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Functional and Nutritional Characteristics of Soft Wheat Grown in No-Till and Conventional Cropping Systems

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ABSTRACT

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The effects of no-till versus conventional farming practices were evaluated on soft wheat functional and nutritional characteristics, including kernel physical properties, whole wheat composition, antioxidant activity, and end-product quality. Soft white winter wheat cultivar ORCF 102 was evaluated over a two-year period from three long-term replicated no-till versus conventional tillage studies in Oregon. Wheat from the no-till cropping systems generally had greater test weight, kernel diameter, and kernel weight and had softer kernels compared with wheat from the conventional tillage systems. Compared with the conventional systems, no-till whole wheat flour had lower protein and SDS sedimentation volume. Ash content as well as most minerals measured (calcium, copper, iron, magnesium, and zinc), except for manganese and phosphorus, were generally slightly lower in no-till than in conventional wheat. Whole wheat flour from the no-till cropping systems generally had slightly lower total phenolic content and total antioxidant capacity. Milling properties, including flour yield, break flour yield, and mill score, were not affected by tillage systems. Refined flour from no-till systems had lower protein, SDS sedimentation volume, and lactic acid and sucrose solvent retention capacities compared with flour from conventional tillage. No-till wheat generally had greater sugar-snap cookie diameter than conventionally tilled wheat. In conclusion, no-till soft white winter wheat generally had slightly reduced nutritional properties (protein, ash, most minerals, and total antioxidant content) compared with wheat from conventionally tilled systems, and it had equivalent or sometimes superior functional properties for baking cookie-type products.

There is a growing interest and demand by consumers for crops that are produced sustainably and in an environmentally friendly manner. No-till cropping systems are one way to enhance sustainability compared with conventional tilling systems. No-till is defined as the absence of any tillage operation, and it often includes a one-pass planting and fertilizing operation (Miller et al. 2008). There are several advantages of the no-till systems. No-till cropping systems improve soil physical, chemical, and biological properties, reduce soil erosion, and improve soil water content and usage by plants (Gürsoy et al. 2010). In no-till systems, residues from previous crops remain on the surface and protect the soil from erosion, aid water infiltration, and reduce water evaporation (Phillips et al. 1980). In addition, formation of a mulch layer by surface residues decreases wind speed at the soil–atmosphere interface (Hatfield et al. 2001). Intact soil macropores improve water infiltration (Logsdon et al. 1990; Machado et al. 2007). With increased water infiltration and decreased water evaporation, soil water availability is increased (Phillips et al. 1980). No-till soil has increased organic carbon concentration, microbial biomass, bulk density, and soil penetration characteristics (Logan et al. 1991; De Vita et al. 2007). Also, energy input and production costs are reduced, and convenient timing of planting and harvesting is possible under no-till systems. However, the disadvantages of no-till cropping systems are increased populations of insects and rodents and decreased soil temperatures (Phillips et al. 1980; Gürsoy et al. 2010). Yields under no-till cropping systems vary depending upon year, location, and agronomic practices. In many studies, grain yield was not affected by tillage treatment (Christian and Bacon 1990; Ehlers and Claupein 1994; Unger 1994), but lower yields have also been reported under no-till cropping systems (Ball et al. 1994). In dry areas, no-till cropping systems often increase wheat grain yield compared with conventional systems, probably owing to the benefits of soil water conservation (Hemmat and Eskandari 2004). Machado et al. (2007) also reported that grain yield of no-till winter wheat was lower than conventional wheat in unfertilized crops, but yields were similar in fertilized crops. These variable effects on yield under no-till cropping systems indicate that many environmental factors contribute to yield responses, including soil and climatic conditions, fertilization level, weed control level, residue management, cultural practices, and drill planting performance (Carefoot and Janzen 1997; Dawelbeit and Babiker 1997).

