Malting Kernza® Perennial Grain

ASSESSING CHARACTERISTICS, QUALITY, AND FLAVOR OF KERNZA® MALT

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Introduction

Our agricultural system is based on an extractive model. It takes nutrients from soil, and leaves it uncovered to blow into ditches and watersheds. It relies on nutrients from fossil fuels, heating our planet. It draws down our aquifers while polluting our rivers. It takes from the health of people and financially rewards consolidated corporations. It's unsustainable, and cannot heal itself or continue into the future.

Natural systems are the opposite. They're regenerative, meaning they create, and create again. They are sustainable, existing into the future with their own diverse, self-supporting complexities. When you look at a forest, you see a perennial polyculture, an ecosystem full of different species living year after year. When you look at an agricultural field, you see an annual monoculture, a field of one species planted anew each year.

In a time of increasing adversity from climate change, we need to substantially and meaningfully reimagine our relationship with nature in pursuit of the continuation of life. We need to break the philosophical dichotomy of the past, and not see ourselves as separate from nature or masters over it. We need to embrace our role as a part of nature, and humbly acknowledge that though our progress is great, the mysteries are larger.

Food is a sensible place to pursue large-scale change in our relationship with nature. We eat food each day, intimately connecting with plants, animals, and soil. We also regularly commune with others over food, creating culture and connection. Many people have pursued this type of work for decades, developing organic agriculture and local food systems while challenging extractive agriculture. However, these paths have pursued change within the existing framework, relying on the tools of today.

There is a movement to develop new tools for a new agriculture, rooted in natural systems. A step change is happening, in which our relationship with soil, water, and plants is being reimagined into regenerative systems that could offer scalable paths forward for continued human life on earth. This work is focused on breeding perennial grains and oilseeds. Grains provide 70% of the world's calories and impact an enormous amount of land. Minnesota farms 25.5 million acres, 8.4 million in corn, 7.6 million in soy, 1.2 million in wheat, 4.5 in pasture, and .5 in sugar beets. Row crops dominate this acreage, and perennial versions of these crops offer the possibility of substantial landscape change.

Kernza® Perennial Grain is the leading crop of this vision. Over 20 crops are in development within this larger vision, and breeders have been tirelessly working on Kernza since 2001. Kernza is a cousin of wheat and the first commercially viable perennial grain launched into US markets. Today, in 2023, Kernza is finding its way into our communities and onto our plates, and numerous researchers, entrepreneurs, non profits, farmers, and champions are helping bring it to life. This report is an attempt to boost the impact of Kernza in Minnesota by sharing the detailed research performed by Perennial Pantry since 2019 on Kernza. It is the conclusion of a multi year Crop Research Grant awarded by the Minnesota Department of Agriculture.

Through this grant, titled "Assessing Characteristics, Quality, and Flavor of Kernza® Malt," we advanced new uses for Kernza by researching the crop's malting characteristics, malt quality, and malt flavor traits. This research helped determine if malted Kernza has commercial viability, an important and necessary unknown in the efforts to increase acreage and build a supply chain around the promising and ecologically beneficial perennial crop. During our research, we also examined malted Kernza's culinary applications while creating a robust Kernza baking foundation from which to understand the crop's culinary opportunities.

This report will cover Kernza's supply chain, offering an introduction to the grain, grain cleaning methods, malting, brewing, milling, baking, and recipes using Kernza. It will share detailed research results set within the non academic context of an entrepreneurial supply chain. We believe that the more information shared on Kernza, the greater the likelihood that the crop's deep roots tangibly and legitimately impact Minnesota's soils, rivers, and livelihoods.

Our aim in writing this report is to create an accessible introduction to Kernza, communicating our rigorous malting and culinary trials, while acknowledging that we are entrepreneurs, not academics. Our team sits in a dynamic location between academia and business. We are unique in being a vertically integrated, hands on business that actively processes Kernza from out of the combine to finished products. We rely on the basic research conducted by our colleagues and friends in academia, and seek to translate their foundational work into applied results.

Our research was led by Joe Kaplan, Perennial Pantry's Director of Research and Development. Christopher Abbott, President, and Nick Gardner, Director of Operations, played crucial roles supporting and shaping the research.

Kernza offers a new path forward for Minnesota. We believe in its possibility to build soil and stop erosion, prevent nitrate pollution of our rivers and lakes, sequester carbon, and create economic opportunity in our rural communities. Kernza is at a tipping point with growing acreage, genetic improvements, products, and awareness. Natural systems agriculture is being successfully demonstrated, and a regenerative, abundant agriculture is ready to scale up and reimagine our relationship with nature and one another.

Executive Summary

Kernza® Perennial Grain (Intermediate Wheatgrass) is a perennial cousin of wheat, and the first commercially viable perennial grain launched into US markets. It is spearheading the movement towards a regenerative agricultural model that mimics natural ecosystems.

Relatively little is known regarding the scope of its applied uses. This research project explored Kernza malting towards the goal of boosting the impact, awareness, and use of Kernza by Minnesotan farmers, millers, bakers, brewers and researchers.

Kernza Malt Quality Analysis

- Kernza can produce viable malt
- Highest extract achieved (CGDB): 69.2%
- Kernza malt quality generally showed low extract, but high diastatic power, which could mean the enzyme content is good, but the starch quantity is low.

Optimal Schedules per Parameter						
Isolated Parameter	Total Steep Time	Steep Temp.	Day 0 Moisture	Germination Time	Germination Temp.	Avg Acro Length Day 4
a-Amylase (35 D.U.)	32 hr.	15.6 C	51.70%	7 Day	15.6 C	89.5%
CGDB (69.2 %) & b-Glucan (57 mg/l)	16 hr.	15.6 C	45.50%	7 Day	12.8 C	78.5%
Diastatic Power (172 ° L)	24 hr.	12.8 C	45%	7 Day	15.6 C	76.5%
FAN (198 mg/l)	24 hr.	15.6 C	46.90%	7 Day	15.6 C	85.5%
Soluble Protein (6.8%)	16 hr.	10.0 C	40.30%	7 Day	15.6 C	41.5%

Quality Analysis for Schedules per Parameter								
Targeted Variable	AA (D.U.)	B-Glucan (mg/L)	Diastatic Power (degrees L)	Extract (CGDB) (%)	FAN (mg/L)	Sol. Protein (%)	Post Steep Moisture (%)	Avg. Acrospire Length Day 4 (%)
Base Malt Benchmarks (Barley)	Above 30	Less than 200	110-150	85%	200-250	5% (varies)	N/A	N/A
a-Amylase	35	85	149	55.7	195	9	51.7	89.5
CGDB & b-Glucan	33	57	156	69.2	197	10.8	45.51	78.5
Diastatic Power	23	122	172	61	152	8.1	44.98	76.5
FAN	22	83	171	54.2	198	8.8	46.91	85.5
Soluble Protein	20	96	148	49	129	6.8	40.32	41.5

Flavor Profiles of Kernza Malt Wort

Kernza Base Malt: Bready, earthy, grassy, grainy, vegetal, nutty.

