Breeding, Selection, and Quality Characteristics of Soft White Wheat

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ABSTRACT

Whereas hard kernel wheats are used for yeast-leavened breads, soft wheats are used for cookies, cakes, and confections. The U.S. Pacific Northwest produces 6.5–7 Mt of soft white wheat annually. This soft white grain is marketed as either "common" soft white, "club," or a blend of the two. Breeding new cultivars of soft white wheat requires an understanding of the foods that are best suited to this class and of the physical and chemical properties of grain and flour that contribute to consistent, superior consumer products. The Pacific Northwest Wheat Quality Council facilitates communication among wheat breeders, millers, food manufacturers, and farmers to identify and define soft white wheat quality targets. Soft white wheat exhibits high break and straight-grade flour yields, at low ash and low starch damage. Their flours have low water absorption and low water-, carbonate-, and sucrose-solvent retention capacities. Soft white wheat produces large-diameter cookies and sponge cakes with large volumes and tender, fine crumb grain. Gluten strength of soft white common wheat ranges from moderately weak to moderately strong. Club wheats are uniformly weak. Innovations in soft white wheat include soft kernel durum wheat, "super soft" wheat, partial waxy wheat for noodles, and full waxy wheat for puffing and unique processing. The subject of whole wheat flavor is explored for the breeding and selection of soft white wheat.

The majority of the wheat grown globally is aimed at producing yeast-leavened breads of various styles and shapes. As such, gluten rheological characteristics are a major focus for these wheats. Further, at least in the major exporting countries of the United States, Canada, Australia, and Argentina, these wheats are hard kernelled. In contrast, soft wheats are usually targeted toward making cookies, cakes, and other confections. Because the specific end use dictates the definition of "quality," the breeding, selection, and quality characteristics of these soft wheats are often markedly different. Here, we review the breeding, selection, and quality characteristics of soft white wheat in the United States.

Two types of soft wheat are grown in the United States: soft red winter and soft white. These two types are defined by law and represent "Market Classes." Soft red winter wheat is grown almost exclusively east of the 94th meridian west, where higher rainfall and humidity prevail. Soft white wheat is concentrated in the Pacific Northwest (PNW) states of Washington, Idaho, and Oregon, with lesser production in Michigan, New York, and California. The PNW produces on the order of 6.5–7 Mt of soft white wheat annually (46). The majority of soft white varieties are winter-sown and, as such, have a "vernalization" requirement that must be fulfilled to complete their reproductive cycle. Planted in the fall, they remain dormant (often under snow cover) until resuming growth in the spring. Soft white spring wheats are also grown. They are spring-sown and develop and mature within one growing season.

U.S. statute defines three "Sub-Classes" of soft white wheat: "Soft White Wheat," "White Club Wheat," and "Western White Wheat." The defining feature of the first two sub-classes is the head (spike) morphology (Fig. 1). The third sub-class is simply a blend of the first two. Club wheats possess the "Club" or *C* locus, a genetic system that results in reduced internode length of the rachis and, thus, reduces the overall length of the spike. Wheat without the *C* locus is simply referred to as having a "common" spike, and thus, soft white wheat is often referred to as "common soft white." The *C* locus does not have any direct bearing on the quality of club wheat, although it does influence kernel size and shape. In contrast, breeding and selection do have a direct bearing on the quality of club wheat varieties.

Historically, there was a dramatic transformation of the PNW soft white wheat crop in the early 1960s associated with the introduction of semi-dwarf plant stature. (N.B., this reduction in plant height through the use of "dwarfing" genes is what, in part, drove the Green Revolution.) In 1960, the ratio of club to common wheat was 78:22. All of these were tall, "standard height" wheat varieties. Dr. Orville A. Vogel introduced to the region the semi-dwarf plant stature with the release of soft white common winter wheat cv. Gaines, followed by cv. Nugaines. By 1964, these semi-dwarf common soft white varieties had been so widely adopted by growers that the club to common wheat ratio was 14:86. Over the subsequent 55 years, club wheat pro-

Fig. 1. Heads (spikes) of "club" and "common" soft white wheats. The two heads on the left exhibit the characteristic compact spike architecture of club wheat, whereas the two on the right have the "common" spike morphology. The length of the spikes is due to the length of the rachis and rachis internodes.