Wheat quality is affected by many factors including cultivar, soil, climate, cropping system, and grain storage conditions (López-Bellido et al. 2001). No-till cropping systems, which improve soil properties, have the potential to influence wheat quality and nutritional parameters. High available soil water content is associated with decreased grain protein content because protein content increases with water stress (Robinson et al. 1979; De Vita et al. 2007). Reduced water evaporation and increased water infiltration in no-till cropping systems might reduce stress by increasing the availability of water to the plants (Unger 1994). Lower protein content was observed in no-till wheat compared with conventional wheat (López-Bellido et al. 1998, 2001; De Vita et al. 2007; Wilkes et al. 2010), although protein content was unaffected by tillage systems in other studies (Baenziger et al. 1985; Bassett et al. 1989; Peterson et al. 1992; Carr et al. 2003; Gürsoy et al. 2010). Higher test weight for no-till wheat compared with conventional wheat was reported in no-till wheat by several researchers (López-Bellido et al. 1998; De Vita et al. 2007; Gürsoy et al. 2010), whereas there was no significant difference in test weight in other studies (López-Bellido et al. 2001; Carr et al. 2003).

Improved soil water content and other soil properties under no-till cropping systems have the potential to improve plant nutrition and growth, which may affect nutritional and functional properties of wheat. However, there is limited information about nutritional and functional properties of no-till wheat. Therefore, the objective of this study was to evaluate the effect of no-till

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cropping systems on the nutritional and functional properties of soft wheat.

MATERIALS AND METHODS

Materials. Grain of the soft white winter wheat cultivar ORCF 102 was obtained from three long-term replicated tillage studies in Oregon. The rotations were scheduled such that winter wheat was harvested each year from each study. For studies reported here, we evaluated three replications of wheat harvested from each of these studies in both 2010 and 2011. Two studies were conducted at Columbia Basin Agricultural Research Center (CBARC) stations, with one study (Pendleton I) conducted near Pendleton, Oregon (45.72°N, 118.60°W, at an elevation of 438 m) and the second study (Moro) conducted near Moro, Oregon (45.48°N, 120.72°W, at an elevation of 575 m). The third study (Pendleton II) was conducted at the USDA-ARS Columbia Plateau Conservation Research Center (CPCRC) northeast of Pendleton, Oregon (45.72°N, 118.62°W, at an elevation of 458 m). Nitrogen fertilizer was applied as urea at 135 kg of N/ha (120 lb of N/ac). The urea was banded at 10 cm depth during wheat planting. Other details of these studies are reported elsewhere (Machado et al. 2008; Smiley and Machado 2009; Reardon et al. 2014). The CBARC and Moro sites receive an average of 406 and 282 mm of annual precipitation, respectively. The Pendleton I study (Machado et al. 2008) was a winter wheat–spring pea (two-year rotation) study that included multiple tillage treatments. We selected no-till versus conventional spring plow treatments for this study. There were four field replications, and three of these were selected at random for this study. The Pendleton II study was a two-year winter wheat–fallow rotation. In this study, the no-till A (NTA) plots were established in 1982 and no-till B (NTB) and conventional tillage plots were established in 1997 (Reardon et al. 2014). For the purpose of the current study, we assumed NTA and NTB plots were equivalent and evaluated one NTA and two NTB replicate samples each year along with three replicate samples from the conventional tillage plots. The Moro study was established in 2003 as a two-year winter wheat–fallow rotation that included conventional tillage fallow and no-till (chemical) fallow (Smiley and Machado 2009). There were three field replications, each of which was evaluated in the current study.

Physical Characteristics of Wheat Grains. Wheat grain was cleaned with a cyclone grain scourer (model 6, Forster and Son, Ada, OK, U.S.A.) and analyzed for test weight (AACC International Approved Method 55-10.01). Moisture content of wheat grain was determined by near-infrared reflectance; mean grain moisture contents were 10.42% for no-till and 10.35% for conventional tillage. Single-kernel size, weight, and hardness were determined by the single-kernel characterization system (SKCS 4100, Perten Instruments, Hägersten, Sweden) (AACCI Approved Method 55-31.01). Brightness (L^*) was measured with a chromameter (CR-310, Minolta, Osaka, Japan) (Nair et al. 2010).

