Creating Test Baking Methods Specifically for Whole-Wheat Sourdough Breads, In the Context of Local Grain Economies

By
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Recently local grains have become an area of economic growth. Local grain products, including whole-wheat and sourdough products, are increasingly in demand for their health benefits, unique flavor profiles, and association with local food movements. These local grain economies are beginning to boom, but they lack the technical aid that already exists in the commodity grain systems. This project aims to address the technical needs of local grain economies by exploring potential test bake methods using formulas including whole-wheat and sourdough. The key findings in the project were as follows:

- Screen size (inferring flour particle size) did not affect baking performance.
- My baking skills allowed me to repeat test bakes across independent baking days without significant differences in aspect ratio and loaf volume (strengthening the validity of the data throughout the project).
- There was no systematic influence on loaf quality (aspect ratio or loaf volume) when the duration of starter fermentation was ± 1 hour from the targeted optimum duration.
- To test a flour for a sourdough product, sourdough leavening must be used, and yeast is not an appropriate substitute in the formula (arguably the most important finding from the entire project).
- Any bake method that separated the Red Fife and Espresso flours free-standing loaf aspect ratio by 10% or more was a potential candidate for an optimal method. As such, the optimized method that showed the most promise was the optimized mix-time, no-yeast methods, 25%, method because it met the aspect ratio parameters noted above and showed the largest difference in loaf volume between the samples.
- While there is no current test bake method universally used in the local grain community, a test method of this nature is very much wanted and needed.

Key Words: whole-wheat, sourdough, test-baking, local grain economies

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I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

____________________________________________________________
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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1: General Introduction

Commercial commodity grain production has increased dramatically over the last two centuries. However, more recently local grains have become an area of economic growth and local grain products are increasingly in demand. The large-scale commodity grain industry has the technical expertise and equipment to support its production system, something the newly emerging small-scale grain systems do not have. This support includes a range of grain and flour quality testing methods and equipment that are capital and labor intensive: e.g. Test Baking, Single Kernel Characterization System, Farinograph recording dough mixers, and the Falling Number Method (Ross and Bettge, 2009). Local grain systems still lack these important elements of infrastructure and may have little access to costly testing equipment, facilities, and expert employees. Developing low-tech and low-capital test methods, such as a simple whole-wheat sourdough test bake method, is a necessary step in the development of an inexpensive and accessible infrastructure that supports local grain economies. There are currently no whole-wheat, sourdough test bake methods that provide convenient testing for grain selection in breeding programs. I contend that the most relevant baking techniques for local grain systems are based on whole-wheat flours and natural fermentations because in the United States these are the types of breads that are being revitalized in the local and small scale grain communities (Community Grains, 2018).

This technical support is critical to the success of local grain systems because, if successful, it will empower small-scale millers and bakers to be able to test their own materials. Accordingly, this will assist the continual progression of the local grain systems by providing technical evidence as to what cereal varieties are most viable in the current market. This technical support will also provide an infrastructure to promote social and cultural development in relationship to whole grains and local whole-grain food systems. To create a system that can effectively provide whole grain products to consumers, quality testing must be established to make the production system more reliable.

1.1: What is Wheat and What is Whole Wheat?

Today, wheat is one of the world’s most important plant crops and has been a staple crop for centuries in Europe, North Africa, and Asia. Currently, world wheat stocks are at an all-time high at over 900 million tons (FAO, 2018). In 2007 wheat was the third most produced cereal after maize and rice with a world production of over 600 million tons (FAO, 2018). Wheat is such an economically and socially important crop because of its ability to grow in a variety of climatic conditions, its nutritional value, its ability to be utilized in a variety of different ways, and its taste.

1.1a: What is a Whole Grain?

Intuitively, a whole-grain is an entire cereal seed in an unbroken form. However, for some cereal grains we commonly eat partially processed versions of the seeds. As a result, a definition for whole-grain was needed. The American Association of Cereal Chemists International (Aaccnet.org, 2018), the world’s peak society for cereal science, created the following formal definition of whole grains: “whole grains shall consist of the intact, ground, cracked, or flaked caryopsis (kernel or seed), whose principal anatomical components—the starchy endosperm,
germ, and bran—are present in the same relative proportion as they exist in the intact caryopsis.” (AACI). As such, “whole-wheat” can be the entire grain of wheat, whole-grain flakes, grits, or semolina. Un-sifted flour milled from the whole-kernel is whole-wheat flour.

1.1b: Why Do Whole Grains Matter?
Wheat, rice, and maize make up about two thirds of the human diet (Cassman, 1999). Whole grains have been recognized for their connection to good health for centuries (Graham, 1837), yet society has continually moved away from whole grain consumption. Studies show that whole grain consumption reduces the risk of heart disease (Jensen, 2004), hypertension, strokes, type 2 diabetes, cancer, and obesity (Borneo, 2012).

Whole grains have also been recognized for their contribution to the local food movement. Commercial commodity grain production has increased dramatically over the last 60 years alongside increased agricultural intensification (Neumann et al., 2010). With the increased commodity grain production, small scale and local grain production almost disappeared (Wallinga, 2009). However, more recently the local agriculture movement, which was at first focused on produce, has begun to boost local grain production. Local grains have become an area of economic growth and local grain products are increasingly in demand. They are increasingly in demand because of their association with health benefits, and their associated with sustainable farming techniques (Community Grains, 2018). To meet these increased demands, farmers need to have access to cereal varieties that are suitable for small-scale sustainable agriculture. To support the needs of these farmers, cereal breeders need to be able to identify existing varieties, landraces, or species that are already suitable for a final product and/or one that may be used as parents in the breeding of new cereal varieties. Both existing and new cereal varieties need to be specifically suited to small to medium scale enterprises, simple milling techniques (e.g. stone milling), whole-grain products, organic crop management, and natural fermentations (sourdough: i.e. mixed Lactobacillus and wild yeast cultures).

1.2: Wheat in the United States Food System
The story of wheat in United States began with colonialization (Kansas Wheat, 2014). Europeans brought wheat to the Americans with them. Previously, the natives in the Americas had been consuming native grains, such as maize. Wheat production has changed dramatically over the past two centuries. The breeding, farming, milling, and baking processes have evolved from being a part of small scale and regional systems, to becoming a part of large scale commodity systems. Changes have also developed as a result of social movements – from the growing “anti-wheat movements” to heritage grain movements – impacting the way individuals in the United States view wheat.

1.2a: How Milling Changed the Way We Eat Wheat
For millennia, wheat was milled using stone-based technologies. Milling technology progressed from reciprocal motion (hand grinding/pounding) to rotational motion (stone- and roller-milling). The basic template for stone milling was to have two large circular stones placed on top of one another with a gap in between. Powered originally by human or animal labor, and eventually by wind or water, the top stone (the runner) would rotate above the bottom stationary stone (the sleeper) as the wheat grain passed through the gap. The movement of the stones crushed each wheat kernel in its entirety. This type of mill system was most effective on soft-textured wheat.
varieties because, typically, you could attain the desired flour fineness in one pass since the wheat was physically soft. This also meant that these flours were almost always whole-wheat because as a single pass flour, the bran was rarely sifted out. While a semi-refined white flour could be produced, it was an expensive process and thus was not common, and largely consumed by the privileged classes (Rubel, 2011). In America, the original wheat varieties grown were soft-grained and thus could be ground into acceptable flour with one pass through the mill.

