Shepherd's Grain
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Title: **Exploring the quality and functional characteristics of flour derived from "tillage-free" agronomic production systems**

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Abstract
Shepherd's Grain (SG) has adopted a tillage-free agronomic management strategy for wheat production in the Pacific Northwest, and the corresponding flour has been reported to possess atypical quality and performance characteristics. This study systematically compared low (soft white wheat), medium (hard red winter wheat) and high (hard red spring wheat) protein flours from SG with comparable commercial flours grown under conventional tillage practices in the Pacific Northwest. No definitive conclusions can be made regarding quality differences on the basis of tillage-free versus conventional tillage agronomic management. However, this study confirms the anecdotal evidence from SG customers and points to gluten proteins as a potential source of the unusual quality characteristics.

Introduction
Shepherd's Grain (SG) is a grower-centric organization focused on wheat production using the alternative agronomic management strategy of tillage-free production. Most of the growers are located in the Pacific North West (PNW) region and into California, but expansion into the great plains of the U.S. and Canada is under development. The wheat varieties contracted for production are identified through bake testing for quality and flavor, delivered to ADM Milling Co. for flour production, and then distributed to bakers and other end-users primarily in the PNW and California.

End-users have reported that SG flour possesses unusual quality and functional characteristics. Farinograph curves typically display high water absorption and the rare double peak feature. Abnormally high viscosities are observed in batter systems at normal water:flour ratios. Doughs made from SG flour are generally more tolerant to processing conditions than normal commercial flours, reducing bakery rework and waste.

- The higher water absorption allows for a reduced amount of flour to be used in formulations opening the door to significant cost savings for end-users on the front end of production.
- Greater processing tolerance also promises significant cost savings on the back end of production through reduced waste, energy costs, and production downtime.

The source of the atypical quality and functional characteristics in SG flour has yet to be identified. Wheat varieties, weather, site specific agronomic management (e.g. soil amendments, crop rotations, cover crops, etc.) and growing region have all varied over the course of 18 years while the flour behavior has remained consistent. The one constant has been the tillage-free agronomic management strategy adopted by all growers producing wheat for SG.

- Tillage-free seems to be a significant factor in the unusual flour quality observed by end-users, but this has yet to be experimentally validated.
- There is a need to perform a controlled study to establish whether tillage-free is a critical factor influencing flour quality characteristics.
- There is a need to also establish the specific flour component(s) responsible for the unusual quality characteristics and end-use performance.

The first phase of this study compared sets of flour and their end-use product quality from SG (tillage-free) versus ADM/ Grain Craft (conventional tillage). This allowed us to best replicate the current customer experience and establish a benchmark for future study.

Materials and Methods

Materials

Three commercial flours, Pastry (soft white wheat), Low Gluten (hard red winter wheat) and High Gluten (hard red spring wheat) flours, were provided by Shepherd's Grain (SG). Two commercial control flours (soft white wheat and hard red winter wheat) from ADM Milling were compared against SG Pastry and Low Gluten Flours. Power High Gluten (hard red spring wheat) flour from Grain Craft served as the commercial control to compare with the SG High Gluten flour.

Table 1. Sample Information

Comparison	Flour	From	Agronomic condition
Group 1	Pastry	SG	Tillage-free
	Swan Pastry	ADM	Conventional Tillage
Group 2	Low Gluten	SG	Tillage-free
	Crown Best Bakers	ADM	Conventional Tillage
Group 3	High Gluten	SG	Tillage-free
	Power High Gluten	Grain Craft	Conventional Tillage

Methods

Flour Quality Analysis

Flour composition (moisture, ash, and protein), falling number values, Farinograph values (water absorption, dough development time, and stability), Alveograph values (P, L, and W), solvent retention capacity (SRC) tests (lactic acid, sucrose, sodium carbonate, and water), RVA values, and starch damage were measured using standard methods.