Composition of Whole Wheat Flour. Grain samples were ground in a cyclone mill (Udy, Fort Collins, CO, U.S.A.) with a 0.5 mm screen. Whole wheat flour was analyzed for moisture (AACCI Approved Method 44-15.02), ash (AACCI Approved Method 08-01.01), protein (AACCI Approved Method 46-30.01), and SDS sedimentation volume (Axford et al. 1979). Starch content in whole wheat flour was determined according to the procedure of Englyst et al. (1992). Inductively Coupled Argon Plasma (Perkin Elmer 3300) at the Grand Forks Human Nutrition Research Center in North Dakota was used to determine calcium, copper, iron, magnesium, manganese, phosphorus, and zinc contents (Murphy et al. 2008).

Antioxidant Properties of Whole Wheat Flour. Free phenolics in whole wheat flour (0.1 g, db) were extracted with acidified methanol (HCl/MeOH/water = 1:80:10, v/v) under N_2 by shaking in the dark at ambient temperature for 2 h (Mpofu et al. 2006). After centrifuging at 2,500 × *g* for 10 min, the supernatant was collected for free phenolics, and then the residue was hydrolyzed with 2N sodium hydroxide for 1 h under nitrogen gas by shaking in the dark at ambient temperature to extract bound phenolics (Inglett et al. 2011). The extracts were acidified to pH 2 with 2N HCl and centrifuged at 2,500 × *g* for 10 min to collect bound phenolics in the supernatant. The phenolic content was determined for each of the supernatants by the Folin–Ciocalteu colorimetric method (Singleton et al. 1999).

Most measurements of total antioxidant activity rely upon first solubilizing antioxidant components, following methods similar to those described earlier, for which there are the following issues: 1) diversity of methods used (not standardized), 2) multiple time-consuming steps, and 3) procedures may not solubilize all antioxidant constituents (Serpen et al. 2008b). Because the vast majority of antioxidants in cereals are insoluble, we utilized the direct procedure (extraction independent) in which both soluble and insoluble portions of a flour suspension react simultaneously with the 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical cations (Serpen et al. 2008a, 2008b). This assay measures 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) equivalent antioxidant capacity. ABTS stock solution was prepared by combining a 7mM aqueous solution of $ABTS^{\cdot+}$ with 2.45mM potassium persulfate and incubating in the dark at ambient temperature for 12–16 h before use. Final $ABTS^{\cdot+}$ reagent was obtained by dilution with water/ethanol solution (50:50, v/v) until attaining 0.70 AU at 734 nm. ABTS reagent (6 mL) was added to wheat flour (10 mg) in a 15 mL tube. The solution was vortexed for 2 min and then shaken on an orbital shaker for 20 min at approximately 30 rpm. After centrifuging at 9,200 × *g* for 2 min, absorbance at 734 nm was measured on the supernatant. Trolox was used for a standard curve.

Refined Wheat Flour. Grain samples were milled on a Brabender Quadrumat Senior laboratory mill (South Hackensack, NJ, U.S.A.) to measure flour yield, break flour yield, and milling score. The refined wheat flour was analyzed for moisture (AACCI Approved Method 44-15.02), ash (AACCI Approved Method 08-01.01), protein (AACCI Approved Method 46-30.01), and SDS sedimentation volume (Carter et al. 1999). The refined wheat flour was analyzed for solvent retention capacity (AACCI Approved Method 56-11.02) and baked into sugar-snap cookies (AACCI Approved Method 10-52.02) and sponge cakes (AACCI Approved Method 10-90.01) to evaluate end-use quality.

Statistical Analysis. All results for whole wheat and refined flours are reported on a dry-weight basis. All measurements were taken in duplicate with three field replications. ANOVA was conducted with SAS statistical software (SAS Institute, Cary, NC, U.S.A.), and the data were assessed by least significant difference at $P < 0.05$.

RESULTS AND DISCUSSION

Physical Properties of Wheat Grain. Test weight was significantly greater under no-till cropping systems than under conventional systems in most trials and in the combined analysis (Table I). Test weight is a measure of the bulk density of wheat grain and is used as a grading factor. In the market, high test weight values are desirable because of their positive impact on grade and price (Gürsoy et al. 2010). Similar to our result, no-till wheat showed higher test weight than conventionally tilled wheat in previous studies (De Vita et al. 2007; Gürsoy et al. 2010) possibly because of conserved soil water and nitrogen (López-Bellido et al. 1998), whereas Carr et al. (2003) found no difference in test weight between no-till and conventionally tilled wheat. We attribute these different observations to different environmental conditions, soil properties, and cropping practices.