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https://doi.org/10.1094/CFW-65-5-0053

duction has remained around 10% of soft white wheat production. A minimal amount of club wheat is used as pure club; essentially all is used to create the Western White blend.

Quality Targets for Soft White Wheat

There is an enigma in wheat breeding. On the one hand, the breeder strives to create genetic variation through crossing different parents, but then works to eliminate all but a tiny fraction of that variation. The "beneficial" variation aims to increase grain yield, increase resistance/tolerance to insect and microbial pests, and improve responses to heat, drought, and cold. At the same time, the maturity, plant height, and other agronomic features desired by farmers must be maintained. What about quality? It is true that wheat quality is in the eye of the beholder. In other words, there is no absolute definition of quality. Quality is defined by the suitability of a flour to produce, on a consistent basis, a consumer product with particular characteristics, such as texture, size, and color. This description is largely the reason why we have soft wheats—they have the inherent characteristics needed to make specific products desired by consumers.

This, then, is the nexus of wheat breeding for end-use quality: first defining the characteristics of a food (sometimes many foods), and then figuring out how to select for genetic consistency of those traits. Along the way, it can be hugely beneficial to understand the physical and chemical basis for quality variations. Since its inception in 1915, and through its evolution of names, the Cereals & Grains Association has to a large degree been focused on this issue of understanding, defining, and measuring end-use quality of wheat and other grains.

The USDA Western Wheat Quality Laboratory and the Pacific Northwest Wheat Quality Council

The USDA Western Wheat Quality Lab (WWQL) was established in 1946. In its first year, Barmore and St. John (3) stated that,

> The two primary purposes of the laboratory are variety characterization and research. Neither one can be considered secondary. The first is needed to supply the plant breeders with information of such a nature that an accurate, intelligent decision can be made relative to the suitability of new varieties of wheat for processing. This necessitates the application of the best available laboratory methods…. The research is essential in order to determine the fundamental factors responsible for the desirable and undesirable characteristics of wheat and flour from the utilization standpoint. This necessitates research on methods, ingredients used, chemistry of constituents of wheat and flour, and the devising of new methods based on the knowledge obtained.

Those two original purposes remain essentially unchanged. Currently the WWQL measures the grain, milling, flour, and baking quality of around 4,500 samples a year; the major share are soft white wheats. Most of the testing protocols follow AACC Approved Methods (1). The WWQL has been involved in evaluating, modifying, and establishing methods for measuring soft white wheat quality, including gluten strength, enzymatic discoloration, solvent retention capacities (SRCs), arabinoxylans, and enzyme assays (2,5,9,13,20,21,23,33,38,39,41).

If measuring quality is considered half the equation, the other half (which is often more problematic) is defining what quality attributes are desirable and at what level. For example, if a bagel requires a strong gluten flour, how strong should it be, and what is too strong or not strong enough? The answer to this question is largely empirical, and by no means universal. In the U.S. PNW, the Pacific Northwest Wheat Quality Council plays an essential role in this process.

The PNW Wheat Quality Council was established in Portland, OR, in 1995 by the senior author and Dr. Edward J. Souza, then a wheat breeder at the University of Idaho. The council is organized around an annual collaborator evaluation of new wheat varieties. The mission of the council is "To enhance the quality of wheat produced in the Western States by promoting the development of superior cultivars." The council has played an essential role in connecting wheat breeders with millers and end users, while emphasizing to growers the importance of end-use quality, and not "just yield." The council has also established and promulgated specific end-use quality targets for soft white common and club wheats using the WWQL as a reference laboratory (Table I).