While one pass milling had been standard for centuries, in the 16th century the French developed the technique *mouture économique*, also known as the French System (Campbell, 2007). This system was a gradual reduction system requiring grinding and then sifting to obtain the desired quality flour (Storck and Teague, 1952 [Fig.1.1]). American inventor Oliver Evans took this system further by developing the first automated system for milling that allowed the work of several men to be accomplished only by a few (Evans, 1848 [Fig. 1.2]) driving both efficiency and quality, but also changing the American job market as the continual shift towards automation required less workers for the same processes. Evans’ invention came at an opportune moment - the American milling industry was about to be revolutionized. As the Westward Expansion began in America, the opportunity for agricultural production expanded – this meant wheat production expanded as well. Rivers played a critical role in this expansion for two major reasons 1) water power drove mills until the advent of steam power and 2) the rivers of America allowed the country to keep sharing what the continued agricultural expansions allowed the country to grow despite the increasing miles of separation. As the availability of wheat grew in the U.S., the need for storage and successful transportation from ship to shore grew as well. Joseph Dart solved this by developing the Grain Elevator (Storck and Teague, 1952).

![Diagram of a French Process mill](image)

*Figure 1.1: Storck, J. and Teague, W.D., 1952. Flour for man's bread. Geoffrey Cumberlege; London.*
As the mid-west became America’s bread basket, every part of the American milling process was greatly improved except for the most basic element of milling: grinding. The French System never became popular in America; most American millers still used the one pass system where all quality levels of flour were produced by simply moving the millstones closer to one another. It was also because of this system that soft wheats were preferred – they were easier to grind in the typical American milling process. While soft wheats produced finer quality and whiter flour, they did not have the strong gluten required for good bread (high loaf volume, light texture, etc.). Hard wheats did have this strength, but in the millstones, hard wheats underwent a more severe grinding process, producing flour discolored by specks of bran – not what consumers wanted. Systems had been developed to address this problem of hard wheat, they just never had been adopted in America. The mouture en infini (milling to infinity) system was developed by Hungarians in the mid 1800’s in order to mill their very hard wheats. The infinity system was complex and intensely laborious, so the very white flours it produced where only accessible to the elite. What this system created was a reality where both expensive and cheap flour could be sold from one process, and this social complex was a major driver behind the existence of the method in Hungary. In the U.S., the social hierarchy within society was not as attached to the different qualities of flour – Americans wanted a standard flour that was efficient to make and could be sold to as many people as possible.

Figure 1.2: The First Automated Milling System. Evans, O., 1848. The young mill-wright and miller's guide. Lea & Blanchard.

In the 1870’s, American millers heard of a new type of mill; the roller mill. For years, Europe had been attempting to perfect this new method that got rid of the cumbersome millstones all together. American millers were attracted to the idea of the roller mill because it was more economical – there was a lot less room for error and it was less financially burdensome, after the
substantial initial capital cost was met (e.g. the stones did not have to be dressed regularly). The new roller mill system was also a gradual reduction system, like the French-process and with the invention of the air purifier by Ignatz Paur (Horsford, 1875), flour sifting was more effective. The air purifier separated the bran and germ particles from the endosperm by density instead of size which made the production of white flour more attainable for millers and the product more accessible for buyers. As the global wheat market grew more intermixed, hard wheats became more popular in the U.S. The use of roller mills also addressed this influx of hard wheats as a result of their efficiency. It was then, in Minneapolis in the 1880s, that the modern automatic, all-roller, gradual-reduction method of milling of today first evolved (Storck and Teague, 1952). The American mill industry continued to progress with mechanization and efficiency, outspiring Europe to the point that “[even in the 1890s,] the mills of Budapest required about 4,000 men to produce a considerably smaller quantit[ies] of flour than was turned out at Minneapolis by less than 1,500 workers.” (Storck and Teague, 1952).

1.2b: Breeding and Farming
It is estimated that 90% of crops grown globally 100 years ago are no longer grown today (What is Agrobiodiversity?, 2018). While 50,000 edible plant species exist today, only 15 crop species provide 90% of the calories consumed in the current human diet (Rogosa, 2016). As the world’s most produced crop at over 600 million metric tons (FAO, 2018), wheat is one of those 15 crops. As noted above, before the late 19th century, wheat grown in the United States was primarily soft wheat (soft white and soft red winter). Soft wheat was the wheat of choice because of the milling infrastructure present in the States at the time. As the wheat milling industry evolved, so did the wheat breeding and farming industry. As American’s moved westward, their agricultural environment also changed. During the 19th and 20th centuries, the introduction of different wheat varieties from Europe allowed American farmers to push wheat cultivation into environments that would have previously never been thought plausible in the States. The new varieties, breeding innovations, and farming techniques, allowed farmers to grow in new environments such as Texas and California, outside of the country’s traditional “bread basket”.

1.2c: Wheat Consumption in United States: 20th Century
Wheat consumption in United States has evolved substantially since the birth of the country. American bread production is no longer a home process – it is an industrialized one. In the 1800s, 90% of the bread in the U.S. was homemade and made primarily by women (Howard, 2016). By the early 20th century, bread baking had taken a shift; 90% of the bread in North America was now produced in factories and made mostly by men (Bobrow-Strain, 2012). Americans shifted to factory made bread for several reasons. Around WWII there was a huge factory movement as companies attempted to convince consumers that factory produced products were safer and more sanitary than the homemade counterparts. White was also in style, both socially and in the bread world. Bleaching of flour became prevalent during 20th century to appeal to the white is better mentality coursing through the U.S. And store-bought bread was a time saver. As the identity of housewives changed in the 1940s and 1950s, time saving techniques were all the rage, and what is more timesaving than buying a loaf of bread instead of making it.

Bread at its core should be simply flour, water, salt, and microbes. However, to become a part of the industrialized bread system, producers changed the “core” to include a variety of additives
(i.e. emulsifiers, sugars, hydrogenated oils, etc.) to adapt to the needs of extended shelf life, convenience, and shift in the desires of consumers for particular tastes and textures that developed from these changes. So, industrialized bread production had a profound impact on the way Americans consume wheat, and how their wheat consumption affected their health. Within one century, bread consumption went from homemade and often whole wheat, to store-bought and almost invariably white.

1.2e: Sourdough and Yeast
Another major driver behind the industrialization of bread was the advent of commercial yeast. The first fermented bread doughs were inoculated with wild yeasts. These yeasts came from everywhere – the air, ground, insects - and were preserved by saving portions of the raw dough and feeding it with more flour and water, a method that produced a microbial ecosystem with yeast and bacteria, and that is now known as sourdough. Within this ecosystem lactic acid bacteria and yeasts ferment becoming the sourdough (also known as a starter or a preferment), potentially enhancing the quality of the resulting bread and creating natural shelf-life extending preservatives (Lorenz, 2003). The yeast species important to bread bakers is *Saccharomyces cerevisiae*; its diet is glucose, fructose, sucrose, and maltose sugars. Hieroglyphics suggest that that ancient Egyptians were using the process of fermentation to produce alcoholic beverages and to leaven bread beginning over 5000 years ago. Since yeasts are living organisms, they need to consume food. Flour contains all the sugars the yeasts need to satisfy their appetite. After consuming the sugars in the flour, the bacteria and yeasts leave behind CO₂ (the gassing power), alcohol, and organic acids (the tangy taste of sourdough) that give leavened bread its characteristics. It was not until the invention of the microscope that we were able to understand the life and work of yeast in our daily bread consumption, let alone know that yeasts were living organisms. Through the work of Louis Pasteur in the late 1860’s yeast was identified as a living organism and its abilities to produce alcoholic fermentation and dough leavening was discovered. Yeast did not produce gas and alcohol immediately after being “fed”. It was a time-consuming process. But in the 1950s, scientist isolated certain strains of *Saccharomyces cerevisiae* that acted faster than others, shortening rise time for the dough, and so that the yeast did not need to continue being inoculated in the microbial ecosystem of the pre-ferment. During WWII the company *Fleischmann's Yeast* developed active dry yeast for the US Armed Forces. This yeast could be kept without refrigeration unlike commercial yeasts before and would help a loaf of bread rise even faster, cutting down production time and costs. The advent of commercial yeast is what moved bread bakers away from traditional pre-ferments (a.k.a. sourdough).