No-till wheat had greater kernel weight and diameter in the combined analysis as well as in each trial except Pendleton I (2010), Pendleton II (2011), and Moro (2011) (Table I). The larger kernel diameter may have contributed to the high test weight value of no-till wheat. Increased kernel volume results from more rapid starch and protein matrix deposition (Ghaderi et al. 1971). The differences in kernel size, shape, and color of wheat grown in Moro in 2010 under no-till versus conventional till cropping systems are evident in

Figure 1. The no-till wheat kernels were plumper compared with conventionally tilled wheat kernels. No-till wheat kernels also appeared more opaque (reduced vitreousness) and showed higher brightness values (L^* = 62.6, 60.2, and 62.2) than under conventional systems (L^* = 60.6, 59.6, and 60.1) (in Pendleton I, Pendleton II, and Moro, respectively, in 2010). In Pendleton I (2010) and Moro (2010), wheat kernels under no-till cropping systems had significantly softer kernels than under conventional tillage systems (Table I). Greater kernel brightness (L^*) and softer kernels are often associated, because the brightness is affected by decreased vitreousness, which is a result of less compact endosperm in which starch granules are loosely packed in a discontinuous protein matrix with numerous air spaces (Chandra et al. 1999; Nair et al. 2010). The softness of kernels grown under a no-till cropping system might also be related to the larger kernel size and volume of the less compact kernel structure. Turnbull and Rahman (2002) reported that growing conditions such as water and nutrient availability affect kernel vitreousness. No-till cropping systems, with increased water availability, may contribute to a more opaque kernel with softer texture. Therefore, our results indicate that wheat grown under no-till cropping systems often has heavier, larger, and softer kernels than does wheat grown under conventional systems.

Composition of Whole Wheat Flour. Protein content and SDS sedimentation volume of whole wheat flour were compared in no-till and conventional tillage cropping systems. Protein content was lower in no-till wheat than conventional wheat in the combined analysis and was generally lower in the individual trials as well (Table II). Lower protein content has been previously reported in no-till wheat (López-Bellido et al. 1998, 2001; De Vita et al. 2007; Wilkes et al. 2010), and López-Bellido et al. (1996) explained the lower protein content by low soil nitrate content under no-till cropping systems. Also, reduced water stress under no-till cropping systems because of increased soil available water may contribute to decreased grain protein content (Unger 1994), because increased water stress is likewise often associated with increased protein content (Robinson et al. 1979; De Vita et al. 2007). Gürsoy et al. (2010) found no significant difference in protein content and SDS sedimentation volume between no-till and conventionally tilled wheat. As mentioned earlier for test weight, these differing results are most likely because of the multiple effects and interactions among environment, soil quality, and crop management (Rieger et al. 2008). The SDS sedimentation volume likewise was reduced in no-till whole wheat flour compared with conventionally tilled whole wheat flour in the combined analysis, and this trend was similar across most of the individual trials (Table II). The lower SDS sedimentation volume of no-till compared with conventionally tilled wheat may be because of both lower protein content and weaker gluten strength.

No-till and conventionally tilled wheat showed similar starch content in all trials, except for Pendleton I (2010) (Table II). Wilkes et al. (2010) also reported that tillage practice had little effect on starch content. Ash content was significantly lower in no-till wheat than in conventionally tilled wheat in the combined analysis and in most of the individual trials (Table II). Likewise, individual minerals were lower in no-till wheat than in conventional wheat in the combined analyses, with the exceptions of manganese and phosphorus (Table II). Lower ash content in no-till wheat is a desirable trait often associated with increased flour extraction potential during milling. However, from a nutritional aspect, lower mineral content and ash could contribute to reduced nutrient levels, although the differences seen here would likely not be large enough to significantly alter overall human nutrition and cause deficiencies (Welch and Graham 1999).

Antioxidant Properties of Whole Wheat Flour. Effect of tillage on free phenolic content varied slightly and was not significantly different in the combined analysis. Both bound and total phenolics were slightly but significantly lower under no-till than conventional tillage, and similar trends were observed in most individual trials. Previous work has shown that antioxidant properties of soluble wheat extracts were affected by growing conditions, including temperature stress and total solar radiation (Zhou and Yu 2004), but there is limited information on the effects of tillage on phenolic content.