Pancakes Making and Quality Evaluation

The performance of pancake batters and pancakes made from SG Pastry and ADM Swan Pastry flours were evaluated using a standard pancake method. The pancake formulation was: flour (262.5 g), sucrose (25.5 g), dextrose (8.1 g), baking soda (4.7 g), monocalcium phosphate (1.3 g), sodium acid pyrophosphate (5.3 g), salt (3.9 g), canola oil (16.5 g), and water (363 g). Flour was mixed with the other dry ingredients at speed 1 in a Hobart mixer with a whisk attachment for 2 min. Canola oil was added to the dry mixture and mixed for another 2 min. Then, water was poured in a second mixing bowl and the dry mix added on top. The batter was mixed at speed 1 for 20 sec. Batter viscosity was measured with a Bostwick consistometer, and the distance the batter travelled down the ramp in 40 sec was recorded as the Bostwick viscosity. Batter specific volume (cc/g) was measured by weighing the batter in a cup and recording the weight of batter versus weight of water in the same cup. Batter pH was determined on the residual sample from the specific volume.

Full pancake batter was dispensed by a #20 food scoop onto the griddle and cooked for ~75 sec at 190 ^{O}C. After that, the pancakes were removed from griddle and cooled to room temperature. The pancake weight, height, and diameter were determined after cooling.

Separately, a Brookfield rheometer was used to measure the viscosity of a water and flour batter without additional ingredients. The water:flour ratio of the batter was 1.5:1.

Bread Making and Quality Evaluation

The bread baking performance of the four hard wheat flour samples (SG Low and High Gluten flours, ADM Crown Best flour, and Grain Craft Power High Gluten flour) was evaluated using a standard straight dough method. The formulation included flour (200 g), shortening (6.0 g), salt (3.0 g), sugar (12.0 g), non-fat dry milk (2.0 g), instant yeast (2.0 g), and ascorbic acid (5 mL). Loaf volume (cc) and specific volume (cc/g) were recorded. Crumb texture was measured with a texture analyzer as a function of compression force (g) where greater force reflects a firmer texture.

Statistical Analysis

Student's pairwise t-tests were run to compare sample means at a significance level of P<0.05.

Results and Discussion

Table 2. Compositional Analysis, SRC values and Starch Damage of flours

	Moisture	Protein	Ash	FN	SRC Water	SRC Lactic Acid	SRC Sucrose	SRC Sodium Carbonate	Starch Damage
	%	%, 14%mb		s	%, 14%mb				ucd
Group 1									
Pastry	12.5b	8.9a	0.53a	414	57.6	86.0b	92.1	70.6	16.1b
Swan Pastry	12.9a	8.7b	0.51b	385	57.3	94.7a	95.5	73.1	18.1a
Group 2									
Low Gluten	11.6b	11.8a	0.52	305a	69.3	142.4b	113.9	88.2b	22.8b
Crown Best	13.3a	11.1b	0.55	218b	71.5	152.1a	116.6	95.9a	24.0a
Group 3									
High Gluten	13.8a	13.5	0.49	269b	69.1	161.1a	116.6b	87.7b	20.5
Power High Gluten	13.6b	13.5	0.63	492a	66.5	143.4b	121.4a	93.0a	22.7

Values with different letters in the same column are significantly different at $P<0.05$.

Table 2 shows that SG High Gluten and Grain Craft Power High Gluten flours had no difference in protein content (13.5% protein). Protein content was also similar between SG Pastry (8.9% protein) and Swan Pastry (8.7% protein) flours. In contrast, a larger difference (0.7%) in protein content was observed between SG Low Gluten flour (11.8% protein) and Crown Best (11.1% protein). This difference in protein content is worth noting because it is big enough to potentially give SG Low Gluten flour flour a performance advantage over Crown Best flour.

Falling number values for the Pastry and Swan Pastry flours were in line with that for sound grain. The lower falling number values observed for SG Low Gluten, SG High Gluten, and Crown Best are consistent with the addition of α-amylase at the mill. Power High Gluten generated a falling number value of 492 sec, indicating either a more heat sensitive fungal α-amylase was used instead of malted barley flour or that α-amylase was not added at all. The addition of α-amylase is done at the mill because it enhances bread making potential. If no α-amylase was added to the Power High Gluten flour, then it was potentially at a disadvantage in bread making performance relative to the other samples.