1.2f: Wheat Consumption in The United States: Today
After years of an evolving people and industry, America has found itself in an interesting scenario regarding wheat consumption. U.S. consumption of wheat reached its per capita peak in the early 1900s, declining precipitously to the 1960s, then peaking again in the 1990s (Kasarda, 2013). But beginning in 2000, consumption began to drop, reversing the trend of growth in per-capita consumption over the previous three decades. Consumption fell even further between the 2000 and 2010 from 146 pounds per person to 133 pounds per year (Ers.usda.gov, 2018). This drop in consumption does not come from low supply – in fact, wheat production is the highest it has ever been globally (FAO, 2018). The decline in wheat consumption in the U.S. comes from a shift in consumption patterns revolving around the modern desire to find the “ideal diet”. Low carbohydrate diets became popular with the Atkins diet (Atkins, 1973) in the early 1970s as an
apparently effortless way to lose weight. Similar diets emerged following the Atkins diet with different characteristics, but what they all shared was the restriction of carbohydrates. This had a huge impact on the demand for wheat products in the U.S.A. as the country’s struggle against obesity rose. The desire to attempt different “fad diets” as a means to cure weight gain ensued. It was also in the 1970s that gluten free diets began to emerge as researchers discovered the autoimmune characteristic of Celiac disease, and later defined the term non-celiac gluten sensitivity (Catassi et al., 2013), a definition that has been strongly challenged by direct evidence (Biesiekierski et al., 2013). It was not until the early 2000s that the gluten-free industry truly boomed, but the increase in medical diagnosis of celiac disease and commonly self-diagnosis of non-celiac gluten sensitivity that has occurred over the past decade is also connected to this more recent decline in wheat consumption. Today you can walk into a grocery store and find an array of gluten-free products that continues to promote opposition to eating wheat.

There are still lots of Americans that consume wheat products, but for those who do, their diets mostly contain refined wheat products. As a whole grain, wheat has three anatomical parts: the bran, the germ, and the endosperm. Each part contributes something different nutritionally. The bran and germ contain nutrients and phytochemicals, whereas the endosperm holds the majority of the starch, contains the gluten, and provides most of the energy and protein. Refined grains only consist of the endosperm, cutting out a great number of nutrients and phytochemicals. The average adult in the United State consumes 5.7 servings of refined grains per day and the average consumption of whole-grain foods among US adults is only 1 serving per day (Cleveland, 2000). The USDA recommends that half of all grain consumption be whole grains (Health.gov, 2018) (See Fig. 1.3). Americans are clearly not meeting the recommendations for whole grains. But, as discussed earlier, this consumption pattern towards refined grains evolved over several centuries as wheat breeding, farming, and milling changed as well.
Figure 1.3 \textbf{NOTE:} Recommended daily intake of whole grains is to be at least half of total grain consumption, and the limit for refined grains is to be no more than half of total grain consumption. The blue vertical bars on this graph represent one half of the total grain recommendations for each age-sex group, and therefore indicate recommendations for the minimum amounts to consume of whole grains or maximum amounts of refined grains. To meet recommendations, whole grain intake should be within or above the blue bars and refined grain intake within or below the bars. \textbf{DATA SOURCES:} What We Eat in America, NHANES 2007-2010 for average intakes by age-sex group. Healthy U.S.-Style Food Patterns, which vary based on age, sex, and activity level, for recommended intake ranges.

1.3: How Test Baking Fits Into The Story

"Test baking is often referred to as the ultimate test of wheat flour quality and has been used for decades to determine the inherent strength of wheat flour" (Dupuis and Fu, 2017).

If you go to the grocery store and walk down the baking section, you will find an array of different flours. Whole Wheat, All Purpose, Bread Flour, Pastry Flour, Rye Flour, etc. These commercial labels, other than rye, very simply describe the uses of each flour -- flours can be characterized in more depth based on characteristics such as protein content, ash content, solvent retention capacity, etc. These characteristics allow buyers to understand clearly what the potential uses of a flour are. If you walk around the store more, you will find an array of different wheat products. Cookies, crackers, pastas, bread, etc. All of these products were produced using a flour uniquely characterized as suited for the product. These characterizations are made in wheat quality labs and in wheat breeding programs. Numerous types of tests can be run, e.g. Test Baking, Single Kernel Characterization System, Falling Number, Farinograph, Alveograph (Ross and Bettge, 2009). But these tests are almost all cost and labor intensive, often requiring dedicated laboratories and skilled technicians to run them. Local grain systems still lack these important elements of infrastructure and may have little access to testing equipment, facilities, and the necessary expertise, largely as a result of their expensive natures.
Test baking is needed at various stages in the process of creating grain-based products. Key stages of the supply chain where test-baking is relevant are in wheat breeding programs, in flour milling both at the grain buying and flour testing phases, and in bakeries for testing incoming flours. The most common test bake method for bread in wheat breeding programs is the AACC-I Pup Loaf Method (AACC-International Approved Methods, Method 10-09.01 Basic Straight-Dough Bread-Baking Method). This method is popular for its simplicity and efficiency, but it is effectively a commercial sandwich bread formulation containing in addition to the flour, water, salt, and yeast, also shortening, sugar, oxidants, and ammonium phosphate (yeast food). However, it is not suited to, nor does it address the use of whole wheat grains or sourdough fermentation. As stated earlier, local grain systems have special requirements with respect to resources and scale. Additionally, they are more focused on natural leavening, whole-grains, and grains that do not necessarily fit into the commodity system: e.g. purple hull-less barley, einkorn, other hulled-wheats, wheat varieties specifically bred for unique traits such as flavor or enhanced nutritional value, and varieties targeted at local, small-scale, and sustainable agriculture. Local grain systems need a test that is simple, small scale, and time-efficient. They also need a test that does not require a trained baker. Baking is a skill, and it requires training. Trained bakers are not always going to be available. This is why it is necessary to have a test bake method that is simple so that an un-trained baker could produce the very similar, or the same, results as a trained baker. The test bake methods trialed in this study are an amalgamation of methods and formulations published by award-winning craft bakers (Hamelman, 2012; Robertson, 2013; Suas, 2008), and are not yet small enough for the needs of a breeding program. They are, however, guiding us towards the direction of a smaller and more efficient one.

