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## Breeding away from all purpose

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Wheat, like all living things, has a straightforward path through life – to live and reproduce. Because humans cultivate and eat wheat, we have introduced an additional, contradictory, path for the plant – optimization of its seeds for consumption. It is the task of the plant breeder to merge these two paths in ways that benefit the plant and farmers (optimization of plant life) and the consumer (planned seed death). Although these goals may seem at odds, they are achieved with minimal compromise through selective breeding. When a breeder is successful, the two paths coalesce as a new wheat variety that serves farmers, millers, chefs, bakers, and eaters equally well.

To maximize seed production for a given environment, the first path – the wheat's path to continuing life – can be selected for improvement by the farmer, indirectly by the environment, and most directly by the actions of breeders. For farmers and breeders, this improvement in the life path results in maximizing seed for harvest and replant, a cycle that has occurred in millions of fields once a year, every year, for the past 10,000 years.

The professionalized improvement of this path has, for the past 150 years or so, involved basic field breeding. The breeder generates variation, plants the various types within a representative farming system, and identifies those genotypes or plants with superior performance. Although plant breeding can have multiple and often complex steps, it basically involves looking for characteristics that lead to plant health and good yields such as disease resistance, time to maturity, efficient use of water or nitrogen, tolerance to heat or cold, and ultimately the quantity of seed produced. A breeder identifies key targets for these end goals and then identifies and selects plants that meet those criteria. Upon replanting, these plants (and their genetics) continue to live for one more generation and get one more chance to be selected or rejected. It is simple, and it does work.

The second path, where seeds would be smart to avoid if they could choose, leads not to replanting for the production of more seeds through pleasant springtime procreation, but to death by milling. If this now, crushed, ground, and torn into tiny pieces of seed is lucky, it will emerge transformed into a live sourdough of fermentable sugars, alcohols, amino acids, proteins, enzymes, and a deliciously low pH. The seed sacrifices itself for yeasts and

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bacteria until it, alongside the microbes that it has fed, experiences death once more, this time through baking. In this new baked form, a naturally fermented bread, the wheat seed, yeasts, and bacteria give sustenance and life for humans. If the bread is good, eaters will demand more, which means more seed and in a beautiful evolutionary loop the wheat, and the genes that it carries, wins (after all).

This path to milling, cooking, or baking is wide and difficult to define because it branches depending on human preferences and industrial needs. To simplify the industrial (public and private) breeding process, the end goal of quality is based on its performance in one of three basic categories: pastry, breads, or noodles. Each category requires a very different product, and if the path toward improvement is taken for one use, it will likely be suboptimal for the others. Want weak protein for crumbly, melt-in-your-mouth cookies? That variety will never have strong enough protein for risen, open-crumb sandwich bread or dried noodles. Complication and compromise arise when we acknowledge that not all bread, or all pastries, or all noodles are the same, but within each category the wheat pretty much is.

For bread, which is what we will limit the discussion to here, the milling and baking path can have endings as divergent as a four-ingredient, hand-formed, long-ferment, rustic whole-wheat sourdough loaf and an essentially under- or unfermented 27-ingredient, whipped-into-a-frenzy-dough that will become a fast-food hamburger bun. Which bread is bred for almost exclusively? The latter. All bread wheat is bread wheat even though all bread is not bread.

Conventional wheat breeding justifiably attempts to produce varieties that benefit the greatest number of farmers, producers, and consumers. Consistent targets aimed at large consumer bases are the easiest for public and private breeders to justify, receive funding for, and hit. Quantifiable and uniform end-use quality targets enable sorting through thousands of breeding lines with efficiency, allowing breeders to make quick decisions and advance only promising lines. Simply put, large industry has always supplied breeders with the targets. Industry not only creates markets and products at a scale that will reach a large number of consumers, but also knows exactly what works and what does not work when wheat grain or flour enters mechanized assembly lines. Thus, industry in essence also provides breeders with a predefined assembly line of their own, one that specifies high protein content and strength, very white flour color, and very low ash (mineral) content. By breeding for uniformity, breeders have bred out diversity in the wheat gene pool with the end goal of also removing variation in milling and baking operations. The result is a loss of nutrition, flavor, and ultimately consumer choice of products and the businesses that make them.

