Published in final edited form as:
. 2013 ; 7(4): 525–531.

Interdependence of Cultivar and Environment on Fiber Composition in Wheat Bran

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Abstract

Starch and cellulose are among the best known renewable reinforcing components. Scientists are continuously looking for various renewable sources such as flax, hemp, jute, and corn hulls with polymer matrixes to form composite materials and make structural biocomposites a reality. Wheat is a major cereal grain in the US and the world. During wheat milling, a large amount of wheat bran, a by-product, is disposed off as waste. The high percentage of water-insoluble fiber in wheat bran could be advantageous for reinforcing industrial material. However, the utilization of cellulosic fibers derived from wheat byproduct has not been explored in processing of biocomposites. Therefore, the objectives of this study were to characterize wheat bran fiber compositions including dry matter (DM), ash, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose (Cell), hemicellulose (Hemi), calcium (Ca), fat, starch, and acid detergent lignin (ADL); identify the interrelationship between the fiber composition traits and the influence of the environment and genotype on these traits. The experiment included six diverse and popular hard red spring wheat (HRSW) cultivars commonly grown in spring wheat region of the Northern Plains of USA. The experiment was installed in three different environments in the Dakotas States, USA. Results from this study showed that the DM, ash, Ca, Cell, starch, and ADL contents were influenced mainly by environments. However, CP along with fat, ash and Ca contents were influenced by genotypes in addition to environment. All bran components were influenced by the genotype × environment (G × E) interactions. We observed significant negative correlation of Cell with CP and ADL which make wheat bran a suitable reinforcing industrial material. However surface treatment of bran fiber would make it even more efficient. These preliminary results indicate the potential use of wheat bran components as biocomposite, but further studies to elucidate more these finding are warranted.

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Keywords

Wheat bran; biocomposite; fiber components; genotype by environment interactions; reinforcing components

