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Harnessing flour recovery in the Indian wheat

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ABSTRACT

Flour recovery in 100 wheat (*Triticum aestivum* L.) varieties samples received from different locations and regions of India during 2005-11was studied for its association with baking and 15 other grain quality parameters. Differences in flour recovery were noticed between and within different regions of the country. Environmental influence in flour yield was not consequential due to absence of crop year variations and the varietal interactions with crop years and locations were also insignificant. In certain regions, interaction between locations and crop years assumed significance and sites with better flour recovery could be noticed. Wheat from peninsular region was rated best for milling yield, i e 71% whereas the most productive wheat land of the country, i e north western plains, was restricted to 68% only. Wheat grown in northern hills was very poor with flour yield as low as 65%. Suitable varieties and most conducive locations were suggested to harness flour recovery in different parts. Relationship between extraction rate and end-product quality was very strong and positive with bread volume, bread and *chapati* qualities; and negative with biscuit spread factor. Impact of various physico-chemical grain properties was affirmative, except for â carotene. Route to flour yield was examined through multiple regression analysis and the key contributing traits were test weight, grain appearance, grain protein content, sedimentation value, grain hardness index and certain micronutrients like iron, copper and manganese. Backward multiple regression analysis emphasised high contribution of some micronutrients like copper and iron, under various trait combinations. Contribution of these constituents varied at the regional level, strategy for genetic improvement in flour yield, therefore, would also vary accordingly. Defining constituent grain parameters in Indian varieties shall be useful to develop varieties with enhanced flour recovery.

Key words: Extraction rate, Flour recovery, Indian wheat, Milling yield, Product quality, Quality parameters, Varietal interactions

Flour recovery in wheat (*Triticum aestivum* L.) is vital for the milling industry both in domestic as well as international markets. Varieties with higher milling efficiency swell profit of the industry from bump up in quantity of the products produced from more flour extracted per unit of wheat milled. Flour recovery amounts to the white flour extracted from wheat grain during milling; therefore it is also denoted as flour yield or extraction rate. In wheat, 100% extraction is achievable in the wholemeal flour where all grain parts are consumed. Since white flour is derived through endosperm excluding bran and the germ part of the grain, extraction rate gets dropped. Even though, 85% of grain by weight is endosperm, the flour yield differs between the varieties. Flour yielding ability of a wheat variety depends not only on the genetic constitution but also on the environment in which it was grown (location, soil and agronomy), the milling process and the machinery used to extract flour. As per international standards, milling yield of new high yielding Indian wheat varieties can be rated moderate (range: 63.3-71.8%) and just a handful of them exceed 71%. In comparison, average monthly flour extraction rate in USA was 74.6% during the period from 1990/91 to 2007/08 and it had shown upward trend averaging 77% during the period 2008-10 (Vocke 2012). In fact, certain varieties with better flour recovery (75-78%) were available earlier in the Indian wheat programme (Hanslas 1986) but in pursuit to boost grain yield, the new genetic backgrounds perhaps added erosion in flour yield. The constant industrial demand of better flour yielders urges the wheat researchers to find ways and means through genetically superior varieties and better production cum processing management. It is imperative to revive that approach with new interventions so that the growers and industry both get benefitted. The study based on set of diverse wheat aimed to identify the stable genetic resource and suitable sites, examine influence of environment and G × E interactions, identify the key

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contributing traits and plan strategy to harness better flour recovery under Indian conditions.