Kernza malt toasted at 300F: Earthy, grassy, grainy, grassy, nutty, sweet aromatic, smoky.

300F malt was consistent favorite amongst malts roasted between 300 - 450 F.

Flavor Profiles of Kernza Malt Beer

Sweet caramel, fruity, cereal, barnyard.

Challenges

Small seed size is an issue when grinding.
May struggle with attenuation.
High protein level needs mitigation.
May need hull supplementation on large scale (Kernza hulls can be used).

Milling

Kernza mills well when blended with wheat and passed through mill simultaneously.

Blending and milling with wheat increases throughput rate compared to milling Kernza alone.

10% seed moisture during milling produced best results. Quality dropped after moisture dropped below 8% and as it approached 12%.

Stone mills may need to be dressed more frequently when consistently milling Kernza.

Heat also increases rapidly during milling, due to small kernel size.

Sifting

Retaining roughly 50-60% of the weight is normal when sifting Kernza compared to 85%+ when sifting wheat through a 60 mesh screen.

Kernza Malt Powder in Baking Applications

Flavor boost. Exceptional flavor when combined with milk powder.
Crumb softening.
Deepens color.
May boost initial fermentation (first 30 minutes) at 1.5% Diastatic malt powder.
Addition of diastatic malt to strong doughs made handling easier during mixing/kneading.

Best Kernza Malt Baking Applications

Bagels
Shortbread

Chapter 1: Kernza® Perennial Grain

Kernza® Perennial Grain is the trademarked name for the grain produced by the plant Intermediate Wheatgrass. The Land Institute, the originators of the name, trademarked it in order to thoughtfully steward this new crop into the world. "Kernza" is a combination of the words kernel and Konza, the name of a local indigenous tribe in Kansas; "Indigenous people of the Kaw (Kanza) Nation inhabited and stewarded this area until their forced removal between 1846 and 1872, when they were relocated to a small reservation in what is now Oklahoma. The depopulated Kaw land was subsequently used to finance the Land-Grant University system under the Morrill Act of 1862, including Kansas State University'' (source).

Intermediate wheatgrass is a forage crop originally from the Ukraine region, which has been grown in the United States since the 1920's. Researchers at The Rodale Institute, inspired by the vision of natural systems agriculture articulated by The Land Institute, evaluated grasses for domestication in the 1980's. Intermediate wheatgrass had larger seed sizes and interesting flavor, and was selected as a viable candidate.

In 2001, Lee Dehaan, a PhD graduate from the University of Minnesota, moved to Kansas to begin a breeding program in earnest to domesticate Intermediate Wheatgrass. Since then, seed size has increased, lodging has decreased, hulless lines have been developed, and the crop has moved from a grass to a grain. Additional breeding programs have joined the work, with a second home of Kernza beginning at the University of Minnesota's Forever Green Initiative in 2011.

Kernza is a perennial, growing 10 foot deep root systems and regrowing each spring without additional planting. It is planted in August and September in Minnesota, and establishes before the winter. Come spring, growth restarts, and fields can be grazed. 3 foot tall biomass grows during the summer, eventually heading out and developing a grain crop. Grain is swathed and combined in August. Currently, Kernza yields around 425 lbs of clean grain per acre in Minnesota. This can range widely due to agronomics. Straw may be harvested and baled during grain harvest. A final forage crop can be harvested and baled during the fall.

These multiple revenue opportunities intertwine with Kernza's reduced needs for inputs. Seed is planted once every 3-4 years, dramatically reducing fieldwork requirements. Innovative agronomic research into intercropping Kernza with nitrogen fixing plants like alfalfa offers future opportunities of self-sustaining fields without the need for additional fertilization. Interested in additional agronomic information? The University of Minnesota maintains an excellent grower's guide, available at landinstitute.org/interested-in-growing-kernza.

Growers accessed the first official variety of Kernza in 2019, when MN-Clearwater was released by the U of MN: "It is the world's first commercial food-grade intermediate wheatgrass grain cultivar. It was developed as a synthetic population at the University of Minnesota, St. Paul, MN. MN-Clearwater (experimental designation MN1504) was created by intercrossing seven parents selected for high grain yield, reduced shattering, high free grain threshing, reduced lodging, and uniform maturity. MN-Clearwater was advanced for two generations before being evaluated in statewide yield trials, after which the fourth seed generation was released as the cultivar in a limited public release. The first 2 years produce the highest grain yields under Minnesota conditions, and third-year yields are significantly lower (average reduction of 77%) than the first 2 yr." (Bajgain 2020).

Breeders state that Kernza is in a honeymoon phase of breeding, offering significant breeding gains at a pace currently unattainable in wheat. Lee Dehaan believes Kernza will surpass wheat in yield/acre in 17 years, due in part to his innovations in reducing breeding cycle time. The current and future genetic diversity in Kernza due to active domestication is a dynamic component of establishing supply chains. Seeds will continue to change as new varieties are released, overlapping with existing perennial acreage. Processors must adapt, and aspire towards consistent ingredients for widespread adoption.