Introduction

Processing of agricultural products usually produce agricultural wastes which are mostly organic matter and could be used to produce biodegradabe composites. The use of biodegradable composites can enhance the strength of composites and also reduce material costs (Zhang et al 2011). Composites prepared with agricultural wastes and macromolecular materials are advantageous than other fiber material because of their better water absorption, workability, and mechanical strength (Panthapulakkal et al. 2006). Wheat is a major cereal grain in the US and the world and the wheat-based industry is a multi-billion dollar market. The milling process of wheat produces large amount of wheat bran as a by-product. During milling, the endosperm is broken down into fine particles (flour) and bran and germ are removed. In general, wheat kernel contains about 83% endosperm, 2.5% germ, and 14.5% bran (Xie et al. 2008). Bran fraction constitutes approximately 11% of total milling by-products and only 10% of bran is used as fiber supplement in breakfast cereals and bakeries while the remaining 90% is sold as animal feed at an extremely low price. Wheat bran is often disposed off as waste by millers as the cost of transportation is more than its market value thus causing potential environmental concern ((Xie et al. 2008). Biomass derived natural fibers have a backbone built of crystalline straight chain polymer cellulose which contains numerous hydroxyl groups. These hydroxyl groups are able to form hydrogen bonds with the oxygen molecules of other cellulose chains (Kalia et al. 2011). This produces cellulose microfibrils, which have excellent strength due to the hydrogen bonding, and it is through these microfibrils that biomass fibers derive their strength. The other constituents of biomass, such as hemicellulose, starch, lignin, and protein are all amorphous polymers, and thus lack the strength seen in cellulose (Tingaut et al. 2010). In a lignocellulosic structure the carbohydrate polymers, cellulose and hemicellulose, are constrained to the lignin by hydrogen and covalent bonds (Boukari et al. 2009). As a result, they form an agglomeration along with the other components, and subsequently exhibit weaker mechanical properties than pure cellulose. Therefore, the pursuit of high cellulose content biomass is crucial in the development of functional lignocellulosic fillers. Mechanical fractionation has been utilized to break down the lignocellulosic fibers to allow for better dispersion in a polymer matrix (Noureddini et al. 2009). It also allows achieving higher ratios (the ratio of fiber length to diameter), leading to higher strength and stiffness potential. Furthermore, since crystalline cellulose is a nano-sized structure, fractionation breaks some of the constituent bonding due to lignin (Oliviero et al. 2011), thus increasing the strength potential of the individual fibers as loads can be carried more efficiently through the cellulose. The processing of biocomposite materials has re-emerged with renewed interest for research and development in recently. The use of cellulosic fibers as reinforcement in polymeric composite materials is advantageous due to its low cost, high stiffness, low density, renewability, biodegradability, and low toxicity. Coupled with substantial backing from the agricultural industry, a large array of fiber sources have been explored, including wood, hemp, feather, kraft pulp, pineapple leaves, and corn hull. However, the utilization of cellulosic fibers derived from wheat byproduct has not been explored in processing of biocomposites. Wheat bran contains a number of high value components, such as phenolic compounds (Kim et al. 2006), starches (Evers et al. 1974; Peng et al. 1999), soluble and insoluble dietary fiber (Cui et al. 1999) and proteins (Fellers et al. 1966). Isolated proteins from wheat bran may be used as ingredients in food formulations or special feeds, and contain superior nutritional value. The high percentage of water-insoluble fiber constituted by cellulose, hemi-cellulose and lignin offering advantages as reinforcing material such as low density, non-abrasive nature, availability, low cost and renewability (Taj et al. 2007). The remaining insoluble fiber after separating other components could be used as a dietary supplement or further processed into fillers or building components for plastics and hard board. Wheat bran is an important and very cheap agricultural by-product, containing about 650 mg/g of cell wall polysaccharides (Micard et al. 1994). Cell wall polysaccharides consist largely of heteroxylans, cellulose, and lignin. In combination with other materials, chemically modified starch and cellulose from wheat bran could make constituents for biodegradable packaging materials. There has been limited study on the utilization of wheat bran fiber in biocomposite as reinforcing filler. However, suitability of wheat bran as bioplastic by esterification has been studied (Chauvelon et al. 1998). The esterification of cellulose by fatty acids (acetic, propionic, butyric, etc.) has been widely studied and used in various industries including film (Engelhardt 1995). Chauvelon et al. (2000), compared esterification of cellulose of two important agriculture byproducts, wheat and maize brans. In this study, the cellulose of the two brans were enriched by removing heteroglycan and lignin and esterified with lauroyl chloride. The influence of wheat bran content in biodegradable composites shifted the glycerol-rich phase glass transition temperature toward higher temperatures and suggested that the presence of bran fiber led to an enhancement in the glycerol dispersion (Fama et al. 2009). However, lignin and hemicellulose in fiber decreases the accessibility of cellulose to fatty acid or decrease the suitability of fibers as reinforcing materials (Bismarck et al. 2001). There are several reports of surface treatments which partially dissolved lignin and hemicellulose present in the fiber, increasing the amount of exposed cellulose (Corradini et al. 2006; Valadez-Gonzalez et al. 1999; Varma et al. 1986). However, there is limited study on wheat bran compositions, variability among the components of wheat bran, influence of genotypes and environment on wheat bran components, and its potentiality of using as industrial materials. Wheat bran mineral composition for nutritional aspects has been studied and found to be influenced by growing environment, cultivars, and their interactions (Peterson et al. 1986). The wheat bran could be utilized for bioethanol feedstock and efficient pretreatments have been proposed for extracting suitable polysaccharides for ethanol production (Palmarola-Adrados et al. 2005). The US growers have long suffered from the record low domestic prices of wheat grain, and are looking for alternative approaches to enhance their market competitiveness. The objectives of this study were to 1) characterize wheat bran for its fiber compositions, 2) identify interrelationship among the fiber components, and 3) estimate the environmental influence on fiber composition. This study may lead to the improved utilization of US wheat in bio-based processing industries while benefiting local agricultural economy.