Measuring and Selecting Soft White Wheat Quality

The foregoing laid the stage for a presentation of the various traits important to soft white wheat quality and how they are measured (Table I) (25). When referenced as "historically observed/attainable value based on the 80th percentile of the soft white crop," large datasets generated by and available at the WWQL included 7 years of the Genotype & Environment study and the Overseas Varietal Analysis Program on cvs. Stephens

Table I. Quality targets for soft white common and club wheats adopted by the Pacific Northwest Wheat Quality Council based on historical values obtained at the USDA Western Wheat Quality Laboratory, which serves as the reference lab

Quality Parameter	Common	Club
Grain		
Test weight (lb/bu)	>60	>58
Kernel hardness (SKCS 4100)	<35	≤35
Kernel diameter (mm) (SKCS 4100)	>2.5	>2.36
Kernel weight (mg) (SKCS 4100)	>35	>35
Falling number (sec)	≥300	≥300
Protein (%, 12% mb)	10.5	<10
Ash (%, 12% mb)	≤1.30	≤1.30
Flour		
Protein (%, 14% mb)	<8.71	<8.3
Ash (%, 14% mb) at 67% extraction	<0.38	<0.39
Flour yield (%)	>68.15	>69.2
Break flour yield (%)	>46.75	>50.64
Milling score	>83.47	>84.62
Wet gluten (%, 14% mb)	<27	<26
Farinograph absorption (%, 14% mb)[a]	<55	<52.0
Farinograph stability (min)[a]	<7.0	<2.0
Mixograph absorption (%)[a]	<53.97	<50
Color/polyphenol oxidase (L-DOPA A_{475})	<0.5	<0.5
Solvent retention capacity: water (%)	<58	<56
Solvent retention capacity: carbonate (%)	<75	<72
Solvent retention capacity: sucrose (%)	<95	<93
Solvent retention capacity: lactic acid (%)	90–120	<72.0
SDS sedimentation volume (mL/g)[a]	7.0–14.0	<5.0
End product		
Sugar-snap cookie diameter (cm)[a]	9.3	9.4
Sponge cake volume (cm^3)	1,280	1,300

[a] Common wheat protein reference at 8.7%; club wheat protein reference at 8.3%.

soft white winter wheat, Alpowa soft white spring wheat, and Rely winter club wheat. For these three cultivars, 1, 10, mean, 90, and 99 percentile values were calculated. Further, the mean of the then contemporary cultivars comprising 80% of the production area were calculated. These analyses were used as a guide in setting the values for the various traits. These values provide a specific value to guide breeding and selection. More commonly, judgements on potential new cultivars or breeding lines are based on fully balanced *t* tests, wherein the experimental line is paired with one or more "check" varieties. This limited ANOVA accommodates the lack of field replication. The balanced design facilitates the partitioning of the environmental effect (but not the G × E interaction).