SRC values were recorded to indirectly assess the flours for differences in flour composition and functionality. Lactic acid induces swelling of glutenin proteins, concentrated sucrose solutions are specific for swelling of soluble fibers, sodium carbonate causes swelling of damaged starch, and water acts on all flour components. Flours from hard wheats generally exhibit greater SRC values due to greater quantities of each component, greater swelling capacity, or a combination of the two. Few differences were observed for pairs for sucrose and water SRC values. Lactic acid SRC values did indicate differences in the glutenin proteins between samples with SG Pastry and SG Low Gluten flours both ranking lower than their ADM counterparts. This was unexpected for the SG Low Gluten flour considering the 0.7% greater protein content relative to Crown Best flour. Only the SG High Gluten flour showed a greater lactic acid SRC value compared to the Grain Craft control (Power High Gluten). As a group, SG flours exhibited lower sodium carbonate SRC values and starch damage compared to control flours. This is likely a result of differences in kernel hardness with harder kernels more prone to greater levels of starch damage.

Table 3. Farinograph and Alveograph parameters of flours

Sample	Farinograph			Alevograph		
	WA	DT	ST	P	L	W
	% (14% mb)	min	min	mm	mm	10^{-4}J
Group 1						
Pastry	52.0b	1.2b	2.9a	42a	90	95
Swan Pastry	53.6a	1.5a	2.5b	40b	92	84
Group 2						
Low Gluten	60.0b	2.7a	14	108	91a	352a
Crown Best Bakers	60.8a	2.5b	6.6	102	77b	285b
Group 3						
High Gluten	62.9	4.6b	14.5	92b	130	374b
Power High Gluten	63.3	11.6a	14.2	119a	115	497a

WA=Water absorption; DT=Develop time; and ST=Stability.
Values with different letters in the same column are significantly different at $P < 0.05$.

Farinograph characteristics are displayed in Table 3. Farinograph water absorption (FAB) was similar between pairs, although SG flours generally required slightly less water to reach the same dough consistency. Dough develop time was also similar for 2 out of 3 pairs, with only the SG High Gluten showing shorter development time (4.6 min) than Power High Gluten (11.6 min). Longer mixing times are typically not preferred because they limit how many batches can be mixed per production period. Mixing stability was similar at ~14 min for both SG High Gluten and Power High Gluten and ~3 min for SG Pastry and Swan Pastry flours. The largest difference in mixing stability was observed between SG Low Gluten (14 min) and Crown Best (6.6 min), confirming reports of SG Low Gluten flour exhibiting greater processing tolerance.

Alveograph results are also shown in Table 3. The Alveograph measures the balance of strength and extensibility potential in flour by blowing a bubble from a thin sheet of dough until it ruptures. L (extensibility) and W (energy to blow the bubble) values were greater for SG Low Gluten flour than those observed for Crown Best flour. The greater L value (better extensibility) for SG Low Gluten flour is likely to have allowed for a larger bubble, thereby increasing the W value (energy to blow the bubble). Their respective P values (resistance to expansion) were similar, indicating similar strength profiles. This means that the SG Low Gluten flour, while having similar strength to Crown Best flour, is better able to expand and retain gas during fermentation. Likewise, a greater P value (resistance to expansion) for Power High Gluten flour resulted in a greater W value (energy to blow the bubble) compared to the SG High Gluten Flour despite having similar L values (extensibility). This indicates a strength advantage for Power High Gluten flour with the same potential for expansion as SG High Gluten flour.

Table 4. Pancake Quality of flours

Sample	Batter Specific Volume	Batter Viscosity	Batter pH	Pancake Weight	Height	Diameter	Brookfield Viscosity
	cc/g	cm		g	cm	cm	cP
Pastry	1.00a	16.625	6.54	12.3	3.1	11.7a	2320
Swan Pastry	0.98b	16.875	6.55	12.2	3.2	11.0b	2280

Values with different letters in the same column are significantly different at $P < 0.05$.