Material and methods

Plant Material

To address the objectives of this study, six diverse hard red spring wheat (HRSW) cultivars were included in a field experiment across three locations in North Dakota and South Dakota spring wheat region. The cultivars included two North Dakota State University releases, Faller (Mergoum et al., 2007) and Glenn (Mergoum et al., 2005). These two cultivars are the leading cultivars in the spring region (about 1 million ha) since 2007 and 2009 for Glenn and Faller, respectively. The other four cultivars, Granite, Knudson, Trooper, and Banton were released by private companies. The experiment was conducted during the summer of 2009 and was laid out in a randomized block design with four replicates. Each cultivar was assigned to an experimental unit of seven rows 3.5 m long and 15 cm apart. Each plot was harvested separately and a sample of seed was taken from each plot and were stored in a cold room and milled later.

Milling and Bran Extraction

The hard red spring wheat samples were milled using a Buhler MLU 202 laboratory mill. A sample of approximately, one kilogram (1kg) of wheat was prepared from each harvested plot for milling by cleaning on a Carter Day dockage tester with a number 8 sieve. The samples were then tempered in three stages: pre-tempered to 12.5% moisture 72 hours before milling, if moisture was below 11%; tempered to 16% moisture 24 hours before milling; and finally tempered to 16.5% moisture 20–30 minutes before milling. The Buhler MLU 202 produced six flour products, one bran product, and one shorts. The bran fractions were collected and used in this study.

Wet Chemical Analysis

Quantitative analysis of fiber constituents was performed at North Dakota State University, Animal Sciences Department, using dry matter analysis, neutral detergent solution and acid detergent solution characterization, and starch spectrophotometry. The data on dry matter, cellulose (Cell), hemicellulose (Hemi), acid detergent lignin (ADL), starch, and ash were collected based on the following measurements. Dry matter was determined according to AOAC standard 930.15, where samples were weighed at room temperature, heated at 100°C for 24 h, conditioned in desiccators, and weighed again. Percentages of neutral detergent fiber (NDF), acid detergent fiber (ADF), and ADL were performed using an ANKOM-200/220 Fiber Analyzer, according to methods specified in USDA Agricultural Handbook No. 379. Percentage starch was determined using an assay involving acid and enzymatic isolation using a micro-titer reading with a SPECTRAmax® 340 Microplate Reader. The cellulose and hemicellulose percentages were calculated as:

$$\%\ \text{Cellulose} = \%\ \text{Acid Detergent Fiber} - \%\ \text{Acid Detergent Lignin};\ \%\ \text{Hemicellulose} = \%\ \text{Neutral Detergent Fiber} - \%\ \text{Acid Detergent Fiber}.$$

These analyses produced bran constituents such as Dry Matter (DM) (100 ºC) in percentage (%), Ash in %, Crude protein (CP) in %, NDF in %, ADF in %, ADL in %, Crude Fat (CF) in %, Starch (ST) in %, Calcium (Ca) in %, and Phosphorus (P) in %.

Data Analysis

Analysis of variance (ANOVA) of the phenotypic data was performed using GLM procedure of the Statistical Analysis System (version 9.3, SAS Institute Inc., Cary, NC, USA). Pearson correlation coefficients were used to evaluate correlations for pair-wise bran components traits by using the CORR procedure of SAS.