An example of this change is found in the size of kernels. Current kernels are 1/3rd the size of wheat. See the following table from 2020 for Kernza dimensions of a variety of recent breeding lines:

Kernza Dimensions Across Different Genetic Lines							
ID	**Seeds measured**	**Weight (mg)**	**Area (mm2)**	**Width (mm)**	**Length (mm)**	**Circularity**	**L/W Ratio**
2016 TLI C3	157	0.937	6.5	1.6	5.5	2.0	3.5
2016 TLI C4	165	1.050	6.9	1.6	5.6	2.0	3.5
2016 TLI C5	189	1.228	6.7	1.6	5.4	1.9	3.4
MN1501-SYN2	75	0.637	8.3	1.7	6.4	2.2	3.8
MN1502-SYN2	185	1.028	6.2	1.5	5.4	2.1	3.5
MN1503-SYN2	235	1.348	6.7	1.5	5.8	2.2	3.9
MN1504-SYN2	185	1.107	6.5	1.6	5.5	2.0	3.5
MN1505-SYN2	130	0.740	6.6	1.5	5.9	2.2	3.9

Kernza’s small size impacts the ratios of the different parts of a seed. Seeds have an endosperm, germ, and bran. The endosperm is typically the white, starchy section of the seed, made up of mostly starches and proteins among other things. During germination, enzymes break down this energy reserve, making sugars available for plant growth before photosynthesis. The germ is the source of oils and enzymatic synthesis. The bran is a protective layer around the seed. Kernza, due to its size, has a much higher bran to starch ratio than wheat. As Kernza is bred, these ratios will continue to change, directly impacting the malting and baking qualities of the grain.

In addition to a bran layer, Kernza has a protective hull around the seed. This hull prevents damage to the germ section of the kernel, enabling successful germination once the seed has separated from the plant. However, this hull is not edible, and requires processing to remove. In addition, plant material and biomass harvested with Kernza require separation to produce clean grain ready for cooking, malting, baking, and brewing.

Grain cleaning is the art and science of sorting homogenous material out of heterogeneous material. Current agronomic practices result in harvested Kernza products containing a wide range of grain, hulls, straw, weed seeds, and other material. Grain cleaning entails the use of a variety of machines to separate out material by width, length, density, surface area, color, and other unique characteristics. Due to Kernza’s size, hull qualities, and additional material received from combining, it takes upwards of 10 times as long to clean Kernza as it does to clean wheat. Cleaning methods and advice can be found in the Agricultural Utilization Research Institute’s (AURI) overview paper “Kernza® Perennial Grain: Cleaning & Dehulling Process.”

For the purpose of malting, it’s important to recognize different forms of Kernza at current breeding and agronomic levels. Harvested Kernza entails free threshed kernels and dehulled kernels. Free threshed means grain that has already been freed from the protective hull at the time of harvest. Dehulled kernels means kernels that have gone through one or several rounds of impact dehulling in order to remove the hull. The impact dehulling process can damage the germination capacity of Kernza, as the germ is relatively exposed at the pointed end of the seed. AURI has seen some success with impact

Wheat Next to Kernza

dehulling that doesn’t impact germination rates, yet we found the highest germination capacity in free threshed seeds. We have not evaluated the germination capacity of Kernza harvested with a stripper head, which dramatically reduces the amount of biomass coming out of the combine.

Though Kernza is a cousin of wheat, it is not a substitute for wheat. Due to its small size and bran to starch ratio, it exhibits very different baking characteristics compared to wheat. It contains a higher protein and dietary fiber content versus wheat, but has both less gluten and different gluten-forming protein ratios than wheat. See the following table from AURI’s overview paper on Kernza titled “Kernza® Perennial Grain as a Cereal Grain.”

Comparison of the Nutritional Values of Kernza and All Purpose Flour (AURI)			
Types of Grain	Unit	Kernza Whole grain	All Purpose Flour
Moisture	%	8.6	11.9
Ash	%	2.4	0.47
Calories	-	368	364
Protein	g	19.2	10.3
Carbohydrates	g	67.3	76.3
Dietary Fiber	g	18.0	2.7
Soluble Fiber	g	3.6	0.9
Sugar	g	1.7	0.3
Total Fat	g	2.9	1.0
Sat Fat	g	0.5	0.2
Mono Fat	g	0.5	0.1
Poly Fat	g	1.9	0.4
Trans Fat	g	0	0
Cholesterol	mg	0	0
Calcium	mg	120.0	15.0
Iron	mg	5.5	1.2
Potassium	mg	480.0	107.0
Sodium	mg	0	2.0

Chapter 2: Malting

What is Malt?

In short, a malted grain is one that has been partially germinated, or sprouted, in a controlled environment for a specific period of time and then dried. Its origins predate recorded human history. Properly dried grains were stable sources of food, but further processing was needed in order to consume them and draw out nutrients otherwise unattainable from eating the raw seed. Using a combination of heat and water was one way of early processing, but another discovery allowed a similar outcome with no heat: merely soaking, draining and sprouting. This alone made the seed easily consumable. Keep in mind, these early processes of utilizing stored grain predate the advent of agriculture. Since then, malting and, in turn, brewing techniques have coevolved with civilization. (Liu 2018)

Today, the techniques of malting grains are still evolving, but the process itself along with the precise interactions of seed components during this process is very well understood. As mentioned above, a malted grain has been partially germinated and fully dried to below 6% moisture. On the surface, malting is carried out in three phases: steeping, germination, and kilning. Very significant changes occur during this deviously simple process.

Essentially, when a grain is submerged in water, it is “tricked” into believing spring has arrived, and it begins processes necessary to grow. Inside of the seed, this comes in the form of a few occurrences: Once hydrated, the structural components of the seed can interact via the medium of water. When this happens, a cascade of interactions take place that begin the life cycle of the plant. First, enzymes previously motionless begin to move about and break down specific portions of the seeds’ scaffolding. The first enzymes released have the task of breaking down a starch blanket called the beta glucan barrier. This barrier, made of cellulose, surrounds each starch molecule and acts as a protector and preserver. Once this blanket is removed, outside influence in the form of water and other enzymes are able to reach the starch. Subsequently, two more enzymes are either released (beta-amylase) or synthesized (alpha-amylase) within the seed. The function of both of these is to break down the starch - made of long links of individual sugars - into smaller forms of sugar, mainly mono and disaccharides. Should sprouting continue to where the enzymes fully convert the starch into usable sugar, the seed will begin consuming this new source of food within itself and use the energy to sprout into a plant. This is where the art of malting comes into play; it is all about halting this process at the precise moment where the beta glucan layer is disassembled, and alpha/beta amylases are present but have not yet had a chance to begin acting on the starch. When all of this has taken place, the grain is dried and kilned, and all biological processes are halted yet again. This is a malted grain; it has all of the components necessary to produce fermentable sugar as it lies in wait to do so. When allowed (during the “mash” process of brewing), alpha and beta amylase will activate for the first time and start making these fermentable sugars. This newly converted sugar in the presence of water will provide food for the yeast added, which will ferment producing alcohol as a byproduct.