MATERIALS AND METHODS

Samples of the bread wheat varieties qualified as checks in the coordinated trials conducted by the All India Coordinated Wheat and Barley Improvement Project (AICW&BIP) in different zones, i e north-western plains zone (NWPZ), north-eastern plains zone (NEPZ), central zone (CZ), peninsular zone (PZ), northern hills zone (NHZ) and southern hills zone (SHZ); were analyzed at the Directorate of Wheat Research, Karnal. Locations representing the zones were Almora, Shimla and Palampur for NHZ; Ludhiana, Delhi, Hisar, Pantnagar and Durgapura for NWPZ; Kanpur, Pusa and Sabour for NEPZ; Kota, Indore, Powarkheda, Vijapur and Junagarh for CZ; and Pune, Niphad and Dharwad for PZ. During 2005-11, 100 released wheat varieties were represented as checks in different zones under AICW&BIP and their zonal mean was considered to identify better flour yielders for different regions. Inclusion of varieties from different agro-ecological regions of the country added diversity to the material under study. This diverse study material was further screened to have varieties with at least three years multilocation testing in the past five years, i e 2007-11. Fifty one varieties qualified on that account which were studied for association of flour yield with quality of end-products (bread, *chapati* and biscuit) and 15 grain quality parameters like grain appearance, test weight, kernel weight, grain protein content, sedimentation value, grain hardness index, wet and dry gluten contents, gluten index, GLU 1 score, yellow pigments, iron, zinc, copper and manganese contents and data was assessed through correlation and multiple regression analysis. AACC (2000) method was applied to examine processing and milling quality while micronutrient content was recorded through atomic absorption technique (Jackson 1973).

To workout regional differences at the country level and location differences within a zone, released varieties and the genotypes in final year of testing under irrigated or semi-irrigated in AICW&BIP (388 genotypes) were examined for flour yield and constituent grain quality characteristics. All sites within a zone had same set of genotypes and t-test was applied to detect differences among them. To gauge interactions in every zone, three years data (2009-11) of three locations and six varieties (three timely sown and three late sown) was statistically examined by two factor analysis. Statistical analysis was done separately for each interaction considering varieties as replication for location × crop-seasons, years for variety × site and locations for variety × year interactions.

RESULTS AND DISCUSSION

Status of varieties and genetic resource

Study on flour recovery of 100 in the Indian bread wheat varieties revealed that only ten of them had extraction rate =71% out of which the irrigated varieties were just five namely HUW 468, K 9107 and K 307 in NEPZ; and HI 977 and HD 2189 in PZ. Another 19 varieties registered flour recovery in the range of 70.0-70.9%. There was no variety with flour yield ≥70% in wheat bowl of the country, i e NWPZ. Flour recovery in the top four varieties of this region (WH 1080, HD 2967, DBW 17 and PBW 175) was ≈69.5% only. Flour recovery in NHZ varieties was very poor (63-66%), hence unprofitable to the flour industry. Extraction rate in timely sown varieties remains similar to that of late sown (Mohan and Gupta 2008) and it did not differ in this set also (≈69%). The rainfed varieties did not emerged commercial unviable (mean: 67.9%) on that ground, especially in the Indo-Gangetic Plains, i e NWPZ and NEPZ. Even though certain rainfed varieties of central and peninsular India did register good flour recovery (≥71%) like NI 5439, MP 3288, NIAW 1415 and HD 2987 but it is difficult to capitalize their superiority at the commercial level due to their low grain yield potential. Cultivar differences in soil fertility show relationship with flour yield in wheat (Bhatt and Derera 1975). Even though modern high yielding varieties could not exceed the 72% level, some old Indian varieties of 1961-86 era had recorded flour yield ≥75% (Hanslas 1986), namely UP 1109 and Kalyansona from NHZ; NP 890, Sharbati

Table 1 Varietal diversity and the genetic resource in 100 bread wheat varieties

Zone	Varieties	Range	Varieties with flour recovery 71.0-71.8%	Varieties with flour recovery 70.0-70.9%
NHZ	19	63.3-66.4		
SHZ	3	68.1-68.9		
NWPZ	19	66.0-69.6		
NEPZ	20	66.6-71.6	HUW 468, K 307 and K 9107	HD 2733, HUW 234, DBW 39 and DBW 14
CZ	17	68.1-71.0	MP 3288	DL 788-2, MP 1203, MP 4010, LOK 1, GW 173, GW 366 and HI 1544, HD 2781
PZ	22	67.8-71.8	NI 5439, NIAW 1415, HI 977, PBW 596, HD 2189 and HD 2987	RAJ 4037, RAJ 4083, HD 2932 MACS 6222, AKAW 4627 and NIAW 917

Sonora, RAJ 1482 and RAJ 2184 from NWPZ; K 68, K 8020and Malvia 213 from NEPZ; and HW 657 from PZ but they got out of cultivation because of poor grain yield and disease susceptibility. Flour yield recorded in research lab of India (63-72%) was low but similar range had been achieved in many experimental research findings carried in USA (Kaldy *et al.* 1991). The actual flour yield achieved by the millers goes higher because of improved processing facilities.