Results

Mineral concentrations

The ANOVA (Table 1) showed highly significant (P<0.01) effect of growing location (environment, e) on DM, ash, and Ca contents in wheat bran. The growing locations also showed significant (P<0.05) influence on Cell, starch, and ADL contents in bran compositions. Significant (P<0.05) genotypic influence was observed on ash, CP, Ca, and fat contents of wheat bran. All of the bran components were highly (P<0.01) influenced by the interaction between growing locations and genotypes (e×g). Ranges in bran components levels indicated that genetic variation in fiber composition in wheat bran was comparable to, or larger than, variation associated with environmental component. Results from our study showed that the important bran compositions varied significantly for all measured traits (Table 2). The percentage of bran weight, measured as DM content ranged from 86.39 to 86.87 and ash content ranged from 3.31 to 5.41 while CP content ranged from 16.45 to 19.75. Similarly, NDF ranged from 18.87 to 30.82; ADF from 5.09 to 9.55; Cell from 2.87 to 6.99; and Hemi from 13.62 to 21.27. Starch meanwhile, ranged from 35.8 to 48.42, and ADL from 2.12 to 2.98 (Table 2). The significant influence of g×e interaction contributes to the relative wide and overall variation in each of the fiber components examined in this study. The genotypes included in this study were significantly differed in the contents of 11 different components of wheat bran (Table 3). The ADF content of wheat bran varied most among the genotypes in this study followed by Cell, Ca, and fat contents. Among genotypes, the least variation was observed in ash, CP, stach, and ADL contenets. The highest Cell content (5.65%) was observed in the genotype Trooper, which also contain lowest amount of ADL (2.43%) but relatively higher content of Hemi (17.31%).

Genotype by Environmental (g×e) effects

A ratio between the variances associated with the environmental effects (σ^2_e) genetic effects (σ^2_g) provides an indication of the relative influence of environment and genotype components on fiber composition in wheat bran. A ratio larger than 1.0 indicates a greater influence of environmental on variability while a ratio less than 1.0 indicates the relatively higher influence of genetic component. Ratios of environment by genotype variances ranged from 0.0257 to 7.9537 among the bran constituents (Table 4). Based on the σ^2_e/σ^2_g, there was no strong indication that genetic variances associated with the variability of DM, NDF, Hemi, starch, and ADL contents in wheat bran was significant (Table 4). The highest genotypic influence, indicated by lowest σ^2_e/σ^2_g value, was observed in fat contents (0.1667) followed by crude protein (0.2349). The highest variances associated with environmental component was found in ADF (σ^2_e/σ^2_g = 7.9537) content followed by ash content (σ^2_e/σ^2_g = 7.4148), Cell (σ^2_e/σ^2_g = 4.3518), starch (σ^2_e/σ^2_g = 2.8879), and Ca (σ^2_e/σ^2_g = 2.5) content of wheat bran. The magnitude of the g×e interaction in relation to genetic effects can be estimated by the variance components ration of $\sigma^2_{g\times e}/\sigma^2_g$. As indicated above for σ^2_e/σ^2_g ratio, a smaller than 1.0 $\sigma^2_{g\times e}/\sigma^2_g$ ratio would indicate greater influence and may be stability of genetic component relative to the variability associated with the interaction of g×e. The low ratios between environment and genetic variances for many bran composition traits indicate a higher influence of g×e effects. This was true for concentrations of fat and CP in wheat bran. The ratio $\sigma^2_{g\times e}/\sigma^2_g$ registered from these two traits was 0.8294 and 0.8613, respectively indicating the greater influence and stability of genetic factor on the concentrations of these two bran components.

Correlations between Wheat Bran Components

Correlation among the componets of wheat bran is presented in Table 5. Highly significant positive correlations between DM and ash, Ca, and ADL contents of wheat bran and significant negative correlations of DM with starch content were observed. Similarly, highly significant positive correations between ash and Ca content and negative associations of ash with NDF and Hemi contents were also detected. The CR was found negatively correlated with ADF and Cell, and positively correlated with ADL contents. Similary, NDF was found to be highly significantly correlated with ADF, Cell, and Hemi. Also ADF of wheat bran was found to be highly significantly correlated with Cell and Hemi. While Cell content of wheat bran was positively correlated with Hemi, a negative correlation with ADL was observed. Highly significant negative correlation between Ca and starch and a negative correlation between starch and ADL was observed in our study.