The overall aim of the project was to develop an optimized whole-wheat sourdough test baking system. The concept was that this method could be used as the reference method for the next phase of the work, the development of the smaller-scale, simplified method that could be applied in breeding programs (limited grain supplies) and operated by technicians who are relatively unskilled in baking techniques. Along the way subsidiary aims were to train the author (Jansen) to be a consistent baker, to adjudicate the resolution of the earlier iterations of the method, and to determine if a dedicated sourdough method was even necessary, or whether, the more convenient approach of using commercial yeast was adequate for screening grain/flour for sourdough baking potential. Lastly, I had the opportunity to participate in a real-world alternative flour assessment initiative established by Community Grains, a whole-wheat milling company in Oakland CA.
CHAPTER 2: MATERIALS AND METHODS

2: Materials, Methods, and Modifications

2.1: Materials

2.1a: The “Screen Test”. Testing The 0.5 and 0.8 mm Screens on the Perten LM 3100 Hammer Mill (Perten Instruments, Hägersten, Sweden).
Stock hard red winter (HRW) and hard white winter (HWW) wheats supplied by the OSU wheat breeding program harvested in 2016 were used.

2.1b: The “Baker Precision Test”
Stone-milled HRW (Community Grains, California), and Red Fife (RF; Breadtopia, Fairfield, IA) whole-wheat flours, and a sifted, stone-milled hard red spring (HRS; Triple 200* [Camas Country Mill, Junction City, OR]) milled from grain harvested in 2016 were used. To feed starters, HRW was used for doughs comprised of HRS flour, and HRS was used for doughs comprised of HRW flour.

2.1c: Starter Timing
A stone-milled whole-wheat HRS flour milled from grain harvested in 2016 were used (Camas Country Mill, Junction City, OR). Starter was fed with a standard HRW flour (Community Grains, Oakland, CA).

2.1d: Test Bake Resolution (Sourdough-raised)
Stone-milled whole wheat HRS and HRW flours (Camas Country Mill, Junction City, OR) and whole-wheat RF (Breadtopia, Fairfield, IA) milled from grain harvested in 2016 were used for doughs. Dark rye flour (Bob’s Red Mill, milled in Milwaukie, OR) was used to maintain the starter. A switch was made to a rye flour starter, as rye does not contain functional gluten, to minimize the impact of the starter on the performance of the tested flour.

2.1e: Test Bake Resolution (Yeast-raised)
Stone-milled whole wheat HRS (Camas Country Mill, Junction City, OR), HRW (Community Grains, California) flours and whole-wheat RF flour (Breadtopia, Fairfield, IA) milled from grain harvested in 2016 were used for doughs. Dark rye flour (Bob’s Red Mill, milled in Milwaukie, OR) was used to maintain the starter.

2.1f: Test Bake Optimization
Stone-milled whole wheat HRS (Camas Country Mill, Junction City, OR), hard white winter (HWW; Bob’s Red Mill, milled in Milwaukie, OR), and whole-wheat RF flour (Breadtopia, Fairfield, IA) milled from grain harvested in 2016 were used for doughs. Dark rye flour (Bob’s Red Mill, milled in Milwaukie, OR) was used to maintain the starter.

2.1g: Community Grains
Whole wheat HWW (high and low protein Patwin), and HRS flour (WB9229), milled from grain harvested at Durst Farms Capay, CA, in 2017, were used. Dark rye flour (Bob’s Red Mill, milled in Milwaukie, OR) was used to maintain the starter.
2.2: Methods

2.2.1: Basic Baking Method
All percentages are “baker’s %”, i.e. all quantities are written as a proportion (i.e. ratio) of total flour, which adds 100%. This is standard protocol in the baking industry and baking research (Suas, 2008).

2.2.1a: Sourdough Starters
Starters were type 1 backslopped cultures (Gänzle, 2014; Huys, 2013). Depending on the experiment they were either dry (65% hydration) or wet (100% hydration). All starters were fed 16 hours (+/- 1 hour) before doughs were mixed. In the study we were processing several samples on a given bake day, multiple starters were made to maintain the 16 hours (+/- 1 hour) fermentation time. One experiment was conducted to ensure that the 16 hours (+/- 1 hour) did not significantly effect baking performance. The starter was maintained between tests with a daily feeding of 10% starter at 100% hydration.

2.2.1b: Dough Formulation
Each dough formulation consisted of some combination of water, whole-wheat flour, salt, sourdough and/or yeast. Some tests also included enzyme-active malt flour in the formulation.

2.2.1c: Mixing
All doughs were formulated to weigh 2100 g (4 x 500 pieces + 100 g for to account for processing losses). Each 2100 g dough was mixed in a Vollrath 40757 20 qt planetary mixer (The Vollrath Co., Sheboygan, WI) using a “J” hook. Mixing was conducted in 2 stages. Stage 1 was a pre-mix at speed 1 to incorporate the ingredients for 3 min. In stage 2 the mixer speed was then increased to speed 2. Speed 2 mixing was conducted in these ways:
  1-for a fixed mix time of 2 min;
  2-until the dough just pulled together (i.e. cleared the sides of the mixing bowl),
  3-until the gluten was developed (based on the windowpane method [Suas, 2009]),
  4-or mixed to “optimal” time (0.5 of the Farinograph development time).

2.2.1d: Bulk Fermentation
Doughs were bulk fermented at room temperature (22 ± 2°C). Doughs containing instant yeast were bulk fermented for 2 hours, dough without instant yeast were bulk fermented for 2.5 hours. Doughs were folded 3 times at 30-minute intervals during the bulk fermentation to complete the development of the gluten.

2.2.1e: Shaping
Each 2100 g dough was divided into four 500 g pieces and each piece was pre-shaped into a round. After resting for 25 minutes, all four pieces were again shaped as rounds. Two pieces were placed into 18.5 cm diameter proofing baskets with a floured fabric liner (a clean, un-used hair net) to make free-standing loaves. The other two pieces were placed into 14 x 8 x 6 cm Fat Daddios straight-sided aluminum baking pans (Fat Daddio’s, Spokane, WA) to make tinned loaves. The pieces were left to rise (proof) for 50 minutes at room temperature.
2.2.1f: Baking

Breads were baked at 232°C F in a Baxter Rotating Rack oven (Baxter Mfg, Orting WA) directly on 2 cm thick FibraMent-D stones (AWMCO, Inc. Orland Park, IL). Dough pieces risen in baskets were turned onto a wooden oven peel, scored once across the top of the loaf (Fig. 2.1), then placed in the oven. Panned doughs were placed directly in the oven, unscored. Loaves were baked for 35 minutes with 12 seconds of steam at the start of the bake.

![Figure 2.1 A scored, baked loaf](image)

2.2.2: Modifications to basic baking method for individual experiments

The following tests were used to collect data for the final experimental design created to identify an optimal test. These tests were also used as training to refine the author’s baking skills and to ensure reproducibility.

2.2.2a: The “Screen Test”

The goal of this test was to identify differences in performance of whole-wheat flours milled into different particle sizes by using two screen sizes (0.5 and 0.8 mm) in the hammer mill. Particle size of whole-milled grains had been shown to affect baking quality by others (e.g. Ross and Kongraksawech, 2018) This experiment was done in order to optimize bake performance and milling throughput in circumstances where experiments require the milling of grain, rather than purchase of commercially milled flours. An additional aim was to improve my baking skill-set for reproducible baking results.

The Screen Test followed the basic baking method (see section 2.1) using a 65% hydration starter and the following formulation: flour (100%), water (90%), 0.3% instant yeast, 2% salt, and 0.5% malt flour. 25% of the total flour was pre-fermented in the sourdough starter. Doughs where mixed till they came together.