Similar to results with total phenolics, no-till wheat had significantly lower total antioxidant capacity than conventionally tilled wheat in the combined analysis, and all individual trials showed the same trend as well (Table III). The lower antioxidant capacity of no-till versus conventionally tilled wheat is at least partially explained by the lower total phenolic content of no-till wheat, because phenolics are a major factor in total antioxidant activity (Adom and Liu 2002; Beta et al. 2005). Phenolic content (discussed earlier) was determined by an extraction-dependent method, whereas total antioxidant capacity was

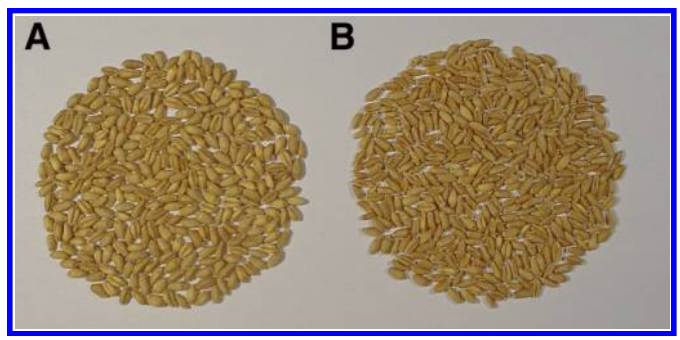

Fig. 1. Soft wheat grain grown in Moro in 2010 under no-till (**A**) and conventional tillage (**B**) systems.

TABLE I
Test Weight, Kernel Hardness, Kernel Weight, and Kernel Diameter of Wheat Grain Grown Under No-Till or Conventional Tillage Systems[z]

				Single-Kernel Characterization System		
Location	Year	System	Test Weight (kg/hL)	Weight (mg)	Diameter (mm)	Hardness Index
Pendleton I	2010	No-till	78.9a	41.0a	2.92a	31.0b
		Conventional	77.7b	37.6b	2.77b	37.0a
	2011	No-till	79.5a	39.0a	2.86a	29.9a
		Conventional	79.0b	38.7a	2.85a	29.8a
Pendleton II	2010	No-till	77.5a	39.2a	2.83a	38.7b
		Conventional	76.1b	34.8a	2.71a	38.7a
	2011	No-till	78.4a	36.2a	2.74a	34.3a
		Conventional	76.2b	31.1b	2.58b	37.6a
Moro	2010	No-till	78.6a	41.4a	2.93a	35.0b
		Conventional	77.9b	39.9b	2.88b	39.3a
	2011	No-till	79.3a	39.2a	2.90b	29.9a
		Conventional	79.3a	40.7a	2.99a	27.2a
Combined		No-till	78.8a	39.3a	2.86a	33.1b
		Conventional	77.7b	37.1b	2.76b	34.9a

[z] Values with different letters within each year in the same location are significantly different ($P < 0.05$). Conventional = conventional tillage; and combined = analysis combined across locations and years.

obtained through the direct, extraction-independent procedure, avoiding several limitations of extraction such as incomplete extraction and lost synergistic effects among antioxidants (Serpen et al. 2008b). Serpen et al. (2008a) reported that genotype and environment influenced total phenolic content and total antioxidant capacity in this direct assay. Therefore, it is presumed that changes in growing conditions under no-till cropping systems influence antioxidant capacity of wheat, although the differences are not large. The differences in total phenolics and total antioxidant capacity may be associated with the differences in kernel size. Larger kernels observed in no-till samples (Table I) may have a reduced proportion of bran layers, which are relatively high in both phenolics and antioxidants.

Milling, Refined Flour Properties, and End-Product Quality. Milling properties were not significantly affected by tillage treatment (Table IV). There were no differences in flour yield, break flour yield, mill score, and refined flour ash content between no-till and conventionally tilled wheat. In this study, milling properties were not significantly affected by the previously discussed differences in kernel physical properties (Table I), although the relationships between milling performance and kernel weight, size, morphology, and hardness are well established (Morris and Rose 1996). The differences in kernel properties that we observed may not have been large enough to influence milling performance.