Discussions

Mineral concentrations

There are limited studies on the bran composition and its potential uses for industrial or reinforcing materials in wheat and related species. However, there are some studies on bran or hull composition for its digestibility or other industrial application such as biofuel production. Thompson *et al.* (2000), studied the influence of genotypes on oat hull chemical compositions. They studied hull composition of 10 oat varieties and found significant genotypic influences on lignin, ADF, and NDF contents. Grove *et al.* (2003) studied the influence of planting dates, irrigation levels, and cultivars on barley hull chemical composition among four barley varieties and found significant varietal differences on the hull compositions like ADF, NDF, DM, CP, and lignin content. Jahn *et al.* (2011) reported that cellulose, hemicellulose, lignin, ash, and soluble fiber content varied widely among 20 rice varieties. The average contents of cellulose, hemicellulose, lignin, and ash varied from genotype to genotype and influenced by growing sites (Govindarao 1980; Nakbanpote et al. 2000; Rahman et al. 1997). The variation in fiber composition in wheat bran due to the genotypes or environment observed in our study was comparable to some previous work done on other crops. In maize hull, the starch content ranged from 72 to73% (Cortez and Wild-Altamirano 1972) and protein content ranged from 8 to 11% (Ortega et al. 1986). Among the fiber composition in maize, NDF ranged from 8.21 to 14.17%, ADF ranged from 2.17 to 3.23%, hemicellulose ranged from 4.98 to 11.44 and lignin (ADL) content ranged from 0.12 to 0.14% (Bressani et al. 1989). Similarly, rice husk, the average contents of important bran components measured were 15 to 20% ash (Armesto et al. 2002; Daifullah et al. 2003) and 32.24% Cell, 21.34% Hemi, 21.44% ADL (Govindarao 1980; Nakbanpote et al. 2000; Rahman et al. 1997). In wheat bran, except starch contents all other contents were observed higher than those of maize (Bressani et al. 1989; Cortez and Wild-Altamirano 1972; Ortega et al. 1986). However, except ash and CP, all other components in wheat brans varied widely. Much lower amount of bran components were found in wheat than rice (Table 2) (Armesto et al. 2002; Daifullah et al. 2003; Govindarao 1980; Nakbanpote et al. 2000; Rahman et al. 1997). Among the fiber components, ADL and Hemi are more undesirable because these components decrease the accessibility of Cell to fatty acid or decrease the suitability of fibers for use as reinforcing materials (Bismarck et al. 2001). Acid detergent lignin (ADL), Hemi, and Cell are much higher amount in rice husk than wheat bran but wheat bran has negligible amount of ADL (Table 2) compared to rice husk. However, using surface treatments (Corradini et al. 2006; Valadez-Gonzalez et al. 1999; Varma et al. 1986), wheat bran could be used as a reinforcing constituent in composites. Higher Cell content along with lower ADL and Hemi contents are desirable properties of fiber for use in reiforcing materials (Bismarck et al. 2001). Thus the bran extracted from HRSW genotype, Trooper could be a better candidate for using as reiforcing material after surface treatment.