Environment plays an important role in making wheat quality highly variable. To investigate its gravity in flour recovery, varieties with atleast ten data points (locations cum crop seasons) were examined for consistency levels. Seventy varieties qualified on that ground and the coefficient of variation in that set was just 1.34 to 4.14%. It shows that influence of environment in flour recovery is not high which makes this character highly heritable. This attribute makes flour recovery different from several other important grain quality traits like protein and gluten contents, sedimentation value, grain hardness index, yellow pigments and the physical appearance which are highly prone to the surrounding environmental. Varieties with flour recovery ≥71% and coefficient of variation below 2% were NI 5439, HUW 468, HD 2189, K 307 and PBW 596. Other consistent varieties with flour recovery within the range of 70-71% were RAJ 4037, K 9107, MACS 6222, DBW 39, NIAW 917, GW 366, GW 173 and HI 1544.

Importance of locations

To survey site superiority in flour yield, average performance of only those genotypes was considered which were common at all sites in that zone. It was interesting to note that location differences ceased to exist in the lowest flour yielding region, i e NHZ as well as the highest flour yielding territory, i e PZ (Table 2). It accentuates that high flour yield (≥70%) in PZ is achievable throughout the region and wheat from any part of that area is commercially suited to the millers. In NWPZ, wheat flour recovery at Dugapura, Pantnagar and Delhi (≈68.5%) was statistically better in comparison to Ludhiana and Hisar. Similarly in central India; Junagarh, Vijapur and Kota with flour recovery ≈70% were better choice in comparison to Indore and Powarkheda. In NEPZ also, Pusa had an edge over Kanpur and Sabour. Site selection, therefore, is paramount to harness high flour yield in wheat. Site specific milling efficiency had been reported in wheat (Stenvert and Moss 1974, Marshall *et al.* 1986, Metho *et al.* 1999, Sauza *et al.* 2004, Yong *et al.* 2004, Mohan and Gupta 2008) and it tremendous scope lies to exploit it under Indian conditions as well.

Role of interactions

Even though flour recovery registered low environmental influence, it was important to critically examine the significance of major environment factors like season to season variations (years), locations and interactions among them (Year × Site) along with varietal interactions with these two environmental factors (G × E). Three crop season data pertaining to three locations was examined in six varieties of each zone. It was important to note that crop season did not impose any significant effect on flour yield in any of the zones (Table 3). Consistency in flour recovery under NWPZ conditions of India (Mohan *et al.* 2011) and its high heritability (Bhutt and Derera 1975) had been reported in wheat. Flour recovery was quite stable in NHZ and PZ as no location effect was observed in those regions. Location effect was significant in NWPZ, NEPZ and CZ and so also was its interaction with the crop seasons. Even though location effect is conspicuous in some zones but exploiting milling efficiency by choosing better sites can be very cumbersome in view of the significant location × crop year interactions. Similar interactions had also been noticed in USA for flour yield and hardness (Bassett *et al.* 1989). Interestingly, varieties did not exhibit any interaction with crop seasons and locations. Lack of varietal interaction with year and sites had been reported under NWPZ conditions by Mohan *et al.* 2011. Insignificance of location-cultivar interactions in the presence of large location and cultivar effects had been reported in wheat quality (Souza *et al.* 2004, Yong *et al.* 2004, Pena 2008, Williams *et al.* 2008); as a consequence genotypes tend to rank similarly across locations. Absence of crop year effect and varietal interactions with the surrounding environment