Each of these three processes (steep, germinate, kiln) can be manipulated in countless ways. Harvest state, grain variety, time of year, and beer style all factor into the parameters of each step. The kiln phase, for example, not only dries the grain; it can toast it to a certain degree affecting the color and flavor of the final product. More toasting yields darker beer, but it can also destroy enzymes necessary to convert starch into sugar. Less sugar equals less food for yeast, which will yield a lower ABV. This description is simplified, but one can see how manipulating one step affects the entire brewing process.

Why malt Kernza?

Relatively little is known about Kernza in its applied form, especially when compared to wheat and barley, and the majority of applied research has been conducted within the context of its baking/culinary applications. To really get a picture of the scope of Kernza's utility, applied research must be carried out in a multitude of areas to identify the most promising uses and markets for Kernza. Brewing is a logical direction to explore due to its popularity in the public domain, applied research, and the existing momentum of using Kernza in beer as an adjunct ingredient.

Craft brewing is a 26.8 billion dollar market in the U.S. alone, and is showing steady growth. It grew 8% between 2020 and 2021. The craft world is well known for its seemingly unlimited varieties and iterations of beer types/styles. Though barley is the most common grain used in malting, other malts and ingredients are used and experimented with. The number of total U.S. Breweries is at an all time high today: 9,247 at the end of 2021. This is quite astounding considering there were around 4,800 in 2015, and it seems as though totals are still climbing each year. Given this popularity and growth, there is a swath of published data on malting and brewing, enough to really determine if Kernza has the potential to be a contender in comparison to other grains used in the malting and brewing process. Should malt viability be achieved, one more outlet of this revolutionary grain will exist, and ecological regeneration will take one more step forward. (Watson 2022)

Malting Equipment

Early large scale malting was carried out in barns or monasteries where hundreds of pounds of grain were spread out across the floor to germinate. The grain would be turned multiple times a day to ensure exposure to oxygen and to prevent clumping. The environment early on was much more a factor than it is now, so it was typically a seasonal process. A separate vessel for each stage in the malt schedule was also necessary, whereas today, modern plants can now do each phase in two or even one vessel. There are innumerable vessel varieties, set ups and scales allowing hundreds of tonnes to be malted at one time. Semicontinuous and continuous malting is even possible; before it was strictly a batch process. (3)

Our malting experiment was carried out in 10 pound batches with one piece of equipment: The Acro Personal Malthouse, manufactured by Sprowt Labs. It consists of a 17 gallon (65L) conical attached to a control panel. This device allows each step to be carried out in a single vessel at a small scale. It has a control panel that allows for temperature controlled airflow, humidity, timed water draining, and programmable kiln times/temps., making it almost ideal for controlled experimentation.

Acro The Personal Malthouse

Research Objectives and Methods Overview

The overarching objective of our research was to assess the characteristics, quality, and flavor of malted Kernza over numerous applications and expressions. Though the primary focus was on Kernza in its malted form, it became apparent early on that additional testing would be necessary in order to properly explore its potential. For example, when malted Kernza was to be tested in baking applications, flour of consistent quality was needed in order to produce accurate results. Our entire processes is what makes up the majority of this report, but three primary objectives are listed and explained here:

Objective 1: Develop Malting Technique for Kernza

This was the core objective of our research, and there were many steps in the process. Determining a schedule and potentially producing a viable malt from Kernza would provide the momentum needed to carry out the applied research necessary to give useful data to the public.

To develop a malting schedule and technique for Kernza, germination tests and moisture uptake rates of different seed lots, genetic varieties, and grain states were conducted on the raw seed first. Then, malting was carried out in three separate phases, each focusing on one portion of the malting process (steeping, germination, and kilning). When all testing was complete, malt quality was assessed and results were compiled.

Objective 2: Pursue Applications: Brewing and Baking

Using the optimal malting schedule produced from “Objective 1,” further applied research was conducted on malted Kernza. Naturally, a brewing setting was an appropriate first step, and our malt was used in conjunction with and compared to barley malt to produce beer. The Kernza malt was also tested in baking settings in the form of diastatic and non-diastatic malt powder. These two applications would cover a very broad range of end users.

Objective 3: Investigate Flavor: Sensory Analyses of Wort, Beer, and Baked Goods

Results from objectives 1 and 2 would provide a foundation for sensory analyses. Flavor and overall “likeability” are important factors when it comes to food research. Conducting sensory analyses would also provide an initial glimpse of Kernza malt’s acceptance in the public sphere. Each analysis was conducted with individuals outside of Perennial Pantry.

Initial Testing: Small Scale Pre-Malt Experimentation

Before large batch malting could begin, small scale experiments were conducted in order to hone in on average germination and moisture uptake rates amongst a variety of grain in different states of processing. The tests are listed and explained below.

Bench Top Germination

We performed bench top germination trials to evaluate which grain state had the highest germination rates. In these trials, we tested 50 seed samples of Kernza in three grain states: hull on, dehulled, and free threshed (winnowed and huless, but not sent through dehuller) to determine ideal grain state for malting. Seeds were placed in a ziplock bag containing a damp paper towel and left to germinate for three weeks. After germination, seeds were counted and separated into two categories: no change, and visible acrospires present. Germination rates were then calculated as a percentage.

Results: Average Germination Rates

- Dehulled: 52%
- Free Threshed: 81%
- Hull on: 93%
- Mix of hull on and free threshed: 87%

Small Scale Germination Test Example

Though seeds with their hulls on had the highest germination rate, this would be impractical. At a larger scale required for testing, hulls can fall off during processing, and they make up the majority of the chaff that is skimmed off during the steeping phase. Therefore, it was concluded that a mix of free threshed and hull on grain would be used for pilot testing.