## Breeding “modern” bread

Wheat by default does not make good bread. Most wheat actually makes horrible bread. Consumers never see these wheats because breeders discard them in three to six generations of early selections. Assuming that bakers have a basic level of skill, by the time a sack of flour reaches them, their bread will turn out okay. That’s because the wheat was bred and selected that way, with an all-purpose baker in mind, one who can make all-purpose white flour work.

But wait: What way is that? What is an all-purpose baker?

With the advent of roller mills in the late 1800s, white flour could be produced efficiently and at scale. With the professionalization of wheat breeders around the same time (our university, Washington State, hired their first in 1894), wheat quality began to be defined and bred almost exclusively for industrial white flour and white bread. Turn-of-the-century recipes were developed for home bakers, corner bakeries, as well as for massive industrial bakeries. All of them were, and still are, based on white flour. Breeders took note. Plant breeder and eugenicist Willet M. Hays describes in an 1899 extension bulletin his collaborations with early industrial roller millers to develop some of the first quantitative quality tests for breeders (Hays and Boss, 1899). Today, white flour and bread remain the goal for small and large millers and bakers, as well as breeders. Breeder’s quality tests have been modernized with science; however, they are just an updated version of those that Hays described in 1899. It is industry and by extension consumers that set these targets, as consumers did not, and apparently still do not, want to eat whole wheat.

The nineteenth-century transition from stone milling (and sifting) of whole wheat to the roller milling of modern white flour coincided with a general trend in economically rich countries toward the industrialization of basically everything we consume. And thus home baking gave way to industrial bread. According to Aaron Bobrow-Strain, in *White Bread: A Social History of the Store-Bought Loaf* (2012), 90% of households in 1890 baked their own bread. Forty years later, the country flipped: 90% of households bought mass-produced white bread. During this time, our nation moved from regional milling to centralized white-flour milling on a scale that seems unreal: the country went from over 22,000 flour mills to today less than 200 (Reed 2010; USDA-NASS 2017). Today, as rural sociologist Philip H. Howard (2016) recently reminded us, two firms, Ardent Mills and Archer Daniels Midland, together control over 40% of the US flour market; similarly, Grupo Bimbo and Flowers Foods produce nearly half of the US bread. Flour, bread, and wheat have lost their regional distinctiveness and today is most probably the clearest example of broad-scale uniformity in agricultural and food systems.

During the early part of the twentieth century, at the time of transition to industrialization and centralization of flour, bread, farming, and breeding, the targets for bread wheat were strictly defined: white, yeast-only, presliced, plastic-wrapped loaves. These targets remain in place today though slogans such as “Red Meat, White Bread and Blue Blood” (Bobrow-Strain 2012) no longer openly connote the promotion of eugenics espoused by many wheat breeders, including Luther Burbank (Burbank 1907) and W.H. Hays (Hays 1912).

Industrial bread breeding requirements include the proportion of white flour extracted per seed (about 70%, but the more the better); the high efficiency of refinement measured as low ash (ash is composed of minerals, like iron and zinc, found in the bran); a hard red kernel (originally so wheat production could be expanded and centralized in harsh climates of the Great Plains, but also to easily distinguish from white-kernelled pastry wheat); high protein content and dough mixing strength (for mechanized mixers and big loaf volumes); high water absorption (water is cheaper than flour); and flour color (the whitest of white). All this with the comforting notion that sweeteners for flavor, conditioners, whiteners, emulsifiers, and preservatives for an extra “boost” could always be added when necessary for the assembly line or store shelf (Whitely 2006).

Flour bred for these outcomes is not so much self-rising as it is self-fulfilling – you get what you ask for, or in this case, what you breed for: *White flour? Less bran and germ? Check and check.* White flour and white bread work because “best” is selectively defined and anything else is disregarded and thus discarded in the breeding process. Directed breeding improved varieties for industrial white flour and bread, and these improved varieties were planted, milled, and baked. Now we are stuck in a single definition of wheat quality, and it can only become more and more refined and thus less and less nutritious. It is a closed circle: people want white bread, the government supports refinement, industry models itself on white, and breeders breed for greater, and more, whiteness. And we did it, we made the best white flour and white bread possible.

This system works...until it doesn't. Want delicious bread made with nourishing, slow-fermented whole wheat? Oops, be right back.