2.2.2b: The “Baker Precision Test”

The goal of this test was to identify if significant differences in bread quality would occur between days of baking, and across replicates, again to test the skill-set of the baker to ensure reproducibility. The basic baking method (see Section 2.1) was used, with a 65% hydration starter and the following formulation: flour (100%), water (Red Fife – variable: 72 to 80%; HRW and HRS 85%), 0.3% instant yeast, 2% salt, and 0.5% malt flour. 25% of the total flour was refermented in the sourdough starter. Starters were fed with either the Red Fife, HRW, or HRS flours as appropriate (See section 1.2b). The doughs were mixed until the gluten was developed based on the windowpane method.
2.2.2c: Starter Timing
The goal of this test was to observe the impact of the fermentation time of the starter +/- 1 hour from the optimum 16-hour duration to see how this affected the reproducibility of the baked loaves. This experiment used the basic baking method with a wet (100% hydration) starter (from this point onwards 100% hydration starters were used for their greater ease in maintaining starters) and the following formulation: flour (100%), water (85%), 2% salt, and 0.5% malt flour. 25% of the total flour was refermented in the sourdough starter. Doughs where mixed until gluten was developed based on the windowpane test.

2.2.2d: Test Bake Resolution (Sourdough- and yeast-raised)
The goals of this test were to identify differences in baking performance of whole-wheat flours with contrasting baking potentials and to assess the performance of blends between the weaker Red Fife flour and the stronger HRS and HRW flours (100:0, 75:25, 50:50, 25:75, and 0:100). The sourdough-raised experiment used the basic method with a 65% hydration starter and the following formulation: flour (100%), water (Table 2.1), 2% salt, and 0.5% malt flour. 25% of the total flour was refermented in the sourdough starter. Starters were fed with either the HRW flour or HRS flour as appropriate (See section 1.2b). The yeast-raised experiment followed the basic method except that a starter was not used and with the following formulation: flour (100%), water (Table 2.1), 0.7% instant yeast, 2% salt, and 0.5% malt flour. In both experiments doughs where mixed till gluten was developed based on the windowpane method.

Table 2.1: Water additions for the blends used in the bake resolution tests.

<table>
<thead>
<tr>
<th>Blend</th>
<th>Hydration</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF 100: HRS 0</td>
<td>70%</td>
</tr>
<tr>
<td>RF 75: HRS 25</td>
<td>73.75%</td>
</tr>
<tr>
<td>RF 50: HRS 50</td>
<td>77.50%</td>
</tr>
<tr>
<td>RF 25: HRS 75</td>
<td>81.25%</td>
</tr>
<tr>
<td>RF 0: HRS 100</td>
<td>85%</td>
</tr>
<tr>
<td>RF 100: HRW 0</td>
<td>70%</td>
</tr>
<tr>
<td>RF 75: HRW 25</td>
<td>73.75%</td>
</tr>
<tr>
<td>RF 50: HRW 50</td>
<td>77.50%</td>
</tr>
<tr>
<td>RF 25: HRW 75</td>
<td>81.25%</td>
</tr>
<tr>
<td>RF 0: HRW 100</td>
<td>85%</td>
</tr>
</tbody>
</table>

2.2.2e: Test Bake Optimization
The goal of this test was to identify an optimal method that could be used to identify differences in baking performance of whole-wheat flours, with the ultimate goal of using the optimized method as a reference method for the next phase of the work, reducing the scale and complexity of the test. A full-factorial experimental design was created based on the following factors: fixed vs optimal mix time, ± instant yeast, and different starter amounts. The full factorial design resulted in the following combinations and repeated for the three different flours (Section 2.1f).
Table 2.2: Full factorial design combinations; all combinations were performed in duplicate per flour.

<table>
<thead>
<tr>
<th>Dough</th>
<th>Mix Time</th>
<th>± Instant Yeast</th>
<th>Starter Amount</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>Fixed</td>
<td>0.3%</td>
<td>12.5%</td>
<td>1</td>
</tr>
<tr>
<td>D2</td>
<td>Fixed</td>
<td>0.3%</td>
<td>25%</td>
<td>2</td>
</tr>
<tr>
<td>D3</td>
<td>Optimal</td>
<td>0.3%</td>
<td>12.5%</td>
<td>3</td>
</tr>
<tr>
<td>D4</td>
<td>Optimal</td>
<td>0.3%</td>
<td>25%</td>
<td>4</td>
</tr>
<tr>
<td>D5</td>
<td>Fixed</td>
<td>0%</td>
<td>12.5%</td>
<td>5</td>
</tr>
<tr>
<td>D6</td>
<td>Fixed</td>
<td>0%</td>
<td>25%</td>
<td>6</td>
</tr>
<tr>
<td>D7</td>
<td>Optimal</td>
<td>0%</td>
<td>12.5%</td>
<td>7</td>
</tr>
<tr>
<td>D8</td>
<td>Optimal</td>
<td>0%</td>
<td>25%</td>
<td>8</td>
</tr>
</tbody>
</table>

The combinations were all based on the experience gained in the previous tests and the idea that even though a sourdough method appears necessary, whether boosting the gassing power with commercial yeast gave any benefit. This experiment used the basic baking method with a wet (100% hydration) starter and the following formulation: flour (100%), water (HRS 85%, HWW 73.3%, RF 71.1%), and 2% salt. 25% or 12.5% of the total flour was pre-fermented in the sourdough starter. Either 0% or 0.3% instant yeast was used (based on the factor combination for a given test). Doughs where mixed for either a fixed time (and additional 2 minutes on speed 2) or optimal time (0.5 x the farinograph development time).

2.2.2.f: Community Grains Study

As a part of this project I had the opportunity to participate in a study organized by the whole grain supplier Community Grains. Based out of Oakland, California, Community Grains has been selling whole grains that are grown, milled, and produced in California, since 2010. The company has four core values: 1) all products will be 100% whole grain, 2) all products will come from a transparent supply chain, 3) all products will be grown with integrity, and 4) all products will be crafted for taste.

When a baker is asked what they think about a flour, their first answer is always “I need to try it first”. This is because a baker baking with a flour will provide different insight compared to the industry analysis. This is why Community Grains reached out to us to participate in their study. Their goal is to create a more universal language around wheat by “creat[ing] an alternative system of evaluation for whole grain flour and build[ing] a resource for anyone baking with non-commodity whole wheat” (Community Grains, 2018). The flours Community Grains provided us with were flours produced by farmers that believe in organic, nutrient rich soils, and alternative cropping systems that are not a part of the commodity system. These farmers believe that the quality of the wheat is directly tied to the quality of the farming practices and have, in their view, “begun to produce what seems to be a superior wheat in flavor, nutrition, functionality—and [that] certainly promotes a farm system that’s ecologically sound”. Community Grains believes this too.
Community Grains reached out to us for help with this alternative flour evaluation by participating as test bakers. For the evaluation I was able to directly apply the proposed optimal test bake design from the Experimental Design Test Bake to a real-world application that would allow local grain communities to utilize similar tests.

Community Grains reached out to a total of five bakers. These five bakers came from different baking backgrounds and lengths of experience working with naturally leavened breads. This providing a snap-shot of what the parts of a local grain industry might look like. The baker who has spent the most time working with natural leavens had been doing so for 10 years, but with 30 years of prior experience in the commodity grain industry. Another baker, with a professional background in pastry baking of about 7 years, recently began working with naturally leavened breads about 3 years ago. And another baker, author of the popular blogs Tartine Bread Experiment and Girl Meets Rye, has been baking with natural leavens for 8 years.