- **Test weight.** The bulk density of grain, measured in weight per unit volume (U.S. units of pounds per Winchester bushel). Provides a general indicator of soundness, plump/shriveled kernels; highly influenced by the environment. Target conforms to U.S. Grain Standards for Grade No. 1 (AACC Approved Method 55-10.01).
- **Kernel hardness.** The crushing strength of the wheat kernel, "softness" or "hardness." Unitless, determined by the Single Kernel Characterization System (SKCS) 4100. In addition to identifying that the wheat is genetically uniformly soft, softer kernel texture within the soft wheat class is associated with higher quality. Target aims to convey this goal (AACC Approved Method 55-31.01).
- **Kernel diameter and weight.** SKCS 4100 diameter (mm) and weight (mg). Small kernels are not desirable from a milling standpoint. Established as historically attainable values based on the 80th percentile of the soft white crop (2.6 mm and 38.0 mg, respectively) (AACC Approved Method 55-31.01).
- **Falling number.** Indication of soundness (sec). Lower falling numbers due to preharvest sprouting or late maturity α-amylase (24). Target reflects common commercial specification (AACC Approved Method 56-81.04).
- **Grain protein.** Impacts functionality and texture of products; reference to flour protein (%, 12% mb). Established as historically observed value based on the 80th percentile of the soft white crop (10.6%) (AACC Approved Methods 39-25.01 and 46-30.01).
- **Wheat ash.** Mineral content of wheat grain; reference to flour ash (%, 12% mb). Established as historically observed value based on the 80th percentile of the soft white crop (1.37%) (AACC Approved Method 08-01.01).
- **Flour protein.** Impacts functionality and texture of products (%, 14% mb). The "protein differential," which is the difference between wheat and flour protein contents is greater on the WWQL Modified Quadrumat Milling System than is typical of commercial mills (19). Established as historically observed value based on the 80th percentile of the soft white crop (9.0%) (AACC Approved Methods 39-11.01 and 46-30.01).
- **Flour ash.** Mineral content of flour, referenced to extraction rate (%, 14% mb). Based on an estimated 67% extraction rate on the WWQL Modified Quadrumat system (19). Established as historically observed value based on the 80th percentile of the soft white crop (0.39%) (AACC Approved Method 08-01.01).
- **Flour yield.** Recovery of straight-grade flour (%, wt). Milling performance is emphasized as a key quality trait of soft white wheat. Established as historically attainable value based on the 80th percentile of the soft white crop (68.2%) (AACC Approved Method 26-50.01 [19]).
- **Break flour yield.** Recovery of break flour (%, wt). Reflection of kernel softness and milling performance. Established as historically attainable value based on the 80th percentile of the soft white crop (48.6%) (AACC Approved Method 26-50.01 [19]).
- **Milling score.** A composite score to estimate milling performance. Calculated to balance flour yield against ash content (unitless). Established as historically attainable value based on the 80th percentile of the soft white crop (83.0) (AACC Approved Method 26-50.01 [19,34]).
- **Wet gluten.** Percent on a 14% flour moisture basis (AACC Approved Method 38-12.02 [19]).
- **Farinograph absorption and stability.** Indicates dough water absorption and mixing character (% flour, wb, and min, respectively); 14% flour mb at 8.7% flour protein, 50 g bowl. Lower water absorption and moderate gluten strength are often desirable in soft white wheat (AACC Approved Method 54-21.02).
- **Mixograph absorption.** Indicates dough water absorption (% flour basis at 8.7% flour protein). Most samples at the WWQL are analyzed using the 10 g mixograph as opposed to the farinograph. Established as historically attainable value based on the 80th percentile of the soft white crop (55.1%) (AACC Approved Method 54-40.02).
- **Color/polyphenol oxidase (PPO).** Predictive of enzymatic discoloration of certain foods due to PPO. Enzymatic activity of whole seeds using L-DOPA substrate (L-3,4-dihydroxyphenylalanine); absorbance at 475 nm; lower activity is desirable. Established as historically attainable value based on the 80th percentile of the soft white crop (<0.5 AU) (AACC Approved Method 22-85.01 [2,27,32]).
- **Solvent retention capacity, -water, -carbonate, -sucrose, -lactic acid.** Retention of various solvents by flour (% flour, wb). Diagnostic of polymer characteristics of flour (viz., water, overall hydration; carbonate, damaged starch; and sucrose, arabinoxylans [pentosans]). For these three, lower is desirable. Lactic acid, glutenins. Established as historically attainable values based on the 80th percentile of the soft white crop (55.6, 72.0, 95.4, and 107.8%, respectively) (AACC Approved Method 56-11.02).
- **SDS (Na-dodecyl sulfate) sedimentation volume.** Measure of gluten strength with flour protein effect, based on 8.7% protein (vol/g weight of flour). Broadly defined, reflective of historical range of gluten strength of soft white. Established as historically attainable target based on the 80th percentile of the soft white crop (11.2 mL/g) (AACC Approved Method 56-60.01, but with SDS [9]).
- **Cookie diameter.** End-product test representing low-moisture products. Mean diameter (cm) of two cookies, based on 8.7% flour protein. Established as historically attainable value based on the 80th percentile of the soft white crop (9.34 cm) (AACC Approved Method 10-52.02 [31])
- **Sponge cake volume.** End-product test representing high-moisture products. Established as historically attainable value based on the 80th percentile of the soft white crop (1,274 cm^3) (45).

Club Versus Soft White Common Wheat Quality

There are many commonalities between the two sub-classes "Soft White Wheat" and "White Club Wheat." Yet, there are also notable differences that confer added value to club wheat (and by blending, to "Western White Wheat"). The quality targets for club wheat that were adopted by the PNW Wheat Quality Council are included in Table I.