## Looking forward

Many of the white bread quality traits are in direct and negative contrast to what whole-wheat breads and natural fermentation need to be successful. Quality selections are made only after removing the bran and germ – two obviously fundamental components to consider when using whole wheat. How can the dough strength necessary to carry bran and germ be evaluated without including the bran and germ? And what if we want to target nutrition? By using only the white portion of the seed, wheat is reduced

from a nutrient-dense food to one that lacks basic nutrition: Sixty to ninety percent of individual micronutrients (importantly, most, like zinc and selenium, are not replaced by enrichment) are lost along with all of the fiber by discarding the bran and germ (Schroeder 1971).

What about slow mix speeds or mixing by hand? And flavor? Yes, flour can have subtle but bright flavors, especially when freshly milled with the bran and germ intact. These attributes were never targets of wheat breeders and thus are usually lost by chance or by unintentional negative selection.

Fermentability with not just commercial yeast, but with wild yeasts and bacteria, and at length is another trait not assessed. For modern craft bakers – at least those who use a minimum number of ingredients, a high percentage of whole wheat, and eschew dough conditioners and other crutches – time is an important ingredient, rather than something to avoid or minimize. A slow, acidic ferment made from whole-wheat flour has several advantages over a quick, yeasted, “big bang” white loaf. Flavors start developing during the ferment as microbes convert starches to sugars and leave their by-products behind. The microorganisms essentially begin to digest the wheat, leading to greater micronutrient availability (Katina et al. 2005). Prebiotics, lower glycemic index, and bioavailability of micronutrients are all outcomes of time combined with the use of sour ferments and whole grain. To breed for these slow traits is to empower breeders to improve traits that have never been the target of organized breeding. Ultimately, this can enable bakers to more easily create slow-ferment, whole-wheat products that would be more universally accepted and affordable in the marketplace.

The fact that craft bakers succeed as well as they do is testament to their inherent expertise. Still, many use mostly white flour, a choice based at least in part on the lack of breeding specifically for whole wheat, slow fermentation, and low-intensity mixing. The flour they use was not built for what they are doing, or may want to do. Breeding can make their job easier, but hasn't. And so bakers have sought out heirloom grains and the farmers who grow them. These grains can serve as a stopgap until modern wheats with the baking qualities of heirloom varieties are developed. Improved wheat grown prior to the 1870s was stone milled and baked into products that used a slowly mixed, yeast and bacteria ferment (commercial yeast came to predominate around the 1920s). Much of the flour was bolted (sifted), but not to the level of lily whiteness that we see today, so some of the bran and germ found its way into the flour and bread. The grain was softer than modern bread wheats, and the gluten generally had less strength, enabling the dough to respond well to hand working rather than the high-speed mixing of modern machines.

Although some heirloom wheats are appealing to modern small-scale millers and craft bakers, they do not make sense for farmers. To be sustainable and widely affordable, varieties need to work for farmers. So

we find ourselves back at wheat's first path of life: yield, resistance to disease, efficient use of resources, and ease of harvest for a given locality. Heirloom varieties, when dislocated from place or time, have not kept up with changing climates or pests and disease. Popular heirloom varieties like Sonora or Red Fife grown in western Washington today become coated with a blanket of orange stripe rust, necessitating either fungicide application or suffering in both yield (as low as 10% of the best modern types) and baking quality (Bread Lab, unpublished). Farmer targets can ensure accessible price points, profitability, good land stewardship, and reduced inputs. Breeders must pull the two paths of wheat together so that the seed works for the farmer and the craft miller and the baker: high yields in the field and slow bread in the bakery, at a price that is more within a range of what more members of our communities can afford.

Again, breeding is simple and has been shown to work well in wheat and most crops. What follows is a model using wheat as a framework of how breeding can help those who wish to add diversity to the agro-food system.

## **Breeding for a whole-wheat slow ferment**

### ***Step 1. Define new quality targets***

#### ***Fermentation***

A true long ferment by yeasts and bacteria requires an environment of fermentable sugars, amino acids, micronutrients, and a hydrated substrate to support colonization, growth, and multiplication (Katina, Poutanen, and Autio 2004). The wheat dough – whole-wheat flour and water – provides this. But at what level and to what degree of predictability are these requirements provided by the wheat plant and delivered in the seed? The dough must also maintain strength to handle fermentations that may go on for hours and, in some cases, a day or more. The target is dough that provides a lively but sustained environment for growth. This goal can be achieved through greater predictability in the enzymes that convert starches to sugars and break up proteins and phytic acid; proper timing of the enzyme activation; and judging the appropriate protein strength without too much degradation of the gluten (the proteins). Bakers can add modifiers to a dough, or they can use wheat designed for the end product. These traits can be evaluated in breeding materials by baking craft sourdough loaves in a controlled setting as opposed to the standard test in place today in USDA and other quality laboratories that choose wheats based on a miniature sugared and yeasted white flour-only Wonder Bread-styled pup loaf. Some breeders, such as David Van