Table 2 Regional and location impact on flour recovery (%)

Zone	Data points	Locations				
NHZ	73	Almora 64.4	Shimla 64.6	Malan 64.9		
NWPZ	52	Ludhiana 67.6	Durgapura 68.6	Delhi 68.3	Pantnagar 68.5	Hisar 67.8
NEPZ	47	Kanpur 69.5	Pusa 70.4	Sabour 69.8		
CZ	43	Indore 69.6	Kota 69.9	Junagarh 70.3	Powarkhrda 69.2	Vijapur 69.9
PZ	63	Pune 70.0	Dharwad 70.4	Niphad 70.7		

Table 3 Level of significance (Probability) in interaction for flour recovery

Source of variation		Significance (P value)				
		NHZ	NWPZ	NEPZ	CZ	PZ
A.	*Crop years, locations and their interactions*					
	Crop season	0.974	0.271	0.070	0.178	0.100
	Location	0.143	0.000	0.001	0.000	0.162
	Year × location interaction	0.908	0.003	0.017	0.011	0.237
B.	*Varietal interactions with crop season and locations*					
	Variety × crop season	0.256	0819	0.140	0.558	0.843
	Variety × location	0.472	0.949	0.874	0.245	0.852

make flour recovery a fairly consistent trait in all zones of the country. It is only the location effect that can make flour recovery vary in some parts of the country like NWPZ, NEPZ and CZ. Overall, the peninsular region in the country is better suited not because of high flour yield but also on account of minimal environmental variations and interactions.

Contributing grain parameters

Selection for higher milling yields in breeding programmes is not being addressed currently because it requires a large quality of seed in early generations. Enriching the varieties with component traits therefore can be an alternate route to exhilarate milling efficiency. The correlation study revealed that but for grain look, kernel weight, GLU 1 score, zinc and manganese contents; all other traits under study were associated with flour recovery (Table 4). Correlation was highly significant in case of grain protein and gluten contents, grain hardness index, iron and copper contents. Sedimentation value, test weight and gluten index were also correlated positively whereas association with yellow pigments (β carotene) was negative. Grain hardness also plays an important role in flour milling, affecting the endosperm fracture pattern, starch damage; break flour release, particle size and the ease of separating bran from endosperm (Stenvert 1972). In the past, a range of different phenotypic predictors of milling performance have been assessed, including kernel size, test weight, thickness of the seed coat, grain hardness and depth of crease (Shuey 1960, Hook 1984, Marshall *et al.* 1986). Test weight has long been considered to be a rough but simple measure for estimating milling yield (Zeleny 1964), whereas reports of missing relationship are available as well (Gadheri *et al.* 1971). However, the relationship between test weight and flour yield appears to be both cultivar and site dependent (Stenvert and Moss 1974, Marshall *et al.* 1986). Grain characters like test weight, protein content, sedimentation value, gluten index and grain hardness index are important for baking quality also. Further enrichment with certain micronutrients like copper and iron can prove useful in enhancing milling yield of wheat varieties.

Table 4 Multiple regression analysis

Parameters	Correlation coefficient	Regression coefficient		Beta value	Percent contribution
		Value	Significance		
		R value: 0.876, R^2 value: 0.768			
Grain appearance	0.231	–1.572	0.008 **	–0.228	–6.84
Test weight	0.344*	0.149	0.004 **	0.167	7.45
1000 grains weight	–0.009	0.169	0.189 ns	0.254	–0.30
Grain protein content	0.430**	0.200	0.000 ***	0.096	5.37
Sedimentation value	0.308*	0.037	0.003 **	0.084	3.38
GLU-1score	0.099	0.115	0.362 ns	0.077	0.99
Grain hardness index	0.386**	0.126	0.000 ***	0.494	24.83
Wet gluten %	0.428**	0.095	0.994 ns	0.077	4.30
Dry gluten %	0.448**	–0.009	0.164 ns	0.019	1.13
Gluten index	0.296*	–0.009	0.586 ns	–0.039	–1.52
Yellow pigments	–0.327*	–0.202	0.304 ns	–0.048	2.03
Iron	0.457**	0.080	0.013 *	0.210	12.49
Zinc	–0.010	0.016	0.604 ns	0.030	–0.04
Copper	0.547**	1.897	0.000 ***	0.569	40.53
Manganese	–0.206	–0.116	0.034 *	–0.253	6.78