Refined wheat flour of no-till cropping systems had lower protein content than that of conventional tillage systems in the combined analysis, and similar trends were observed in most of the individual trials (Table IV). The SDS sedimentation volume was likewise lower in no-till than conventional tillage.

The solvent retention capacity (SRC) tests measure the ability of flour to retain a set of four solvents (5% sodium carbonate, 5% lactic acid, deionized water, and 50% sucrose) (Table V) against centrifugation force, and these measurements are associated with flour functionality (Kweon et al. 2011). Generally, carbonate SRC is associated with levels of damaged starch; lactic acid SRC is associated with gluten protein characteristics; water SRC is affected by all water-absorbing constituents in flour; and sucrose SRC is associated with pentosan and gliadin characteristics (Gaines 2000, 2004). Carbonate and water SRC were generally similar in both tillage systems; lactic acid and sucrose SRC were generally lower in no-till than in conventional tillage systems (Table V). The lower lactic acid SRC in no-till wheat may be because of reduced protein, weaker gluten strength, or both, and the lower sucrose SRC may be because of lower pentosan and/or gliadin contents in no-till wheat, both of which would affect soft wheat product quality.

End-product quality of soft wheat was tested with sugar-snap cookie diameter and sponge cake volume (Table V). No-till wheat showed significantly greater sugar-snap cookie diameter than conventionally tilled wheat in the combined analysis, and it generally showed greater diameter in the specific trials. Cookie diameter is affected by protein content (Morris and Rose 1996), flour particle size, and water absorption (Abboud et al. 1985). Decreased protein content is correlated with increased cookie diameter (Ram and

TABLE II
Properties and Mineral Compositions of Whole Wheat Flour Grown Under No-Till or Conventional Tillage Systems[z]

Location	Year	System	Protein (%)	SDS (mL)	Starch (%)	Ash (%)	Mineral (µg/g) P	Mg	Ca	Mn	Fe	Zn	Cu
Pendleton I	2010	No-till	7.58b	29.9b	72.9b	1.36a	2,666a	1,010a	257a	43a	29a	14a	1.8a
		Conv.	9.86a	43.8a	66.7a	1.34a	2,435a	939a	271a	37a	31a	13a	2.1a
	2011	No-till	8.01a	23.8a	69.5a	1.40a	2,521a	974b	267a	43a	29a	12a	1.8b
		Conv.	7.99a	20.8a	71.1a	1.37a	2,601a	1,034b	279a	40a	28a	14a	2.1a
Pendleton II	2010	No-till	8.64a	36.8a	65.4a	1.51a	2,666a	988a	242a	39a	26a	17a	2.9a
		Conv.	9.44a	39.0a	69.3a	1.53a	2,369a	950a	255a	31b	25a	17a	3.0a
	2011	No-till	9.69a	24.7a	62.8a	1.53b	3,011a	1,128b	300a	51a	31a	18b	2.8a
		Conv.	10.37a	29.3a	66.4a	1.70a	3,314a	1,241a	338a	50a	35a	22a	3.3a
Moro	2010	No-till	7.45b	32.5a	69.4a	1.25b	1,723a	881a	198b	31a	27a	9a	2.4a
		Conv.	8.73a	38.4a	68.8a	1.34a	2,006a	948a	221a	33a	29a	11a	2.6a
	2011	No-till	8.18a	22.2a	62.9a	1.40a	2,653a	1,065a	217a	42a	34a	13a	2.1a
		Conv.	7.41a	18.8a	64.0a	1.39a	2,700a	1,157a	227a	44a	37a	12a	2.3a
Combined		No-till	8.26b	28.3b	66.8a	1.33b	2,540a	1,008b	247b	41.4a	29.3b	13.8b	2.3b
		Conv.	8.97a	31.7a	67.0a	1.36a	2,571a	1,045a	265a	39.1b	31.0a	14.8a	2.6a

[z] Values with different letters within each year in the same location are significantly different ($P < 0.05$). SDS = SDS sedimentation volume; Conv. = conventional tillage; and combined = analysis combined across locations and years.