Sanford at the University of Kentucky and state quality labs like the one at Oregon State University run by Andrew Ross, are adding craft baking to their testing, but these programs are in a minority (personal communication).

### ***Bran and germ***

The current end-use quality targets of breeding programs involve testing for efficiency and the rate of extraction in producing refined white flour. Instead of keeping this end goal, targets can be developed around flour that retains the bran and germ. A kernel needs to mill well as whole-wheat flour with particle sizes and distribution that millers and bakers prefer. For example, how are the bran and germ fractionated? Does the variety clog the mill? How are the starches broken open and made accessible for enzymes that break the starch down into sugars? How much bran and germ are desired? It's possible to optimize the percentage of bran and germ in relation to the endosperm produced on a wheat seed. Fiber content, micronutrients, phytonutrients, and flavor in the bran and germ across the wheat gene pool can be determined and then utilized in breeding. Small-scale (benchtop) milling tests with a range of mill types, together with bake tests and nutrient analyses, can assess these traits.

### ***Protein strength***

The protein strength of glutenins and gliadins, providing elasticity and extensibility to a dough, is genetically determined. What are the optimal levels of elasticity and extensibility for craft bakers using low-intensity mixing and long ferments? That said, whole -wheat flour must also be strong enough to carry the bran. If we breed for craft baking and its necessary lower protein strength, we can decrease the need for farmers and millers to strive for high protein content. Alleviating the demand for high protein content can, along with breeding for nitrogen-use efficiency and properly timing organic or chemical fertilization, reduce the amount of nitrogen that is added to the fields without sacrificing the bake (nitrogen is added not so much for yield but to boost protein content). If we change our targets, we can breed specifically for protein strength, which would reduce the negative effects of overfertilizing farmer's fields for the sole purpose of higher protein (gluten) content. A higher-quality gluten means that one needs less of it and thus less fertilizer.

### ***Flavor***

Grassy, nutty, wheaty, bitter, sweet, bright, sour, cardboard-like, and cheesy are positive and negative flavors that characterize sourdough whole-wheat breads. Which flavors come through after the bake? The nuances and interactions of flavor are complex, influenced not only by wheat genetics, but also by growing environment, farmer practices, freshness of flour, and baking recipe and technique. When these variables are controlled and skilled bakers

conduct designed experiments, the results of flavor evaluations are repeatable and can test the variation in flavor due to wheat variety only. The best test, and one (oddly) rarely used, is to actually taste the bread. Slowly.

### ***Step 2. Describe and capture the variation for the traits***

Pre-breeding involves the exploration of germplasm to find desired variation. Before a trait is bred for, it must first be identified in an existing variety or landrace. For example, if the target is nutty bran, that trait needs to first be identified in the wheat gene pool. This process necessitates testing and selecting potential parental lines, preferably first in varieties that are regionally adapted for the life path. Some of this work has already been performed by bakers who have found flavorful wheats such as Red Russian, a soft red wheat introduced into the Pacific Northwest around 1890, and Edison, a modern but locally bred and used non-commodity hard white spring wheat in western Washington. Both have flavors that make them good parent material. Once identified, variation for the desired trait can be captured and combined with other desired characteristics, including those important for the life path, into a single variety. This method has been used for at least 120 years; the difference now will be in the targets.

### ***Step 3. Make crosses and select new lines***

Developing a new wheat starts in the most basic of ways. Pollen from one parent is placed on the stigma of another plant. The pollen germinates, forming a pollen tube that it uses to migrate down to the ovule. Double-fertilization occurs, which leads to formation of the embryo and endosperm of the seed. Six weeks later, the resulting seed is mature and is planted to produce second-generation seed; each of these  $F_2$  seeds are genetically different. In each subsequent generation, wheat plants or families of plants are selected for agronomic traits. Once the preferred agronomic traits are captured and adequate seed is available, selection for end-use is initiated, usually after four generations.