In multiple regression analysis, high R value (0.876) was achieved reflecting that 77% contribution (R^2 value: 0.768) could be accounted by the 15 characters under study. The residual variability can be attributed to other grain properties like the amount of germ, thickness of the bran, depth of the crease, grain plumpness and starch structure (Marshall *et al.* 1984). However, significant contribution in this study came only from eight traits only, i e grain appearance, test weight, grain protein, sedimentation value, grain hardness index, iron, copper and manganese contents as the regression coefficient was statistically significant in those parameters only. Relative importance of those eight parameters was further adjudged by their percent contribution to the descriptor (flour recovery). It was observed that maximum contribution (%) came from copper followed by grain hardness and iron.

In backward regression analysis, order of deletion was wet gluten, zinc, gluten index, GLU 1 score, yellow pigments, dry gluten, TGW, manganese, grain appearance, grain hardness index, sedimentation value, copper, test weight, iron. Parameter that remained till last was the grain protein content, making it most vital attribute in flour recovery. R^2 value (0.739) with just eight significant contributors was nearly similar to the full set stretching their collective contribution to 74% (Table 5). The analysis further showed that 69% contribution could be accounted by six parameters, i e test weight, grain protein content, sedimentation value, grain hardness, iron and copper contents. Grain appearance had very strong correlation with test weight (0.799**). Association of manganese with copper was also very strong (0.423**), therefore these parameters lost importance when only six parameters were applied. Stretching backward analysis to just four parameters deleted sedimentation value and grain hardness index also. Sedimentation value was positively correlated with copper content (0.303*), whereas grain hardness also had strong associated with test weight (0.473**). With those four parameters also (test weight, protein, iron and copper), 58% variation could be described for flour recovery in Indian wheat. It was important to note that percent contribution of copper stood highest in all these combinations. Role of micronutrients therefore is vital in flour recovery. Density of these micronutrients can be increased in the grain either by adding these nutrients in the soil or by identifying genotypes that are more efficient.

Impact on end-product quality

The flour extraction rates affect the protein content, farino graph water absorption and gluten strength (Orth and Mander 1975) affecting the composition of flours. With an increase in the extraction rate, the protein content, fibre, sugar, lipids and mineral matter increases, whereas the starch decreases (Kent-Jones and Amos 1967). In the study material of 51variety, influence of extraction rate on product quality of bread, *chapati* and biscuit was highly significant. The correlations were highly significant and positive correlation with bread loaf volume (0.515**) and bread quality score (0.519**). Its relationship with *chapati* quality was also highly positive (0.671**). However, biscuit quality (spread factor) was adversely affected by increase in flour recovery (–0.517**). Flour recovery, therefore, pulls off importance not only for quantity of flour millers are going to get from the wheat grains but it also connotes industrial quality of the end-products like bread and biscuit. A strong positive impact of flour yield on bread (Orth and Mander 1975, Mohan and Gupta 2008) and *chapati* quality (Hatcher *et al.* 1997, Mohan and Gupta 2008) exists in bread wheat. Benefits of high flour recovery had also been reported in dry noodle making quality (Oh et al. 1985), the water absorption of the vermicelli (Vetrimani *et al.* 2005), pizza (Randhawa *et al.* 2002) and *naans* quality (Mueen-ud-Din *et al.* 2010).