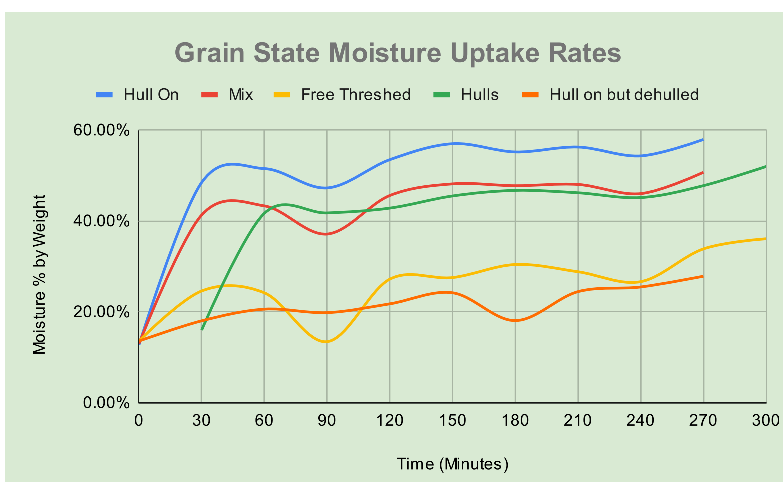
Moisture Uptake Rates

Next, we investigated moisture uptake rates in order to determine the steeping duration windows to evaluate. We were answering the question: How long does it take for Kernza to reach X% moisture content? Numerous tests were conducted to determine moisture uptake rates and patterns from the same variety of grain states at a small scale. A seed's moisture uptake rate and final moisture percentage going into germination is a crucial variable to understand. In short, too little moisture, and the seed will be unable to germinate. Too much, and the seed may over modify during germination. The progression of testing follows:

Test 1: Hull on and Free threshed grain submerged in 15.6 C degree water for 60 minutes. Final moistures showed 46.42% for hull on, and 25.38% for free threshed. It was already apparent that hulls alone take on a considerable amount of water.

Test 2: Hull on, mix, free threshed samples submerged in water over a period of 270 minutes (4.5 hours) with the addition of hulls and seeds separated from what started as hull on grain. The aim being to get a better picture of what moisture is going where in the hull on samples, and also to reveal any differences between dehulled grain and free threshed hull-less grain.

Final Moistures:
- Hull on: 57.9%
- Free Threshed: 33.81%
- Mix: 50.67%
- Hulls: 51.95%
- Dehulled from hull on: 27.8%

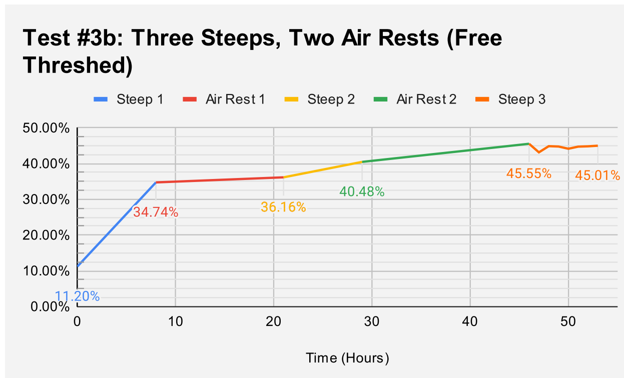


Moisture Uptake Over a Variety of Kernza Grain States

Test 3: Test three was a series of longer steep times and additions of air rests, that culminated in the results and graph below. This culmination shows a schedule of what would mimic the most extreme conditions in a malt: three eight hour steeps with two “air rests” between each steep. This schedule emulates a full day of steeping, and resting the grain overnight, to be steeped yet again the next work day. Free threshed seed is the only grain shown, because it fully depicts the amount of time it takes for the seed alone to reach a given moisture percentage.

Results:

After 53 hours total, the samples reached a moisture content of 45%. The graph also shows moisture continues to rise during an air rest: an important variable.



Moisture Uptake Trend Over Three Steeps and Two Air Rests

Large Scale Malt Testing Overview

Results from small scale experimentation carried over to large scale malting, the backbone of this grant. This process is revealed in much more depth in the next chapter, but a general overview of the process is explained here.

Steeping

The first step in large scale malting trials. The data collected above along with malting references better informed how our matrices would be developed. It was determined that the steeping matrix would consist of three total steep times at three different temperatures. Steeping involved submerging the grain in water for eight hours at a time, then draining it and allowing it to “air rest” overnight. Moisture samples were taken at the beginning, end, and between each transition.

Total Steep Times: 8, 16, 24 hours

Steep Temperatures: 10, 12.8, 15.6 Celsius.

Post steeping, the grain was germinated at one standard length of time and kept at a consistent temperature: 7 days at 15.6 celsius. Acrospire counts were also conducted: 25

Acrospire Lengths: Number of kernels with acrospires (x) times the length of the seed. **Out of 25**								
Day (1/22 - 1/29/21)	0	0.1-0.25	0.26-0.50	0.51-0.75	0.75-1.00	1.01-1.25	1.26-1.50	Germ. Rate	Avg. Germ Rate
0	20	4						20.00%	64.80%
1								0.00%	
2	5	11	7	2				100.00%	
3	1	7	13	4				120.00%	
4	4	2	9	8	2			84.00%	
5	3	1	8	8	5			88.00%	
6	2	3	7	9	4			92.00%	
7	0	3	8	10	2	2		100.00%	

Acrospire Length Measurement Chart Over Seven Day Period

seeds were selected randomly, and their acrospires were measured and recorded as shown in the example below.

The grain was then dried at 44 celsius; warm enough to dry it, and low enough to not ruin any enzymatic activity.

Germination

A similar matrix was developed for germination trials: three lengths of time (5, 7, 10 days) and three different temperatures (12.8, 15.6, 18.3 celsius). Malt quality analyses taken from the steeping trials were assessed, and it was determined that the optimal schedule was a 16 hour (two eight hour) steep at 15.6 degrees celsius. Acrospire counts were again conducted for each trial, and a sample from each batch was sent in for a malt quality analysis. An optimal germination schedule was determined based on these data, and kilning trials began.