Genotype by Environmental Variance

The magnitude of genotypic effects than environment, on bran traits can be critical for improvement of these traits in breeding program. In our study, wheat bran composition traits were affected significantly by either genotypes or environment or by both. The larger genetic effect for the expression of a trait is an indication of improving that trait by breeding programs (Zou et al. 2011). Many studies have been consucted on determining the genetic effects on traits but most of these studies were based on a breeding population developed by crossing between divergent parents for traits of interest. Zou *et al.* (2011) studied the inheritance of traits such as heading date, plant height, harvested stem length, number of nodes, stem diameter, panicle length and panicle neck length, along with sugar concentration in a large recombinant inbred lines (RILs) population of sorghum and found a large proportion of the phenotypic variance for plant height, harvest stem length, panicle length, and sugar concentration was attributed to genotypic variance. Shewry *et al.*2010 analyzed the contents of bioactive components (tocols, sterols, alkylresorcinols, folates, phenolic acids, and fiber components) in 26 wheat cultivars grown in six different environments and found that the extent of variation due to variety and environment differed significantly between components. They also identified significant differences in the effects of genetic and environmental component on the contents of various phytochemicals and dietary fiber components. In their study, they found all dietary fiber components had higher genetic variances compared to total or environmental variances. In our study, we analyzed bran components, whereas, Shewry *et al.* (2010) analyzed whole grain; thus, our results may not be in agreement with those of Shewry *et al.* (2010). However, we found higher genetic variances for bran components including fat and CP. The magnitude of the g×e interaction in relation to genetic effects can be estimated by the variance component ration of $\sigma^2_{g\times e}/\sigma^2_g$. In our study, several bran composition traits were affected more by g×e than other factors. In a study, Zou *et al.*2011, has also made a similar conclusion when higher genetic variance for wheat stem diameter compared to g×e interaction variance was found. Quinde-Axtell *et al.* (2005) using 12 hulled and hulless barley genotypes grown in six different locations, studied the relative contribution of genotype and environment on protein, ash, total polyphenol content, and polyphenol oxidase (PPO) activity. From this study, genetic component were found to have a significant effect in determining total polyphenol content and PPO activity. In our study some wheat bran components were significantly affetced by genotype, environment, and g×e interaction. As revealed in this study, the wheat bran components like crude protein and fat may remain consistent but other component may vary when a genotype grown in different environment. Thus, wheat breeders may find useful these finding for their programs to improve these traits in the future.

Correlations between Wheat Bran Components

Significant correlations between wheat bran composition traits were found in our study. In other crops, similar studies reported in general, similar trends. In a study on fiber component using an interspecific population of perennial ryegrass, Xiong *et al.* (2006), identified highly significant positive correlation among fiber components including ADF, NDF, and ADL. They also reported that the correlation of NDF was higher than correlation of ADF with ADL and NDF with ADL. In our study, we also found highly positive correlation between ADF and NDF (r = 0.7315) but we did not observe significant correlation of ADL with either ADF or NDF. Xiong *et al.* (2006) also reported significant negative correlation of NDF and ADF with CP. In our study, we also found significant negative correlation of ADF with CP but insignificant negative correlation of NDF with CP was found. Similar correlations of CP with fiber components was also reported by Cardinal *et al.* (2003). The NDF measure all the fiber components (Hemicellulose, cellulose, and lignin) while ADF measures the cellulose and lignin. Thus, strong positive correlation among NDF, ADF, Cell and Hemi is expected which are in agreement with our findings. The Cell is a linear polysaccharide polymer of glucose, packed into microfibrils. These microfibrils are attached to each other by Hemi, polymers of different sugar and other polymers, and covered by ADL. These fiber components vary from tissue to tissue and their relationship varied significantly (Jahn et al. 2011). In a study by Allison et al. (2010), a low positive correlation of ADL with Cell and a low negative correlation with Hemi and no correlation of Cell with Hemi was reported. The strength of cellulosic fibers is determined by the Cell polymer but the other components such as Hemi, starch, ADL, and protein are amorphous polymers and lacking the strength seen in cellulose. In wheat bran, we observed highly significant negative correlation of Cell with protein, significant negative correlation with lignin, non-significant correlation with starch but significant correlation with Hemi. Thus, the increasing expression of gene(s) controlling the cellulose content in wheat bran would decrease protein and ADL content and an independent genetic mechanism may be involved in controlling the starch content in wheat bran. However, before using wheat bran lignocellulosic fiber as reinforcing material it would be necessary to pretreat or degrade hemicellulosic component from cellulose polymer by using non-enzymatic or enzymatic degradation (Arantes and Milagres 2006; Bungay 1992; Osborne and Dehority 1989; Saha 2003). Knowledge on correlations is required to obtain the expected response of other characters when selection is applied to a particular character of interest in a breeding program. It was found that the magnitude and direction of correlation coefficients of measured traits varied under different environments (Zou et al. 2011). Among the 11 bran components studied, eight were found to be significantly correlated to one or more of the bran traits in the combined effect of all three locations. Fiber components of wheat bran vary significantly among wheat cultivars. This variability is due to a variety of component including environmental and genetic component and their interactions.