The questionnaire created by Community Grains contained these questions and requests for comment, not all of which would be considered in “conventional” test baking/flour tests.

**Community Grains Questionnaire:**

- Starter hydration percentage:
- Percentage of sourdough starter was added to the levain:
- Levain mature time before mixing dough:
- Notes were requested on times, temperatures, and other baking variables:
- Dough hydration percentage:
- Salt percentage:
- Sourdough percentage:
- Kneading, hand, spiral, etc. type:
- Total kneading time:
- Did it ferment quickly?
- Bulk ferment time/temperature:
- Folds? How many, and time intervals:
- Bench rest time:
- Proof time/ temperature:
- Dough strength/elasticity:
- How does the dough handle/respond?
- Did you need to modify to get the result you wanted?
- How else would you try to manipulate it?
- Describe the rise/oven spring. How quickly does it caramelize in the oven?
- Describe the aroma:
- Describe the flavor:
Describe the crust and crumb:
How would you describe this flour to another baker?
What would you say are the ideal uses for this flour? Beyond bread even?
Is there anything else we could be including in this survey?
CHAPTER 3: RESULTS AND DISCUSSION

3: Results and Discussion
Currently there is no common, universal whole-wheat sourdough test bake method used in breeding programs, small milling facilities, small farming operations, or bakeries. This project arose from this lack of technical support and quality testing that is necessary to create a more inclusive system that would allow production to be accessible to all types of producers and products accessible to all types of consumers. Test baking is the true test of a flour. The data in this project suggests that a method can be created that can differentiate between the baking outcomes of different flours. However, there is work to be done to validate and refine the method. Further work is also needed to reduce the scale of the test (smaller flour amounts) so it can be applied at early to mid-generations in breeding programs, stages at which little seed is available. Further work is also needed to reduce the complexity of the test, so that the type of training that was needed here to have the baker become skilled enough to create reproducible results would not be needed, as most breeding programs would not have unfettered access to a trained baker.

3.1: The “Screen Test”
The goals of this comparison were to test the different baking outcomes of flour created by milling the same grain under two different milling conditions (0.8 and 0.5 mm screens) and to test the precision of the baker over two independent baking days. Results are shown in Table 3.1. The comparison showed that there was no significant difference between the aspect ratio and loaf volumes between the two screen sizes, but that there was a significant difference between the two classes (HRW and HWW). The difference between the HRW and HWW samples was better differentiated when the flour was milled through the 0.8 mm screen. This result meant that there was evidence suggesting that differentiation between classes was achievable through a test method similar to what was used, and that the baker’s repeatability in bakes was sound.
Table 3.1: F-values and overall means from 2-way ANOVA for free-standing loaf aspect ratio and loaf volume (LVOL) comparing two wheat types and two screen sizes in the hammer mill. Values followed by the same letter within each section in a column are not significantly different based on Student's T.

<table>
<thead>
<tr>
<th>2-WAY ANOVA</th>
<th>Aspect ratio</th>
<th>LVOL (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F-values</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class</td>
<td>5.68*</td>
<td>7.19*</td>
</tr>
<tr>
<td>Screen</td>
<td>3.38 NS</td>
<td>0.13 NS</td>
</tr>
<tr>
<td>Class*Screen</td>
<td>0.35 NS</td>
<td>4.66 NS</td>
</tr>
<tr>
<td><strong>Overall means: Class</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRW</td>
<td>0.56a</td>
<td>943a</td>
</tr>
<tr>
<td>HWW</td>
<td>0.51b</td>
<td>914b</td>
</tr>
<tr>
<td><strong>Overall means: Screen</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 mm</td>
<td>0.52a</td>
<td>931a</td>
</tr>
<tr>
<td>0.8 mm</td>
<td>0.55a</td>
<td>927a</td>
</tr>
<tr>
<td><strong>Means: Class*Screen</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRW, 0.5 mm</td>
<td>0.55a</td>
<td>956a</td>
</tr>
<tr>
<td>HRW, 0.8 mm</td>
<td>0.57a</td>
<td>930ab</td>
</tr>
<tr>
<td>HWW, 0.5 mm</td>
<td>0.49b</td>
<td>905b</td>
</tr>
<tr>
<td>HWW, 0.8 mm</td>
<td>0.53b</td>
<td>924ab</td>
</tr>
</tbody>
</table>

HRW: Hard red winter, HWW: hard white winter
*: significant @ p ≤ 0.05; NS: not significant p > 0.05

3.2: The “Baker Precision Test”

As part of the skills training it was important to assess the day to day variability of the baker and the method to detect differences in baking potential on this occasion using three flours of known different baking potential from preliminary testing. Results are shown in Table 3.2.

Aspect ratio varied significantly between varieties. Unfortunately, it also varied between days. This was because of the large variation in Red Fife aspect ratio from D1 to D2. However, this large variation was because of a change in hydration for Red Fife on day 2. The hydration was manipulated because the original hydration made the dough unmanageable compared to the other two flours, although the loaf volume was not affected. When this aspect ratio data was removed, and the data reanalyzed there was no significant difference between days for aspect ratio (data not presented). The aspect ratios of the other two flours were not significantly different from D1 to D2. Despite the significant difference associated with the Red Fife aspect ratio the effect sizes (F-values) showed the dominant effect to be variety, an order of magnitude more impactful on aspect ratio than Day, and two orders of magnitude more impactful on aspect ratio than the Variety*Day interaction.

Loaf volume only varied significantly between varieties. For loaf volume the effect size for Variety was two and three orders of magnitude more impactful respectively than the effect sizes for Day and the Variety*Day interaction. The ultimate goal is to compare varieties or types of flour. Given the large effect size for variety in comparing aspect ratios, the observation that aspect ratio was not different D1 to D2 for the HRW and HRS samples, and that Variety was the
only significant effect for LVOL it was considered sufficient evidence to move on to the next phases of the project.

Table 3.2: F-values and overall means from 2-way ANOVA for free-standing loaf aspect ratio and loaf volume (LVOL) comparing flour of three wheat types across two independent days of baking. Values followed by the same letter within each section in a column are not significantly different based on Student’s T.

<table>
<thead>
<tr>
<th>2-WAY ANOVA</th>
<th>Aspect ratio</th>
<th>LVOL (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-values</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variety</td>
<td>333*</td>
<td>199*</td>
</tr>
<tr>
<td>Day</td>
<td>37.8*</td>
<td>2.40NS</td>
</tr>
<tr>
<td>Variety*Day</td>
<td>9.0*</td>
<td>0.58 NS</td>
</tr>
<tr>
<td>Overall means: Variety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red Fife</td>
<td>0.30c</td>
<td>814.4c</td>
</tr>
<tr>
<td>CG HRW</td>
<td>0.62b</td>
<td>955.9b</td>
</tr>
<tr>
<td>CCM HRS T200</td>
<td>0.68a</td>
<td>1142a</td>
</tr>
<tr>
<td>Overall means: Day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1</td>
<td>0.57a</td>
<td>960.5a</td>
</tr>
<tr>
<td>Day 2</td>
<td>0.49b</td>
<td>981.4a</td>
</tr>
<tr>
<td>Means: Variety*Day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red Fife D1</td>
<td>0.38c</td>
<td>813.9c</td>
</tr>
<tr>
<td>Red Fife D2</td>
<td>0.22d</td>
<td>815.0c</td>
</tr>
<tr>
<td>CG HRW D1</td>
<td>0.64ab</td>
<td>938.0b</td>
</tr>
<tr>
<td>CG HRW D2</td>
<td>0.59b</td>
<td>973.8b</td>
</tr>
<tr>
<td>CCM HRS T200D1</td>
<td>0.70a</td>
<td>1130a</td>
</tr>
<tr>
<td>CCM HRS T200D2</td>
<td>0.66ab</td>
<td>1155a</td>
</tr>
</tbody>
</table>

HRW: Hard red winter, HRS: hard red spring
*: significant @ p ≤ 0.05; NS: not significant p > 0.05

3.3: Starter timing

One important aspect of dedicated sourdough test bake methods is to assess the impact of starter fermentation time either side of the targeted “optimum” fermentation time of the starter. This is important because it allows bakers to use starters that are not exactly 16 hours old, creating some leeway. For example, this means for a bake day of 16 individual doughs, one would need to make four starters instead of 16 starters. If baking performance is not affected by reasonable changes in starter fermentation time it eases the burden on bakers needing to prepare starters the day before the test bake.