Kilning

Kiln trials utilized, again, a matrix of times and temperatures. The aim not being optimization of malt quality, but to record change as temperatures climbed and times increased. Had we wanted optimization, 44 celsius would have been enough, because enzymes would not be destroyed and the grain could reach a low enough moisture percentage. Therefore, temperatures were chosen to represent a range of barley malt varieties that have lightly to heavily toasted malt qualities. Acrospire measurements were still taken, and a sample of each batch was sent in for a quality analysis.

40 lb. Malt Batch

To finish the remainder of the grant, around 40lb. of malt was needed. This was done over two malting sessions using 20 lbs. of Kernza each. The grain was analyzed for malt quality, and was used in remaining brewing, steeping, baking, and dough fermentation trials.

Different Varieties and Lots

Given an optimal malting schedule, further testing was carried out with two newer genetic lines of Kernza: one from Kansas, and one from the University of Minnesota. All data was collected the same as mentioned earlier, and samples of each were sent in for analysis. An additional genetic line currently on the market grown in Kansas was malted as well.

Chapter 3: Malting Methodology and Results

The information provided in this chapter makes up the foundation of our research. We made an effort to provide as much data as possible: from observations and insights, to hard data and analyses, with the hope that, at the very least, anyone reading this will gain one piece of knowledge to further their understanding of malting Kernza or any grain, for that matter.

General observations are explained before diving into the malting process itself, where descriptions of variables are provided alongside the methodology. For the conclusion, any insights gained from malt quality analyses and assessments are revealed.

Delicate Acrospires

The malt required constant agitation or “turning” once germination was underway. Failure to do this resulted in clumping. The photo here shows an extreme example of neglect where the grain bed started rooting through the false bottom and adhered to it. When clumping occurs, the individual seeds get starved for oxygen, pressure builds, and over all growth is inhibited.

Excessive Grain Bed Growth
Without Agitation

Though agitation was required, it had to be done in a way so as to not break the delicate acrospires that were growing along the outside of each seed. This is less of an issue when malting barley; its hull is never removed, and the acrospire can grow safely beneath it. Free threshed Kernza kernels have no protection for their acrospires, and are more likely to be damaged and stop germinating if turning is too rough.

Lost Chaff During Steep

The use of a mix of free threshed and hull on seeds resulted in the highest germination rates. However, we did not have a cleaning process that could remove hull-on seeds that were immature and not viable. During the steep phase, as the grain was submerged in water, chaff (hulls, stems, non-kernza biomass, etc.) would float to the surface. This chaff was skimmed off with a strainer. The grain was soaked and skimmed roughly three times before finally going into a full steep schedule. The skimmed chaff was dried and weighed and averaged around 30% of the original batch weight. This is a significant amount, but whether it will have a positive or negative effect on future malting production is unclear: Hulls and chaff can potentially prevent clogging during a sparge. A large and inconsistent amount of chaff, however, will make economics and diastatic predictions a challenge. Additional cleaning methods to isolate hull on kernels or remove immature hull on kernels could likely reduce this issue.

Germinated Kernza with
Its Acrospire

PARAMETERS, METHODOLOGY, AND DESCRIPTIONS

Steep Trials

As briefly mentioned in the methods section above, nine steep trials were planned, each using a different combination of submersion time and water temperature. Short, medium, and long steeps were combined with low, medium, and high temperature steeps, resulting in each possible combination of variables. A “short” steep time in the context of the experiment refers to two eight hour steeps for a total of 16 hours submerged in water. ”Medium” and “long” steeps are 24 and 32 hours of total submersion time respectively. “High temp.” means the grain sample was submerged in 15.6 C water for each of the steeps. “Low” and “med.” temperatures called for 10 and 12.8 degree water.

Data collection during each trial included moisture tests after each steep and air rest, as well as during each day of germination. Acrospire lengths were counted each day of germination, with 25 kernels examined and acrospire lengths measured and tallied accordinly. Lengths were categorized as a ratio of total seed length. This method made it possible to see acrospire growth rates throughout the entire germination process.

Because we wanted to isolate changes in the steep phase of the process, the germination time and temperature were kept constant; the grain had to be malted to completion in order to run a quality analysis on it. The germination parameters for the steep trials were kept at seven days with a temperature of 15.6 degrees celsius.

Germination Trials

Once an optimal steep schedule was determined, it was used for the remainder of experimentation. A similar matrix of parameters was used during germination trials: three lengths of time (three, five and seven days) and three different temperatures (12.8, 15.6, and 18.3 degrees celsius).

Kiln Trials

At this point, a malting schedule for a standard base malt was revealed. A third and final matrix was developed to test various kilning parameters and their effect on final malt quality. To do this, the Kernza was dried below 10% moisture at 44 degrees celsius to ensure no enzymes were reactivated when the temperature was increased. Once below 10%, the grain underwent kilning schedules (prior to this, the grain was dried entirely at 44 C) consisting of, again, three temperatures and three lengths of time. The temperatures were 100, 149, and 177 degrees celsius. These temperatures were chosen to emulate malts used in different styles of beer. Testing higher temperatures would have been preferred, but our Acro malting equipment could not produce a temperature much higher than 177c. Designated lengths of time at each temperature were 1, 2, and 3 hours.

Moisture and acrospire data was collected in the same manner as previous trials, but relevant trends were only revealed post malt quality analysis. More on malt quality data later.

Roasting Trials

Further processing of Kernza beyond Kilning at various temperatures was also explored; this time with an emphasis on flavor analyses. To do this, various samples of base malt were produced and used, each roasted in an oven at different temperatures for thirty minutes. The temperatures used were 300, 350, 400, and 450 degrees fahrenheit with the intention of exploring a wider range of “specialty malt” parallels strictly for the purpose of revealing any common or unique flavor compounds.

Grain Analysis: Pre Malt

Prior to malting, it is important to analyze the grain itself to determine viability to produce acceptable malt results. Though a rudimentary version of this was conducted by us and explained in the previous chapter, the results from that set of experiments were used solely to inform where to begin when it came to malting. We had a separate grain analysis carried out by the Montana State University Malt Quality Lab to give us a little more information. There are a few simple tests that are run to see if seeds in a grain sample will germinate enough, and be resilient enough while submerged in water to malt successfully. Brief descriptions of variables along with results follow:

Germination Energy: GE

The percentage of seeds that germinate in 4 mL of water over a three day period. If the percentage is less than 95%, the seeds may be dormant or dead.