Conclusion

Wheat is a major cereal grain worldwide and the milling process of wheat produces large amounts of agricultural waste. Applicability of these wastes as industrial resources would increase the usage of wheat and wheat products and wheat industry could find an alternative usage of this important grain. The analysis of wheat bran fiber components and potentiality of using wheat bran as reinforcing material has been addressed in this study. Results from this study showed that the bran components varied significantly among genotypes and locations and all components were influenced by the genotype × environment (G × E) interactions while DM, ash, Ca, Cell, starch, and ADL contents were influenced mainly by environments. However, CP along with fat, ash and Ca contents were influenced by genotypes in addition to environment. We also observed significant correlations among bran components. Among these correlation, a negative correlation between Cell and CP and ADL indicates that wheat bran can be a suitable reinforcing industrial material. However surface treatment of bran fiber would make it even more efficient. In many ways, improvement of plants for both food and industrial uses will require different breeding and selection emphasis that are different from those targeting food purposes. Although increased industry related traits per se has not been a target in wheat breeding programs, selection for high yield or higher quality tagged with higher industry related traits such as cellulose or lignin content could be achieved.

Acknowledgments

This project was partially supported by the NIH and NIGMS grant # P20 RR016741 from the ND-INBRE Program.

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Table 1

analysis of variances of fiber components of wheat bran of six cultivars grown in three environments across south dakota during 2009.

Source	d.f	DM	Ash	CP	NDF	ADF	Cell	Hemi	Ca	Fat	Starch	ADL
Location (e)	2	2.837**	5.36**	2.201	28.122	8.03	12.669*	10.928	0.0011**	0.341	64.231*	0.542*
Genotype (g)	5	0.33	0.469*	3.75*	15.905	2.81	3.052	7.461	0.0006*	0.705*	10.702	0.062
e × g	10	0.34**	0.115**	0.827**	16.262**	2.46**	1.804**	9.947**	0.0002**	0.16**	12.249**	0.079**
MS Error		0.02931	0.03283	0.01874	0.62963	0.024556	0.03035	0.62971	1.90E-06	0.003287	2.756293	0.012519
C.V		0.213	4.42	0.674	3.45	1.79	3.2	4.97	51.51	1.821	3.31	4.436

* < 5% level and

** < 1% level of probability.

Table 2

Minimum, maximum, and mean of fiber components of wheat bran of six cultivars grown across three environments in South Dakota during 2009.

		DM	Ash	CP	NDF	ADF	Cell	Hemi	Ca	Fat	Starch	ADL
Genotype	Min	86.39	3.83	17.83	23.13	6.5	4.02	16.28	0.02	2.98	42.08	2.43
	Max	86.87	4.46	19.35	26.5	8.08	5.1	18.67	0.06	3.8	44.88	2.63
	Mean	86.58	4.09	18.76	24.74	7.42	4.89	17.32	0.03	3.42	43.66	2.54
Location	Min	86.13	3.81	18.4	23.52	6.97	4.3	16.43	0.02	3.3	41.71	2.34
	Max	86.9	5.25	19.1	26.02	8.19	5.85	17.84	0.04	3.57	45.48	2.68
	Mean	86.58	4.46	18.76	24.74	7.42	4.89	17.32	0.03	3.42	43.66	2.54
Overall	Min	85.69	3.31	16.45	18.87	5.09	2.78	13.62	0.011	2.35	35.8	2.12
	Max	87.87	5.41	19.75	30.82	9.55	6.99	21.27	0.054	4.08	48.42	2.98
	Mean	86.575	4.086	18.754	24.736	7.416	4.883	17.32	0.027	3.418	43.658	2.532

Table 3

Means and their significance of wheat bran components of six cultivars grown across three environments of South Dakota during 2009 components

