Medium to high values of breakdown were however observed for the released varieties with known quality. The breakdown viscosity of the individuals in the recombinant populations was observed to be normally distributed and the individuals excelling above the better parent were found in large numbers. Most of the transgressive segregation was on higher side of the better parent. In population ‘A’ the values of breakdown viscosity observed for the parents were 1526.00 cp and 1568.00 cp for C 273 and PBW 343 respectively. Only 2 genotypes out of 70 in this population were observed to have breakdown viscosity in this parental range. 65 genotypes gave higher values than that of PBW 343 and 3 genotypes were found to have values below that of C 273. In population ‘B’ 66 genotypes out of 70 were observed to have breakdown viscosity more than that of PBW 534 (1606.00 cp) and only 1 genotypes gave values less than that of C 306, whereas 3 genotypes gave values in the parental range. In population ‘C’ the parents C 518 and PBW 343 were observed to have breakdown viscosity of 1292.33 cp and 1285.67 cp respectively. 77 genotypes out of 80 gave higher values of breakdown than that of C 518 and 3 genotypes gave values below the value of PBW 343. No genotype was however found to fall in the parental range.

Setback is the difference between hold viscosity and the final viscosity. It determines the viscosity of the wheat flour paste on cooling and the final water holding capacity at a specified viscosity level. The values for setback ranged from 720.67 cp for WH 423 to 1415.67 cp for PBW 509 in first year. The tall wheats C 306 and C 518 were found to have lower values of 953.67 cp and 837.67 cp respectively, whereas C 273 (1030.33 cp) and C 591 (1056.67 cp) were found to have medium-high values of setback viscosity. Similarly the commercial wheat varieties PBW 343 (861.67 cp) and PBW 502 (766.33 cp) gave low values, whereas PBW 550 (1093.00 cp) and PBW 509 (1415.67 cp) gave medium and high values respectively. The advanced lines also gave medium to high values for setback, whereas the genetic stocks gave variable range of values in this season. The winter wheat, Glupro, however gave lowest value of 671.67 cp. In second year the values of setback viscosity incase of tall wheats were observed on same lines as in last season. C 306 (668.67 cp) and C 518 (661.00 cp) gave relatively lower values in comparison to C 273 (801.33 cp) and C 591 (938.67 cp). In commercial wheat varieties group PBW 343 and PBW 502 gave low values again in this season. DBW 16 in this group however gave lowest value of 340.00 cp. The highest value of setback in this season was observed to be 1019.67 cp for PBW 534 from advanced lines group. The released varieties with known quality gave high values of setback, whereas the genetic stocks gave medium to high values except HD 2793 which gave a lower value of 526.67 cp. The genetic variation for setback viscosity in case of recombinant populations was found to be normally distributed in all the three cases. In all the populations the transgressive segregants were observed in large numbers on higher side with few showing values on lower side of the parental range. In population 'A' 69 genotypes out of 70 were observed to have setback values higher than that of C 273 (801.33 cp) and 1 genotype gave values in the parental range. However no genotypes with setback value lower than that of PBW 343 was observed in the population. In 'B' population the parental values of setback observed were 953.67 cp and 1019.67 cp for C 306 and PBW 534 respectively. 19 genotypes out 70 were found to have values of setback viscosity in the parental range whereas 36 genotypes gave values higher than that of PBW 534 and 15 genotypes gave values lower than that of C 306. In population 'C' the parents were observed to have the setback values of 837.67 cp and 889.00 cp for C 518 and PBW 343 respectively. 9 genotypes out of 80 were found to have values in this parental range whereas 66 genotypes gave higher values of setback than that of PBW 343 and 5 genotypes gave values lower than that of C 518.

Correlation of different traits with *chapati* score: Association of traits studied with *chapati* score in set of cultivars and genetic stocks for two years as revealed by genotypic correlation coefficients is given in table 10 and 11 for starch pasting and in table 12 and 13 for mixographic characteristics. Starch pasting characteristics showed mild negative correlation with *chapati* quality, which is again contrasting, to the requirements of bread making. The correlations were not consistent over years possibly due to environmental factor and due to change in the constitution of the set. Similarly mixographic traits showed negative association *chapati* making quality. Thus unlike bread making strong dough is not suitable for *chapati* purposes or we can say that the genotypes chosen were having low mixing time (< 2 min) except for 'Glupro' in first year (3.10 min). This trend is reinforced by mild negative correlation observed for baking strength as well. Other mixographic traits did not seem to have clear implications for *chapati* quality. In general superior *chapati* quality wheats scored low for almost all the mixographic characteristics thus negative correlation as observed in one or the other season was expected. Consistent trends were however not observed possibly due to change in set constituents and differential environment prevailing in two seasons. Thus, the other set of quality parameters associated with bread making were seemed to be of no consequence for *chapati* making quality. A positive correlation trend has been reported earlier (Gupta *et al* 1993; Zhang *et al* 2008; Singh *et al* 2011).

The correlations which prevail in the populations carry much greater weight as these have persisted over several rounds of recombination and are likely to reflect under lying causes of superior *chapati* quality. As various components of *chapati* quality would be disassembled, the relative levels of correlations for individual traits would be uncovered. The present study in this regard represents an important advance as most of previous correlation studies were based on set of cultivars. The availability of single year data in case of populations is to some extent off set by the presence of three populations, namely A, B and C. Valuable correlation trends which extend across the three populations are summarized in table 14. Among the starch pasting characteristics, final viscosity and setback are consistently negatively associated with the *chapati* making quality. In case of the mixographic traits, mixing tolerance index is negatively associated whereas rate of dough development has consistent positive correlation with *chapati* quality.

Conclusion

The above trends have become visible due to availability of three parallel experiments on three recombinant populations. The bias in the correlation landscape generated by the set of cultivars and genetic stocks stands corrected in the aspects that two starch pasting and two mixographic traits have been identified to be associated with superior *chapati* quality. *Chapati*-making properties of flours from different wheat varieties is generally influenced with starch content and rheological properties of gluten. This study is one of its kind as it tries to explain the genetic basis of these traits based on recombinant populations. This work can further is used in wheat grain industry for producing wheat flour with specific characteristics as are desired for chapati quality.

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