Pancake characteristics are provided in Table 4. Specific gravity gives an indication of aeration potential by comparing the weight of a batter to an equal volume of water. The batter specific gravity of SG Pastry flour (1.0 cc/g) was equal to that of water, but Swan Pastry flour (0.98 cc/g) was less than water, indicating that Swan Pastry batter was slightly more aerated than SG Pastry batter. Batter viscosity (pancake and flour + water batters) and pH were similar between both samples. However, despite similar batter viscosities, the diameter was smaller for Swan Pastry pancakes compared to SG Pastry pancakes. The SG Pastry pancakes also had more and smaller gas cells than Swan Pastry pancakes despite the fact that Swan Pastry pancake batter had a lower specific gravity. This indicates that batter made with Swan Pastry flour is less capable of retaining gas cells than SG Pastry batter.

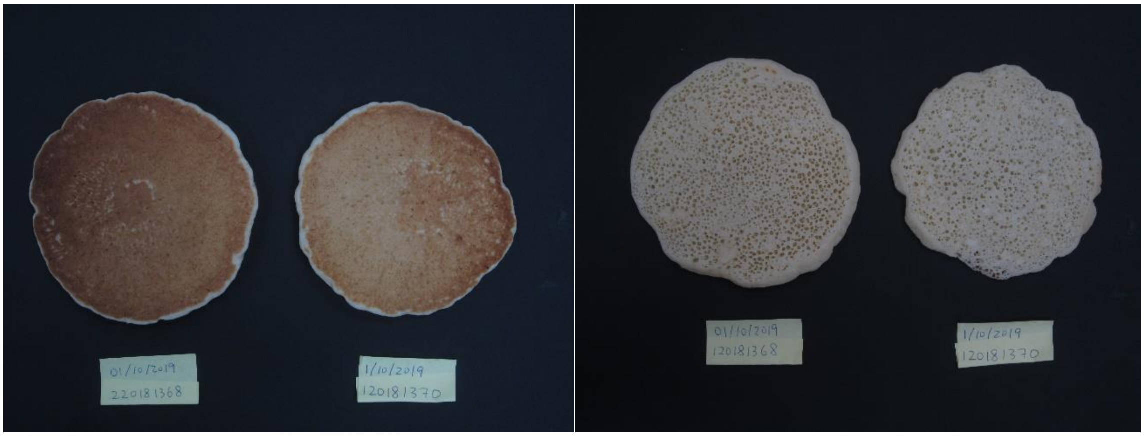

Figure 1. Pancakes: SG Pastry flour (left) versus ADM Swan Pastry flour (right).

Table 5. Bread Baking Performance of flours

	Loaf Volume	Specific Volume	Crumb Texture	Brookfield Viscosity
	cc	cc/g	g	cP
Group 2				
Low Gluten	774a	5.56a	134.5b	11680a
Crown Best Bakers	701b	4.97b	172.5a	7360b
Group 3				
High Gluten	775.5b	5.5b	158.3a	-
Power High Gluten	873.5a	6.3a	84.5b	-

Values with different letters in the same column are significantly different at $P < 0.05$.

Bread making performance is summarized in Table 5. Among the HRW flours, SG Low Gluten had greater loaf volume (774 cc) than Crown Best (701 cc). This is likely related to the greater Alveograph L value recorded for SG Low Gluten flour (Table 3), which would allow it to better retain gas and expand during proofing. Specific volume results were in agreement with the loaf volume results. Crumb texture was softer for SG Low Gluten bread (135 g) than Crown Best bread (173 g), and SG Low Gluten bread had better crumb structure and elasticity which is typically associated with the better gluten characteristics in the flour. Greater flour + water batter viscosity was also observed for Low Gluten flour (11580 cP) compared to Crown Best (7360 cP), in agreement with customer reports.

In contrast to the HRW results, SG High Gluten bread had smaller loaf volume and specific volume than Power High Gluten bread (Figure 2b). This is despite the fact that the Power High Gluten sample lacked the performance enhancing potential of added α-amylase. While the overall strength of SG High Gluten flour was generally similar to (Farinograph mixing stability) or greater (lactic acid SRC value) than Power High Gluten, the balance of strength to elasticity (Alveograph W value) was not as optimal. It's worthwhile to note that although SG High Gluten bread did not outperform Power High Gluten, it still produced acceptable bread and would have more desirable processing properties (e.g. shorter dough development time combined with long mixing tolerance) than Power High Gluten.