TABLE III
Free, Bound, and Total Phenolic Compounds and Direct Assay of Total Antioxidant Capacity of Whole Wheat Flour Grown Under No-Till or Conventional Tillage Systems[z]

Location	Year	System	Phenolics (mg of Gallic Acid eq./g) Free	Bound	Total	Total Antioxidant Capacity (mmol of Trolox eq./g)
Pendleton I	2010	No-till	1.25a	2.84a	4.08a	22.2b
		Conventional	1.26a	2.87a	4.13a	24.5a
	2011	No-till	1.52a	3.33a	4.85a	21.5a
		Conventional	1.45a	3.41a	4.85a	22.0a
Pendleton II	2010	No-till	1.23b	2.85a	4.09a	23.1a
		Conventional	1.32a	2.90a	4.22a	24.9a
	2011	No-till	1.57a	3.35a	4.92a	24.0a
		Conventional	1.59a	3.40a	4.99a	25.9a
Moro	2010	No-till	1.12b	2.92a	4.03a	22.3b
		Conventional	1.26a	2.99a	4.25a	24.6a
	2011	No-till	1.66a	3.42b	5.08a	23.2a
		Conventional	1.57a	3.75a	5.31a	23.5a
Combined		No-till	1.39a	3.12b	4.51b	22.7b
		Conventional	1.41a	3.22a	4.63a	24.2a

[z] Values with different letters within each year in the same location are significantly different ($P < 0.05$). Conventional = conventional tillage; eq. = equivalents; and combined = analysis combined across locations and years.

Singh 2004), because a weaker gluten network allows increased spread of cookie dough (Guttieri et al. 2002; Gaines 2004). The lower protein content and weaker protein quality (as indicated by lower SDS sedimentation volume and lower lactic acid SRC) of no-till wheat compared with conventional wheat were associated with increased cookie diameter. The negative correlation between cookie diameter and sucrose SRC (Table V) has been widely reported elsewhere (Gaines 2004; Zhang et al. 2007, 2008). Pentosan level, as reflected by sucrose SRC, is related with increased water absorption, resulting in undesirable water retention in low-moisture cookies (Levine and Slade 2004).

Sponge cake volume was not significantly affected by tillage system (Table V). Low protein content and weak gluten are generally associated with increased cake volume (Kaldy and Rubenthaler 1987; Yamamoto et al. 1996). Nakamura et al. (2010) found that batter pasting viscosity, related to cake batter expansion, can be reflected by sucrose SRC. However, in this study, the lower protein content and sucrose SRC in no-till flour compared with conventional wheat apparently were not sufficient to significantly increase sponge cake volume.

CONCLUSIONS

Our results indicate that long-term changes in cropping practices such as no-till systems may alter soil conditions and ultimately influence properties of grain, flour, and end products. Although this principle was only demonstrated in one variety, ORCF 102, we suggest that similar qualitative responses to tillage would be seen in other varieties. This suggestion is based on numerous studies in which several varieties were evaluated in multiple environments. In general, varieties are ranked similarly across environments, that is, genetics has a greater effect on quality parameters than does the interaction of genetics and environment (Baenziger et al. 1985; Bassett et al. 1989; Peterson et al. 1992; Guttieri et al. 2002).

Compared with conventional tillage cropping systems, no-till practices often produced small but significant changes in kernel physical properties, composition, antioxidant capacity, and end-product quality. Test weight, kernel weight, and kernel diameter were higher in no-till wheat than in conventionally tilled wheat (Table I). Whole wheat flour from no-till wheat generally had lower protein and SDS sedimentation volume than conventional wheat (Table II). Ash content as well as most minerals measured, except for manganese and phosphorus, were also generally lower in no-till than in conventional whole wheat (Table II). Free phenolic content was not generally affected by tillage practice. However, bound phenolics, total phenolics, and total antioxidant capacity of whole wheat flour were generally lower under no-till compared with conventionally tilled practices, partly because of the increases in kernel size and weight. Larger kernels have a reduced proportion of bran layers, which are relatively high in phenolics and antioxidant capacity. Tillage system had little effect on milling properties (Table IV). However, refined flour from no-till wheat generally had lower