Genotypes	DM	Ash	CP	NDF	ADF	Cell	Hemi	Ca	Fat	Starch	ADL
Faller	86.597^{bc}	4.125^{b}	18.36^{b}	26.5^{a}	8.072^{a}	4.672^{d}	16.276^{d}	0.022^{d}	3.527^{b}	43.027^{bc}	2.630^{a}
Granite	86.395^{d}	3.825^{c}	19.26^{a}	25.728^{ab}	7.830^{b}	4.587^{d}	16.94^{cd}	0.020^{e}	3.540^{b}	44.877^{a}	2.577^{ab}
Knudson	86.488^{cd}	3.863^{c}	18.397^{b}	25.38^{b}	7.627^{c}	5.353^{b}	18.670^{a}	0.031^{b}	3.402^{c}	43.723^{ab}	2.478^{bc}
Trooper	86.867^{a}	4.108^{b}	17.827^{c}	24.103^{c}	7.302^{d}	5.645^{a}	17.308^{bc}	0.042^{a}	3.262^{d}	42.082^{c}	2.427^{c}
Glenn	86.383^{d}	4.135^{b}	19.337^{a}	23.578^{cd}	7.163^{e}	4.022^{e}	16.628^{cd}	0.022^{d}	2.978^{e}	44.877^{a}	2.477^{bc}
Banton	86.717^{ab}	4.456^{a}	19.343^{a}	23.128^{d}	6.500^{f}	5.022^{c}	18.102^{ab}	0.025^{c}	3.802^{a}	43.362^{bc}	2.605^{a}

Means in the same column with same letter are not significantly different at the 0.05 probability level.

Table 4

Environment (σ^2_e), genetypic (σ^2_g), genotype by environmental ($\sigma^2_{g\times e}$) variances and ratios of σ^2_e/σ^2_g and $\sigma^2_{g\times e}/\sigma^2_g$ of wheat bran fiber components of six cultivars grown in three environments across South Dakota during 2009.

	DM	Ash	CP	NDF	ADF	Cell	Hemi	Ca	Fat	Starch	ADL
σ^2_e	0.1387	0.2914	0.0763	0.6589	0.3094	0.6036	0.0545	0.0001	0.0101	2.8879	0.0257
σ^2_g	0.0	0.0393	0.3248	0.0	0.0389	0.1387	0.0	0.00004	0.0606	0.0	0.0
$\sigma^2_{g\times e}$	0.1036	0.0274	0.2694	5.2108	0.8118	0.5912	3.1058	0.00007	0.0522	3.1642	0.0221
σ^2_e/σ^2_g	0.1387	7.4148	0.2349	0.6589	7.9537	4.3518	0.0540	2.5000	0.1667	2.8879	0.0257
$\sigma^2_{g\times e}/\sigma^2_g$	0.1036	0.6972	0.8294	5.2108	20.8689	4.2624	3.1058	1.7500	0.8613	3.1642	0.0222

Table 5

Correlation coefficients and their significance between fiber components of wheat bran of six cultivars grown in three environments across South Dakota during 2009.

	DM	Ash	CP	NDF	ADF	Cell	Hemi	Ca	Fat	Starch	ADL
DM		0.499**	0.070	−0.122	−0.049	−0.152	−0.135	0.559**	0.234	−0.341*	0.499**
Ash			0.077	−0.404**	−.233	−0.254	−.408**	0.446**	0.132	−0.075	0.139
CP				−0.081	−0.448**	−0.519**	0.139	−0.242	0.182	0.004	0.414**
NDF					0.732**	0.700**	0.926**	−0.056	−0.052	−0.145	0.025
ADF						0.978**	0.420**	−0.073	−0.107	0.125	−0.064
Cell							0.391*	−0.102	−0.155	0.190	−0.272*
Hemi								−0.033	−0.001	−0.262	0.068
Ca									0.0003	−0.473**	0.148
Fat										−0.227	0.248
Starch											−0.333*

* < 5% level and

** < 1% level of probability