Germination Capacity: GC

Used to determine if seeds that did not germinate in the GE test are dormant or dead. This is conducted immediately after the GE test on any seeds that did not germinate. The seeds are soaked for an additional two days in a dilute hydrogen peroxide solution. The seeds that germinate were dormant, and seeds that never germinate are dead.

Water Sensitivity: WS

A seed's susceptibility to enter into a second dormancy in the presence of too much water. If a grain is very water sensitive, there is a higher probability that a significant amount of the grain will not germinate, even if it is not dormant.
A sample of seeds is submerged for three days in 8 mL of water. Germination is counted in the same manner.
The total germination is then compared between the 4 and 8mL tests. If the 8mL seeds have reduced germination of 30% or more, the seed is considered water sensitive.

Kernza Results vs. Standard Targeted Barley Results:

GE
- Barley: Above 95%
- Kernza: 64%

GC
- Barley: Above 95%
- Kernza: 87%

WS
- Barley: Under 30%
- Kernza: 44%

These initial grain analysis results are very telling. They imply that a significant amount of the Kernza to be used in experimentation is dormant (total germination went from 64% to 87%), dead (if no grains were dead, the GC would be 100%), and sensitive to water (the total germination dropped by 44% after WS testing had been completed). Should these results be seen in a Barley malt sample, the malt would be considered either not ready to, or not ideal to malt. Therefore, an initial caveat has been established and should be taken into account throughout the remainder of this report.

MALT ANALYSIS METHODS & RESULTS

Each sample of malted Kernza was sent in for malt quality assessments carried out by Montana State University's Malt Quality Lab. Below is a list of variables extracted from these tests along with brief descriptions of each.

Moisture Content
Total moisture present in the sample as a percentage of total weight.

Extract: Fine Grind dry basis (FGDB)
A measure of everything that is water soluble contained in the sample. Fine grind extract is a more accurate representation of soluble compounds than coarse extract.

Extract: Coarse Grind dry basis (CGDB)
Similar to fine extract, but the sample is not ground as fine. This extract better represents the extract that would be found in a larger scale or commercial operation.

F/C Difference

Difference between fine and coarse extract

Beta Glucan

Beta glucans represent a large portion of cell walls. Cell walls need to be broken down in order for enzymes to access the compounds they need to act upon (starch). A higher b-glucan level indicates an undermodified seed, and is less desirable.

Soluble Protein

Water soluble non-enzymatic protein that remains in wort when brewing. Some presence is beneficial, but too much can create haze, an unpleasant mouthfeel, and too much foam. Too little soluble protein will leave a beer feeling “watery” with no body.

FAN

Further breakdown of soluble protein into free amino nitrogen. Higher numbers are preferred, because they provide yeast with nutrients during fermentation. We have seen a minimum benchmark of 130mg/L, with 200-250 as an ideal range. This number is usually correlated with soluble protein.

Diastatic Power

An indication of enzyme content (alpha and beta-amylase). A higher DP generally means more starches will be converted to sugar during the mash which will provide more food for the yeast. 115-150 is a good range in barley base malt.

Alpha-amylase

Alpha-amylase. One of two enzymes (the other being beta-amylase) That break down starches into fermentable sugars. A-amylase is able to begin breaking down larger starch chains, making it possible for b-amylase to continue the process until they are at a size (converted into fermentable sugars) where yeast can act on them.

Color

The color of wort measured in SRM.

Filtration time

Used to determine how effectively a mash will drain or “sparge” in a brewhouse setting.

Clarity

Or “turbidity.” Clarity of wort measured in NTU. Haziness increases as NTU goes up.

PH

Acidity of wort.

Malt Analysis Results

In all, data from 29 batches of malt were compiled, though roughly 40 batches were produced from beginning to end. The following is a list and description of graphs that show any relevant data.

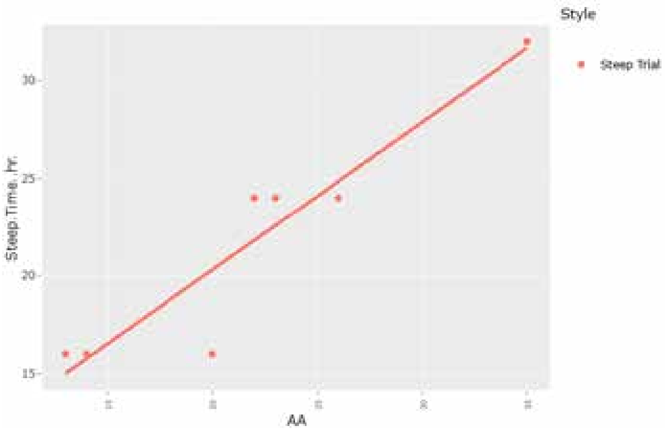
Time/Temperature Effects on Select Variables.

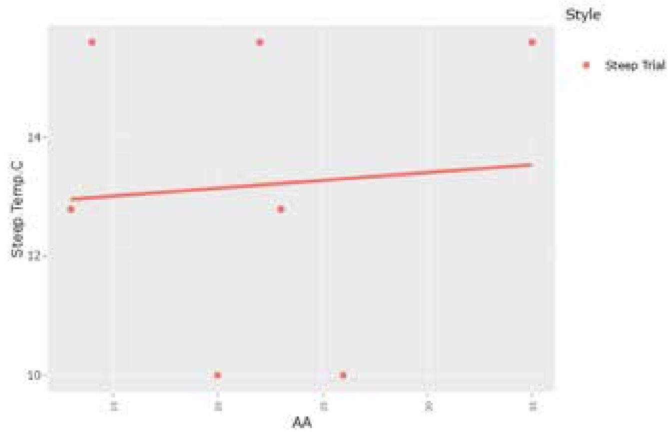
Relevant variables are listed below, and each one is accompanied by four graphs: “Steep Time,” “Steep Temp.,” “Germ. Time,” and “Germ. Temp.” This set of graphs provides a visual comparison aid in extracting significant and less significant trends throughout the malting procedure. Any trends or correlations mentioned are specific to our methodology, and while insight may correlate to other applied malting procedures, we can not say with complete certainty that cause and effect throughout this process completely align. The environment in which malting tests took place spanned multiple seasons making constant ambient temperature, humidity, etc. difficult to maintain constantly. Regardless, many of the trends and notable data points listed below will still be useful to other maltsters using Kernza in their applied setting.