(a) SG Low Gluten flour (left) versus Crown Best flour (right)

(b) Power High Gluten flour (left) versus SG High Gluten (right)

Figure 2. Breads made from different flours

Conclusions

Although we are unable to make any final conclusions regarding the performance of tillage-free wheat flours compared to conventional tillage wheat flours, the results generated in this study confirm the anecdotal evidence supplied by customers regarding the high batter viscosity, excellent processing tolerance and bread making performance of SG Low Gluten HRW flour. Additionally, SG Pastry flour demonstrated excellent potential as a pancake flour and SG High Gluten performed well in pan bread.

Despite differences in end product performance, SG flours were largely similar to their commercial controls in terms of flour quality characteristics. We had anticipated sucrose SRC would reveal differences in soluble fibers among samples, possibly related to tillage practice. However, no major differences were observed that would indicate soluble fibers playing a role in the SG Low Gluten flour batter viscosity phenomenon. RVA starch pasting properties were primarily affected by α-amylase activity as indicated by the falling number values. Overall, the performance differences appear to be related to protein characteristics that are only sometimes captured by traditional flour quality tests. Lactic acid SRC and Alveograph P, L and W all showed some small differences among SG flours compared to the controls. It is possible per conversation with Jill Clapperton that amino acid substitutions may have occurred in gluten proteins from tillage-free systems. If this is true, it is conceivable that small changes in gluten protein amino acid sequences may result in improved end-product performance that is largely undetectable in traditional quality tests. While we cannot draw any conclusions on what role, if any, the tillage-free agronomic management strategy played in the observed end-product performance for SG flours, our research indicates that future flour quality and baking performance studies should focus on gluten proteins over starch or soluble fibers (i.e. pentosans). Additionally, future analysis should be conducted on samples from field trials that control for varietal and environmental factors in an attempt to isolate and clarify the effect(s) of tillage-free agronomic management in direct comparison to conventional tillage practices.

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Supplemental data

Table A. GlutoPeak and RVA of Flours

Sample	GlutoPeak			RVA					
	PT	TM	AE	Peak Time	Peak Viscosity	Trough	Break Down	Final Viscosity	Setback
	s	BU	GPE	min	cP				
Group 1									
Pastry	96a	31b	738b	5.5b	2484	1513	971	3178	1665
Swan Pastry	85b	32a	758a	5.7a	2108	1438	670	2890	1452
Group 2									
Low Gluten	99.5	47	1309	5.15	1152a	366a	786a	1118a	752a
Crown Best Bakers	86	46	1252	4.935	707b	203b	504b	569b	366b
Group 3									
High Gluten	76.5	52	1450	5.2b	1205b	376b	830b	982b	607b
Power High Gluten	78	52.5	1459	6.0b	2515a	1432a	1083a	2768a	1336a

PT=Peak time; TM=Torque maximum; and AE=Aggregation energy.

Values with different letters in the same column are significantly different at $P < 0.05$.

The GlutoPeak measures gluten aggregation properties during high speed mixing. The torque maximum and aggregation energy (gluten protein strength indicators) in combination with peak maximum time (an indicator of the quality of gluten interactions) provide information about gluten performance potential in baked goods. GlutoPeak results in Table A were similar between pairs for the torque maximum and aggregation energy parameters. Peak time showed some differences that approached significance for the SG Pastry/Pastry and SG Low Gluten/Crown Best pairs. In both cases the SG flour exhibited longer peak time than their respective ADM counterpart.

The RVA test involves a heat-hold-cool cooking cycle in which starch granules swell and gelatinize (heat), breakdown due to heat and continual mixing (hold), and re-associate, or retrograde, to form a gel (cool). Peak, trough and final viscosities indicate the starch pasting properties at the gelatinization, breakdown, and retrogradation (gel-forming) phases. The differences in RVA properties (Table A) closely tracked falling number results (Table 2). Those samples in each pair with a lower falling number exhibited lower viscosities throughout the RVA test due to more rapid starch breakdown from increased α-amylase activity.