TABLE IV
Milling Properties and Composition of Refined Wheat Flour Grown Under No-Till or Conventional Tillage Systems[z]

Location	Year	System	Flour Yield (%)	Break Flour Yield (%)	Mill Score	Ash (%)	Protein (%)	SDS (mL)
Pendleton I	2010	No-till	66.3a	43.7a	82.5b	0.36a	5.95b	5.3b
		Conventional	67.4a	43.2a	83.7a	0.37a	7.78a	8.8a
	2011	No-till	69.8a	47.0a	85.8a	0.38a	6.42a	6.7a
		Conventional	70.1a	47.3a	86.4a	0.38a	6.50a	6.2a
Pendleton II	2010	No-till	66.0a	42.7a	78.8a	0.42a	6.78a	7.3a
		Conventional	67.0a	43.9a	79.5a	0.43a	7.45a	9.0a
	2011	No-till	70.4a	47.0a	84.5a	0.41a	7.55a	10.6a
		Conventional	69.8a	48.3a	82.3a	0.44a	8.08a	13.6a
Moro	2010	No-till	68.7a	45.6a	84.9a	0.37b	5.83b	6.2b
		Conventional	69.3a	45.3a	83.5a	0.41a	7.35a	10.0a
	2011	No-till	69.7a	45.2a	84.5a	0.40a	6.83a	7.7a
		Conventional	69.3a	45.2a	85.0a	0.39a	6.33a	6.2a
Combined		No-till	68.5a	45.2a	83.5a	0.39a	6.56b	7.3b
		Conventional	68.8a	45.5a	83.4a	0.40a	7.25a	8.9a

[z] Values with different letters within each year in the same location are significantly different ($P < 0.05$). SDS = SDS sedimentation volume; conventional = conventional tillage; and combined = analysis combined across locations and years.

TABLE V
Solvent Retention Capacity, Cookie Diameter, and Sponge Cake Volume of Soft Wheat Refined Flour Grown Under No-Till or Conventional Tillage Systems[z]

			Solvent Retention Capacity (%)					
Location	Year	System	Carbonate	Lactic Acid	Water	Sucrose	Cookie Diameter (cm)	Sponge Cake Volume (mL)
Pendleton I	2010	No-till	65.4a	72.5b	52.9a	88.3b	9.27a	1,249a
		Conventional	66.1a	84.9a	53.7a	89.7a	9.13b	1,214a
	2011	No-till	70.3a	73.6a	53.5a	78.7a	9.27a	1,252a
		Conventional	69.4a	71.3a	53.0a	77.7b	9.26a	1,248a
Pendleton II	2010	No-till	68.7a	79.7a	55.0a	92.2a	9.05a	1,222a
		Conventional	71.1a	84.5a	54.2a	92.5a	9.07a	1,219a
	2011	No-till	71.6b	82.1a	53.1a	78.7a	9.24a	1,245a
		Conventional	73.2a	87.9a	53.4a	79.9a	9.14b	1,220a
Moro	2010	No-till	68.8a	80.1b	53.2b	89.5b	9.29a	1,222a
		Conventional	73.9a	90.0a	55.0a	94.2a	9.21a	1,229a
	2011	No-till	71.9a	81.9a	53.1a	77.4a	9.34a	1,234a
		Conventional	71.3a	75.1b	53.4a	76.5a	9.34a	1,217a
Combined		No-till	69.5a	78.3b	53.5a	84.1b	9.24a	1,237a
		Conventional	70.8a	82.3a	53.7a	85.1a	9.19b	1,225a

[z] Values with different letters within each year in the same location are significantly different ($P < 0.05$). Combined = analysis combined across locations and years.

protein content, lower SDS sedimentation volume (Table IV), and lower lactic acid SRC (Table V) than flour from conventionally tilled wheat. Lower protein content, SDS sedimentation volume, and lactic acid SRC of refined flour from no-till wheat were associated with improved end-product quality, especially cookie diameter. Sponge cake volume was not significantly affected by tillage system. In conclusion, no-till wheat generally had slightly reduced nutritional properties (protein, ash, most minerals, and total antioxidant content) compared with wheat from conventionally tilled systems, but it often had slightly improved properties for soft wheat end-use quality.

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