The lower test weight for club wheat is reflective of the U.S. Federal Grain Standards for U.S. No. 1 Grade. As noted above, the club head morphology can restrict the growth of the kernel—reflected in slightly lower kernel diameter. Grain protein, and hence flour protein of club wheat, are both historically lower for club versus soft white common wheat. Milling performance of club wheat varieties is historically somewhat higher than common varieties and is reflected in flour yield, break flour yield, and milling score; ash is slightly different. Club wheats are recognized for their low dough water absorption and weak gluten. Farinograph and mixograph water absorptions are lower, as are farinograph stability and wet gluten. All three SRCs for water, carbonate, and sucrose are lower (deemed more desirable) for club wheat. The SRC for lactic acid and SDS sedimentation volume both reflect the weak gluten of club wheats. Lastly, both end-product tests, cookies and cakes, are notably better for club wheat. To summarize the difference (with some oversimplification), one can say that "cub wheats are overall better 'soft wheats', but with uniformly weak gluten." A key feature of club wheat is the effect it has in Western White wheat. Primarily a function of its uniformly weak gluten, which is largely independent of protein content (9), it has the ability to lessen any adverse effect that gluten structure might have on product texture. These subtle but measurable differences between club and common soft white wheats are maintained through breeding efforts and phenotypic and genetic selection (20,21).

There is a long-held notion that club wheats mill better than common soft white wheats. The targets reflect this subtle difference, which although not universal among the two sub-classes, does on average hold true. This perception appears to have resulted from the release of cv. Gaines, the first semi-dwarf common variety. As noted above, this common variety rapidly displaced much of the club wheat production (discussed earlier). In a letter dated May 11, 1964, Dr. Mark Barmore stated that the "flour yields of 43 paired samples of these three varieties were Omar [club] 75.1%, Gaines 70.5% and Brevor [a common released in 1949] 69.1%…, milling scores were of 90.1 for Omar, 81.7 for Gaines and 80.4 for Brevor." It is notable that when Dr. Vogel registered the release of Gaines, he stated that "Gaines has fair milling qualities…."

Innovations in Soft White Wheat

Soft White Durum Wheat. The biggest innovation in soft white wheat quality is the development of soft kernel durum wheat (34,36). It is accurate to describe soft kernel durum as "a new soft white wheat species." As is well documented, the genetic basis for soft kernel texture in wheat is the action of the puroindoline genes and proteins (6). As a result, the replacement of 20.7 Mbp of durum chromosome 5B with 28.2 Mbp of the puroindoline possessing the homoeologous portion of 5D from soft hexaploid wheat effectively converted the hardest of wheats to a tetraploid soft white (7,8,18). Studies have demonstrated that with the expression and softening effect of the puroindolines, kernel texture, flour milling, starch damage, water absorption, dough rheology, and baking are highly similar to hexaploid soft white wheat (7,8,16,41,42,44,47), without any reduction in pasta (43) or couscous quality (R. Daaloul and R. Hammani, *personal communication*).

"Super Soft" White Wheat. Philosophically and practically, there is the question that if kernel softness is at times desirable, then is greater softness even more desirable? To date there have been two approaches to answering this question. First, it is generally true that within the soft wheat class (as defined by puroindoline gene haplotype), softer SKCS values are associated with higher break flour yields, lower SRC water, carbonate and sucrose values, and larger cookie diameters (25,35). However, among these soft white wheats, kernel texture (as measured by the SKCS) infrequently falls below about 20 (Table I). The second approach involves a more dramatic softening of the kernel. A novel kernel softness phenotype, termed "super soft" was identified (34) and partially genetically characterized (29,30). A more detailed understanding of the genetic basis for the super soft kernel phenotype and its potential value to milling and food processing are currently under investigation. A seemingly unrelated super soft phenotype has also been observed in soft durum wheat (17).

Noodles. Noodles are a hugely popular and essential food product in many cultures, especially in eastern Asia. Specific PNW soft white wheat varieties appear to be highly suitable in certain white salted noodle applications, especially those consumed in Japan and South Korea. The soft white spring wheat variety 'Ryan' has gained recognition for its white salted noodle quality and acceptance. Three key features of 'Ryan' and similar soft white wheats are 1) partial waxy starch trait (11,49); 2) low discoloration (32); and 3) moderate level of gluten strength. The partial waxy trait is easily recognized among breeding lines using the flour swelling volume test of Crosbie and Lamb (10) (40).