Preliminary analyses showed no significant difference for either aspect ratio or LVOL between D1 and D2 of the baking schedule. As a result, a 1-way ANOVA using fermentation time as the factor was performed (Table 3.3). Analyses of the time of fermentation of the sourdough starter showed that there was no systematic influence on loaf quality (aspect ratio or LVOL) when the starter fermentation was up to 1 hour greater or lesser than the targeted optimum time. As a result, we chose to use one starter per hour of baking (with the schedule used, 4 doughs) as
opposed to building a starter for every individual loaf that was optimized at precisely 16 hours. This strategy could be transferred to other researchers allowing a small but essential reduction in the complexity of the method.

Table 3.3: F-values and overall means from 1-way ANOVA for free-standing loaf aspect ratio and loaf volume (LVOL) comparing the time of fermentation of the sourdough starter across two independent days of baking. Values followed by the same letter within each section in a column are not significantly different based on Student's T.

<table>
<thead>
<tr>
<th>Time of fermentation (h)</th>
<th>Aspect ratio</th>
<th>LVOL (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.65a</td>
<td>959a</td>
</tr>
<tr>
<td>15.5</td>
<td>0.64a</td>
<td>940a</td>
</tr>
<tr>
<td>16</td>
<td>0.66a</td>
<td>955a</td>
</tr>
<tr>
<td>16.5</td>
<td>0.63a</td>
<td>942a</td>
</tr>
<tr>
<td>17</td>
<td>0.64a</td>
<td>940a</td>
</tr>
</tbody>
</table>

NS: not significant p > 0.05


These test bakes showed no significant difference between D1 and D2 of baking for either the RF/HRS or RF/HRW sets. As a result, a 1-way ANOVA using blend ratio as the factor was performed and used to determine the significance between treatments (Figures 3.1 and 3.2).

Sourdough fermentation - For the RF and HRS blends, there was a systematic increase in aspect ratio with an optimum value at 75% HRS (Figure 3.1.I). There was also a systematic increase in loaf volume (LVOL) as the amount of HRS increased (Figure 3.1.II). For the RF and HRW blend, there was an increase in aspect ratio between the 100% RF and 100% HRW samples, but the increase was not as systematic across the blends as for RF/HRS (Figures 3.1.I, 3.1.III). For LVOL in the RF/HRW blends, any addition of the HRW increased LVOL over that of the 100% RF sample, but there was a maximum LVOL for the 25 and 50% HRW blends (Figure 3.1.IV).

Yeast fermentation - For the RF and HRS blends there was no change in aspect ratio regardless of the RF/HRS (Figure 3.2.V) and an apparent optimum LVOL in the blends containing 50% and 75% HRS (Figure 3.2.VI). This contrasted clearly with the systematic increase in LVOL seen for the same blends in the sourdough process (Figure 3.1.II). For the RF/HRW blends, there appeared to be a systematic increase in aspect ratio as the proportion of the weaker RF decreased (stronger HRW increased: Figure 3.2.VII) from 25% HRW to 100% HRW. There was distinct optimum value for LVOL in the blend containing 50% HRW (Figure 3.2.VIII), which also contrasted with changes in LVOL seen for the same blend in the sourdough process.
Figure 3.1: Changes in aspect ratio and sourdough LVOL of blends of Red Fife/HRS and Red Fife/HRW wheat flours. Different letters associated with any two data points within a plot indicate a significant difference at $p \leq 0.05$ using Tukey’s HSD and 1-way ANOVA.

Figure 3.2: Changes in aspect ratio and yeast-raised LVOL of blends of Red Fife/HRS and Red Fife/HRW wheat flours. Different letters associated with any two data points within a plot indicate a significant difference at $p \leq 0.05$ using Tukey’s HSD and 1-way ANOVA.
3.5: Test bake optimization

Each of the main effects had a significant influence on both aspect ratio and loaf volume (Table 3.4). For aspect ratio, effect sizes (F-ratios) indicated that variety and starter percent were the most influential factors in the test. For loaf volume, addition of commercial yeast (yes or no) was by far the most influential factor. However, the addition of commercial yeast did lower the aspect ratio. Fixed mixed time led to higher aspect ratio and loaf volume, and lower starter% (12.5) was associated with both higher aspect ratios and loaf volumes. Overall, the interaction effects were small. However, they are reflected in reordering of the varieties when observing the individual variety*mixing*yeast*starter% means (Table 3.5).

Table 3.4: F-values and overall means from 4-way ANOVA for free-standing loaf aspect ratio and loaf volume (LVOL). Main effects are variety, mixing, yeast, and starter%. Only the significant interaction effects are reported. Values followed by the same letter within each section in a column are not significantly different based on Student’s T.

<table>
<thead>
<tr>
<th></th>
<th>Aspect ratio</th>
<th>LVOL (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4-WAY ANOVA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>F-values</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variety</td>
<td>104.7*</td>
<td>38.9*</td>
</tr>
<tr>
<td>Mixing</td>
<td>18.8*</td>
<td>7.50*</td>
</tr>
<tr>
<td>Yeast</td>
<td>35.3*</td>
<td>239.5*</td>
</tr>
<tr>
<td>Starter%</td>
<td>207.0*</td>
<td>54.4*</td>
</tr>
<tr>
<td>Variety*yeast</td>
<td>4.39*</td>
<td></td>
</tr>
<tr>
<td>Variety* starter%</td>
<td>4.39*</td>
<td></td>
</tr>
<tr>
<td>Mixing*yeast</td>
<td>7.6*</td>
<td></td>
</tr>
<tr>
<td>Mixing* starter%</td>
<td>12.0*</td>
<td></td>
</tr>
<tr>
<td>Yeast*starter%</td>
<td>14.7*</td>
<td>13.5*</td>
</tr>
<tr>
<td>Variety<em>mixing</em>starter%</td>
<td>3.30*</td>
<td></td>
</tr>
<tr>
<td>Variety<em>yeast</em>starter%</td>
<td>7.28*</td>
<td></td>
</tr>
<tr>
<td><strong>Means: Variety</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Espresso</td>
<td>0.58a</td>
<td>761a</td>
</tr>
<tr>
<td>BRM Ivory</td>
<td>0.56b</td>
<td>739b</td>
</tr>
<tr>
<td>Red Fife</td>
<td>0.51c</td>
<td>726c</td>
</tr>
<tr>
<td><strong>Means: Mixing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed</td>
<td>0.56a</td>
<td>747a</td>
</tr>
<tr>
<td>Optimized</td>
<td>0.54b</td>
<td>738b</td>
</tr>
<tr>
<td><strong>Means: Yeast</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>0.56a</td>
<td>717b</td>
</tr>
<tr>
<td>Yes</td>
<td>0.54b</td>
<td>768a</td>
</tr>
<tr>
<td><strong>Means: Starter%</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.5%</td>
<td>0.57a</td>
<td>755a</td>
</tr>
<tr>
<td>25%</td>
<td>0.52b</td>
<td>730b</td>
</tr>
</tbody>
</table>