A naturally fermented bread can be produced from a potential variety of whole-wheat flour to see how it performs in terms of ease of milling, water absorption, aggressiveness of fermentation, strength maintained through the shaping of the loaf, oven spring, crust color, loaf volume, crumb color and texture, and, ultimately, flavor. Quality evaluation begins with small-scale tests using as little as 1 g of flour to determine the strength of a dough created from an individual breeding line. Formal, long-ferment bake tests can begin in later generations when much more seed is available. Whether the tests are carried out in the lab or a bakery, the tester records what is needed in terms of product or recipe to make a good loaf from the genetic line if it is

possible. Samples can then also be taken to determine levels of micronutrients in the seed and end-products.

#### **Step 4. Make it work for farmer, miller, baker, and consumer**

Before a breeding line becomes a variety, it must work for the farmer, miller, baker, and consumer. On-farm testing of breeding lines can increase the likelihood that a selected variety will perform well for farmers, that there is potential for adoption, and assures that breeders develop the kinds of varieties farmers need. However, there must also be market demand for farmers to sell into. For millers, the wheat variety must mill predictably into high-quality flour on various types of mills; bakers need to be able to make a desirable bread product consistently under often varying conditions; and consumers must want to buy it again and again. The development and success of a variety do not rely solely on breeders. The evaluation of breeding materials by millers and bakers, similar to on-farm trials, can inform or even redirect future breeding activities. Farmers need to get the new seed, millers the new grain, bakers the new flour, and consumers the new bread. All of us take part in this type of process.

#### **Gain from selection**

Breeding is necessary to improve slow-fermented whole-wheat bread that is affordable, accessible, nutritious, and flavorful. First, reasonable targets must be set. Yield? Doable. Yield that requires fewer chemical inputs but still produces a crop with nutrient density, functionality, and flavors? Also doable. This work relies on a wide variety of scientists, from geneticists to cereal chemists to nutritionists to microbiologists. And it takes communities of grain farmers, miller, bakers, and consumers. It takes funding, infrastructure, and knowledge sharing. Once these new goals are clearly defined, they are obtainable – we're not talking about breeding bananas that grow in Vermont. We're just offering to help pull our food in a direction that can be defined as beneficial and accessible.

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#### **References**

- Bobrow-Strain, A. 2012. *White bread: A social history of the store-bought loaf*. Boston, MA, USA: Beacon Press.
- Burbank, L. 1907. *The training of the human plant*. New York, NY, USA: The Century Company.

- Hays, W. M. 1912. Constructive eugenics. *The Journal of Heredity* 3:113–19.
- Hays, W. M., and A. Boss. 1899. *Wheat: Varieties, breeding, cultivation*. St Paul, MN, USA: University of Minnesota Bulletin no. 62. McGill-Warner Company.
- Howard, P. H. 2016. AFHVS 2016 Presidential Address: Decoding diversity in the food system: Wheat and bread in North America. *Agriculture and Human Values* 33:953–60.
- Katina, K., E. Arendt, K.-H. Liukkonen, K. Autio, L. Flander, and K. Poutanen. 2005. Potential of sourdough for healthier cereal products. *Trends in Food Science and Technology* 16:104–12.
- Katina, K., K. Poutanen, and K. Autio. 2004. Influence and interactions of processing conditions and starter culture on formation of acids, volatile compounds, and amino acids in wheat sourdoughs. *Cereal Chemistry* 81 (5):98–610.
- Reed, N. 2010. Flour milling in Washington - A brief history. *History Link*. Accessed December 11, 2017. <http://www.historylink.org/File/9474> Posted July 11, 2010.
- Schroeder, H. 1971. Losses of vitamins and trace minerals resulting from processing and preservation of food. *American Journal of Clinical Nutrition* 24 (5):562–73.
- USDA-NASS. 2017. *Flour milling products (CAIR Program)*. Accessed December 11, 2017. [https://www.nass.usda.gov/Surveys/Guide\\_to\\_NASS\\_Surveys/Current\\_Agricultural\\_Industrial\\_Reports/Flour\\_Milling/index.php](https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Current_Agricultural_Industrial_Reports/Flour_Milling/index.php). (Last Modified:12/04/2017).
- Whitely, A. 2006. *Bread matters*. Kansas City, MO, USA: Andrews McMeel Publishing.