Waxy Wheat. As an extension of the "partial waxy" genetics of white salted noodle wheats, all three granule-bound starch synthase I genes can be eliminated, resulting in zero amylose "full waxy" wheat (15). Why do this? The motivation lies with the fact that waxy starch granules have a markedly different structure (4), which dramatically affects their ability to swell (11), "puff'" (48), extrude (12,28), and paste (Fig. 2). Until recently, the PNW soft white waxy wheat variety 'Waxy-Pen' was used in a puffed cereal (Kellogg Company). Additionally, aquaculture feeds produced from waxy wheat are more nutritious due to the greater digestibility of amylopectin (14).

Flavor. Is flavor the next frontier in wheat improvement? Studies using an animal model clearly indicate strong consumption preferences for different varieties of soft white wheat (26,37). As a stable genetic trait, molecular mapping techniques have identified underlying loci involved in consumption preferences (22). A crucial aspect of this research lies in testing whether the

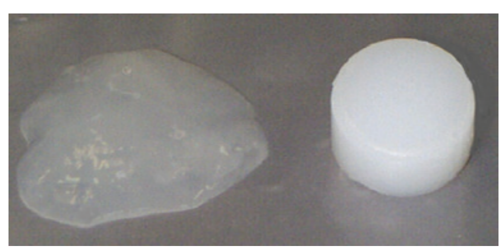

Fig. 2. Starch pastes from waxy (left) and "normal" (right) soft white wheat. Starches were pasted in a Rapid ViscoAnalyzer and allowed to cool to room temperature. Waxy starch has zero amylose, whereas normal starch has approximately 25% (49).

Fig. 3. Consumer volunteers at the Denver Museum of Nature & Science, Genetics of Taste Lab. Participants were asked to taste and then pair uncooked whole wheat wafers based on flavor (similar or different). Two "Yummy" and two "Yucky" wheat varieties were included. Participants performed the pairing twice, with a break between pairings to answer questions about their flavor perceptions of each wafer and their whole grain consumption behavior. (Reproduced with permission—©Denver Museum of Nature & Science, Rick Wicker photo)

ability to discern flavor differences observed in the model species, *Mus musculus*, can be observed in the target species, *Homo sapiens*. A large consumer trial has been completed in cooperation with the Denver Museum of Science and Nature, Genetics of Taste Lab (Fig. 3).

The consumer testing phase of the research is complete, and the results are currently under analysis. The preliminary analysis of data from approximately 1,000 participants shows that humans are indeed able to discern differences between wheat varieties of the same market class that were known a priori from the model system to be "Yummy" and "Yucky" (22).

Summary

In summary, soft white wheat is a major class of wheat grown in the United States. Soft white wheat is classified as either "common" or "club," and although the two share a number of similarities, they also possess distinctly different end-use qualities. They are also blended to make Western White wheat. Soft white wheats possess white bran and soft kernel texture. They exhibit high break and straight-grade flour yields at low ash. Their flours have low water absorption, low starch damage, and low water-, carbonate-, and sucrose-SRCs. In standard bake tests, soft white wheat produces large diameter cookies and sponge cakes with large volumes and tender, fine crumb grain. Gluten strength among varieties of soft white common wheat range from moderately weak to moderately strong. Club wheats, on the other hand, are uniformly weak. Objective quality targets have been developed for soft white wheat by the PNW Wheat Quality Council, which uses the USDA Western Wheat Quality Lab as a reference lab. Innovations in soft white wheat include soft kernel durum wheat, "super soft" kernel wheat, partial waxy wheat for white salted noodles, and full waxy wheat for puffing and unique processing. Lastly, the emerging area of whole wheat flavor is being explored for breeding and selection of soft white wheat.

Acknowledgments

We thank Stacey Sykes, Eden Stout, Carolyn Ross, Nicole Garneau, Tiffany Nuessle, and Adam Heuberger for their assistance. Funding was provided by USDA ARS CRIS Project 2090-43440-008-00D.

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