Regional breeding strategy

Zone-wise assortment of 389 genotypes evaluated during 2005-11 revealed that milling yield poorest in NHZ (≤65%) and maximum (70.1%) in PZ (Table 6). Wheat samples received from central India and north-eastern plains also had flour recovery ≈70% but the region with highest wheat productivity in the country, i e NWPZ, was lowest (68.4%) among the plains. Looking back at the grain quality status of the key components at the national level, it was obvious that

Table 5 Backward multiple regression analysis

Grain components	8 components (R^2: 0.739)		6 components (R^2: 0.688)		4 components (R^2: 0.580)	
	P value	% contribution	P value	% contribution	P value	% contribution
Grain appearance	0.006 **	–1.46				
Test weight	0.003 **	10.15	0.000 ***	11.10	0.001 **	23.59
Grain protein content	0.000 ***	8.52	0.000 ***	13.26	0.000 ***	16.79
Sedimentation value	0.002 **	2.66	0.006 **	4.24		
Grain hardness index	0.006 **	15.01	0.011 *	20.75		
Iron	0.002 **	14.15	0.002 **	15.26	0.000 ***	25.59
Copper	0.000 ***	43.60	0.000 ***	36.16	0.002 **	32.62
Manganese	0.007 **	7.90				

Table 6 Flour recovery in irrigated AVT entries (Period: 2005-11)

Key grain parameters	NHZ (59)	NWPZ (84)	NEPZ (94)	CZ (66)	PZ (61)	SHZ (25)	All India (388)
Flour recovery (%)	64.6	68.4	70.0	69.8	70.1	68.5	68.8
Grain appearance score	5.95	5.70	5.83	6.40	6.01	5.42	5.90
Test weight (kg/hl)	78.8	77.9	78.1	81.5	80.6	78.4	79.0
Grain protein content (%)	11.4	12.6	11.6	12.3	12.6	11.6	12.1
Sedimentation value (ml)	41.5	40.5	43.6	40.5	44.6	43.6	42.6
Grain hardness index	68.8	79.3	73.3	76.2	76.2	80.7	76.0
Iron (ppm)	35.5	41.0	41.6	37.1	48.1	51.5	42.4
Copper (ppm)	4.17	5.06	4.66	5.53	5.38	4.52	5.00
Manganese (ppm)	39.6	38.5	41.0	41.4	40.5	39.3	40.3

the Indian wheat is not highly persuasive in majority of the components identified for good flour recovery. A relook on the defined key components at the zonal level brace the argument that the limiting factor in milling could vary in different regions. The best zone for milling yield, i e PZ, was also good in majority of the key components. In comparison, wheat gown in CZ lacked in sedimentation value and iron content. Flour recovery in NEPZ could be higher with increase in protein content, grain hardness and copper content, whereas in NWPZ; test weight, sedimentation value and iron could be the limiting factors. NHZ stood poor in several grain quality traits like protein, hardness index, iron and copper contents. The investigation clearly demonstrated that the approach to enhance flour recovery genetically may vary in different parts of the country.

Flour recovery, an important parameter in wheat, is embedded with strong commerce not only because of high production and better quality of the products but it also ensures better nutrition, be it protein content or minerals (Mohan and Gupta 2008). The study clearly indicates that could be two alternate routes to harness better wheat milling yield under Indian conditions. One option lies in selecting environments (sites and regions) conducive to high flour recovery as in the peninsular India where high milling recovery could be achieved due to availability of high flour yielding varieties and lack of environmental interferences. In rest of the country; there are certain better suited pockets in some zones like Junagarh and Vijapur in Gujarat, area around Kota and Dugapura in Rajasthan and Pusa in Bihar. Second option for high flour recovery is the genetic enhancement and tremendous scope exists to improve milling efficiency of the Indian wheat varieties. Incidentally, flour recovery in the Indian wheat exhorts high positive association with bread/*chapati* quality. Certain grain parameters accountable for flour recovery are important constituents for bread quality also like test weight, grain protein content, sedimentation weight and grain hardness etc. Along with these components, if grain density of certain micronutrients found vital in this study like copper and iron is also improved, the Indian wheat varieties shall turn out to be efficient in milling yield as well. New interventions like mapping of loci, image analysis and marker based selection can further aid development of flour rich bread wheat varieties.

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