The largest aspect ratio difference between Red Fife and Espresso was provided by the fixed mix time, +yeast, 12.5% starter treatment (Table 3.5). However, this treatment showed no capability of resolving the differences in loaf volume potential of the three varieties. We considered that any bake method that separated Red Fife and Espresso aspect ratio by 10% or more was a
candidate. We were forced to make a decision on inconclusive data. Among the candidates with >10% aspect ratio separation between Red Fife and Espresso, both of the optimized mix-time, no-yeast methods had the largest difference between the two varieties for loaf volume and were able to significantly resolve the difference between Red Fife and Espresso. In an ideal circumstance we would move forward with both methods to validate their performance.

There is certainly more work needed to accomplish the sourdough-based whole-wheat test bake method we sought to develop in the project. I suggest that future work focus on validating the **fixed mix-time, +yeast, 12.5% starter** method and the two optimized mix-time, no-yeast methods. Using that validation, each of the three tests would need to be assessed on how they impact the results before moving towards creating the defined sourdough-based whole-wheat test bake method needed to support the growing local grain economies in the United States.

**Table 3.5**: Individual variety*mixing*yeast*starter% means from the ANOVA grouped by each combination of the main effects. Values followed by the same letter within each column are not significantly different based on Student's T.
3.6: Community Grains Study

Because five bakers were each provided with sets of non-identical flours (each received at least three flours to work with), not all results between bakers were comparable. Each baker processed their flour differently. From different starters to different bake temperatures, the processes used by each baker were always different. This did, however, provide some valuable information. First, it illustrated the reality that baking can be highly subjective and dependent on the baker. For example, 3 bakers tested the flour Hi Pro Patwin, 2015, and each baker used a completely different mix time. One baker mixed the dough for four minutes, another for 15 minutes, and another (myself) for five minutes. The use of different processes also illustrated how completely different results can arise from the same flour. For the flour Frassinetto, one baker said they would describe this flour to another baker as “beautiful rich flavor. Gorgeous for Desem. Nutty and just beautiful. If you want a top-rate wheat, go for this,” while another baker said they would describe the flour as “meh. boring. flavorless. doesn’t hold water well.” While the different processing techniques between the bakers were allowed each baker to personally understand the flour better, this type of manipulation requires a great deal of knowledge and experience. The constant manipulation also prevents the process from being simple and repeatable by someone without the required training or skills. With respect to a test bake method that could be used in a breeding program or small milling operation, this process is rather unrealistic when you consider, again, that bakers should be trained and that they are not always accessible. The methods used by the bakers in this evaluation were also greatly varied in time (some proofing times went over night, while others only took 45 minutes), starter (some starters were hydrated at 65% while others were hydrated at 100%, and different types of flours were used), and formulas (dough hydrations ranged from 83%-100% and sourdough amounts ranged from 12.5%-55%).

This alternative flour evaluation was a great way to wrap up my project for several reasons. It allowed me to understand the place of my project in the greater scope of small scale grain economies and it gave me a chance to understand the nuances of developing a testing method when you apply it to the real world. The way I choose to bake bread might be very different from how another baker chooses to bake bread — the alternative flour evaluation clearly illustrated this. Considering that the mindsets of each baker going into this evaluation was also different, and that we all had different perspectives on what good bread should be, is another point as to why developing an accepted method will be difficult. Our end goals were all slightly different. Thus, all of our approaches were going to be different. That being said, no matter what our own personal perception of how a flour would work for a product, everyone wanted to know the basic answer to: is the flour worth it. Which is why a small scale, simple, efficient, test bake method is necessary.

CONCLUSION

Local grain producers are growing in numbers as our global food system shifts towards smaller-scale, often organic, production and as consumers increasingly acknowledge the importance of whole grains. The search for a definitive “reference” sourdough-based whole-wheat test bake method that would aid growing local grain systems was inconclusive with the experimental design employed in this project. That being said, there were indicators of what might constitute the next steps and that a specific test bake method for the use of sourdough and whole wheat products is both wanted and necessary.
For the Screen Test experiment, I concluded that using the hammer mill we have access to, that the screen size (inferring flour particle size) did not affect baking performance. This result is contrary to the findings of others including Ross and Kongraaksawech (2018). The experiment also showed that I was able to reproduce results across two independent days of baking.

For the Baker's Precision test, I concluded that my baking skills allowed me to repeat test bakes across independent baking days without creating significant differences in aspect ratio and LVOL. This reinforced the findings of day to day consistency seen for the screen test experiment. From that point forward all further bakes were done on two independent days for the sake of precision. The results of this test, and thus the entire study, are very strong because I was able to repeat each experiment on separate days strengthening the validity of the data.

For the Starter Timing test, I concluded that there was no systematic influence on loaf quality (aspect ratio or LVOL) when the duration of starter fermentation was ± 1 hour from the targeted optimum duration. This allowed the use of, for example, four "master" starters per 16 dough test bake day, as opposed to 16 individual starters, one per dough. This strategy saves time, effort, and reduces complexity in setting up the starters for dedicated sourdough test baking. The information is valuable other sourdough test bakers.

For the Assessing the Resolution of the Baking Method test, I concluded that to test a flour for a sourdough product, sourdough leavening must be used and yeast is not an appropriate substitute in the formula. This is arguably the most important finding from the entire project.

For test bake optimization, I concluded that any bake method that separated Red Fife and Espresso aspect ratio by 10% or more was a potential candidate for an optimal method. As such, the fixed mix-time, +yeast, 12.5% starter method and the two optimized mix-time, no-yeast methods, 12.5%/25% starter methods are potential candidates for future work. Using that validation, each of the three tests would need to be assessed on how they impact the results before moving forward. However, the combination that showed the most promise was the optimized mix-time, no-yeast methods, 25%, because it met the aspect ratio parameters set above and showed the largest difference in volume between the samples.

For the Community Grains Study test, I concluded that while there is no current test bake method universally used in the local grain community, a test method of this nature is very much wanted and needed.

The culmination of all these conclusions in the context of assisting local grain economies as they continue to grow are:

- It is possible to train a baker to be consistent in baking outcomes in handcraft techniques
- There are differences between baking results of sourdough and yeast-leavened bread, and yeast should not be used as a substitute for sourdough when testing.
- There is a need for a dedicated sourdough whole-wheat test bake method in small-scale grain production communities.
The three methods suggested from the results of the Optimal Method test can serve as a reference for future work on the topic - creating a more efficient and optimal test bake method.

As such, these conclusions can now serve as reference for further work in the development of the smaller-scale, simplified, and low-cost method that is needed to support the small-scale and local grain systems that are growing across the country.

References


Kasarda, D.D., 2013. Can an increase in celiac disease be attributed to an increase in the gluten content of wheat as a consequence of wheat breeding?. *Journal of agricultural and food chemistry, 61*(6), pp.1155-1159.