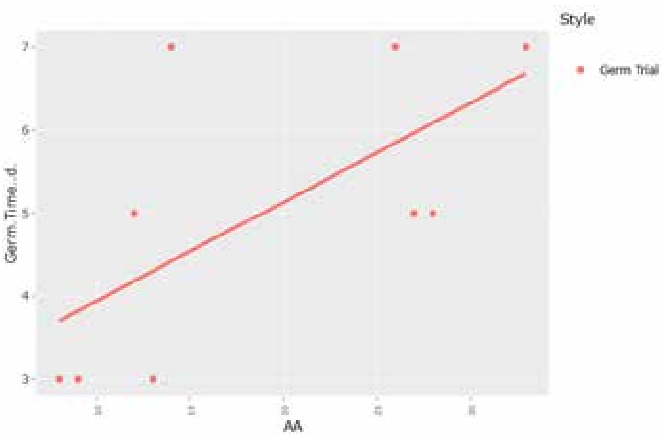
Alpha-Amylase

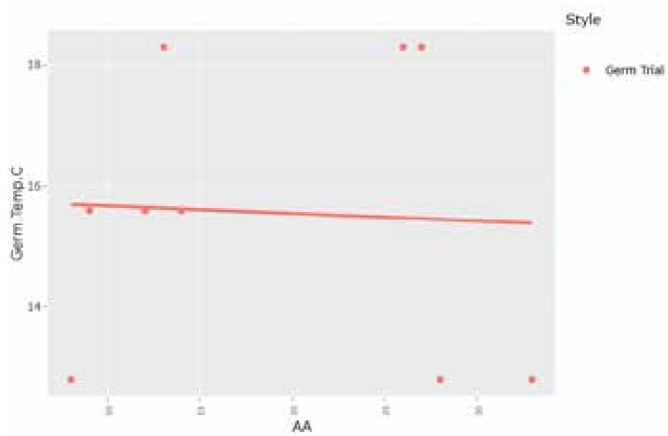
Steep time seems to have drawn the strongest correlation with final AA content. Though one cannot see specific labels (we used malt analysis software that was very useful in an applied format, but not ideal for papers such as this), the temperature within each steep time does increase AA as it goes up as well. The effect is not as profound as total time submerged in a steep, however.

Another interesting point to note in the “Germ. Time vs. AA” graph is how the range of each data point begins to spread out as time increases. This seems to be a theme in our malting process. One possible explanation for this is as germination goes on, respiration, moisture and heat exchange, volume and density of the grain bed all change more and more rapidly making it more difficult to maintain control of the ambient and inner grain-bed environment, producing less concise trends amongst many variables.



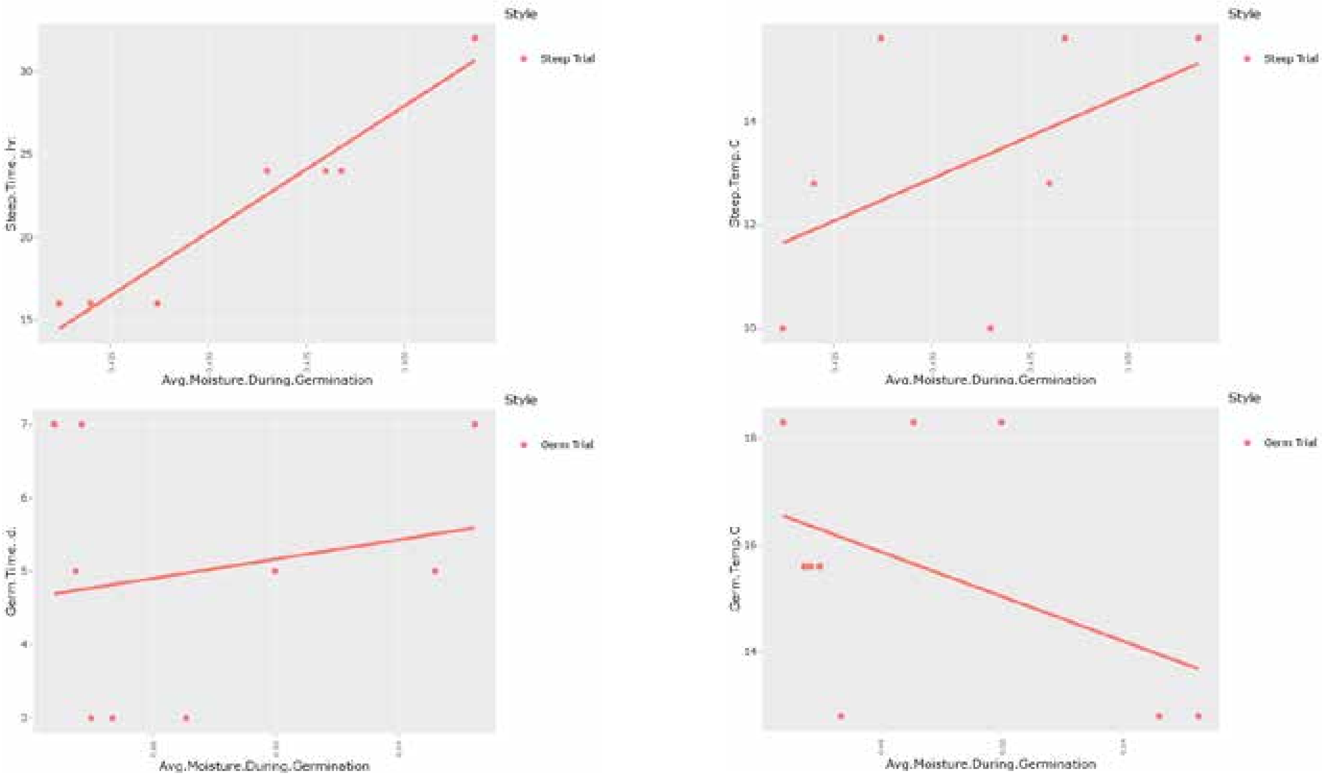






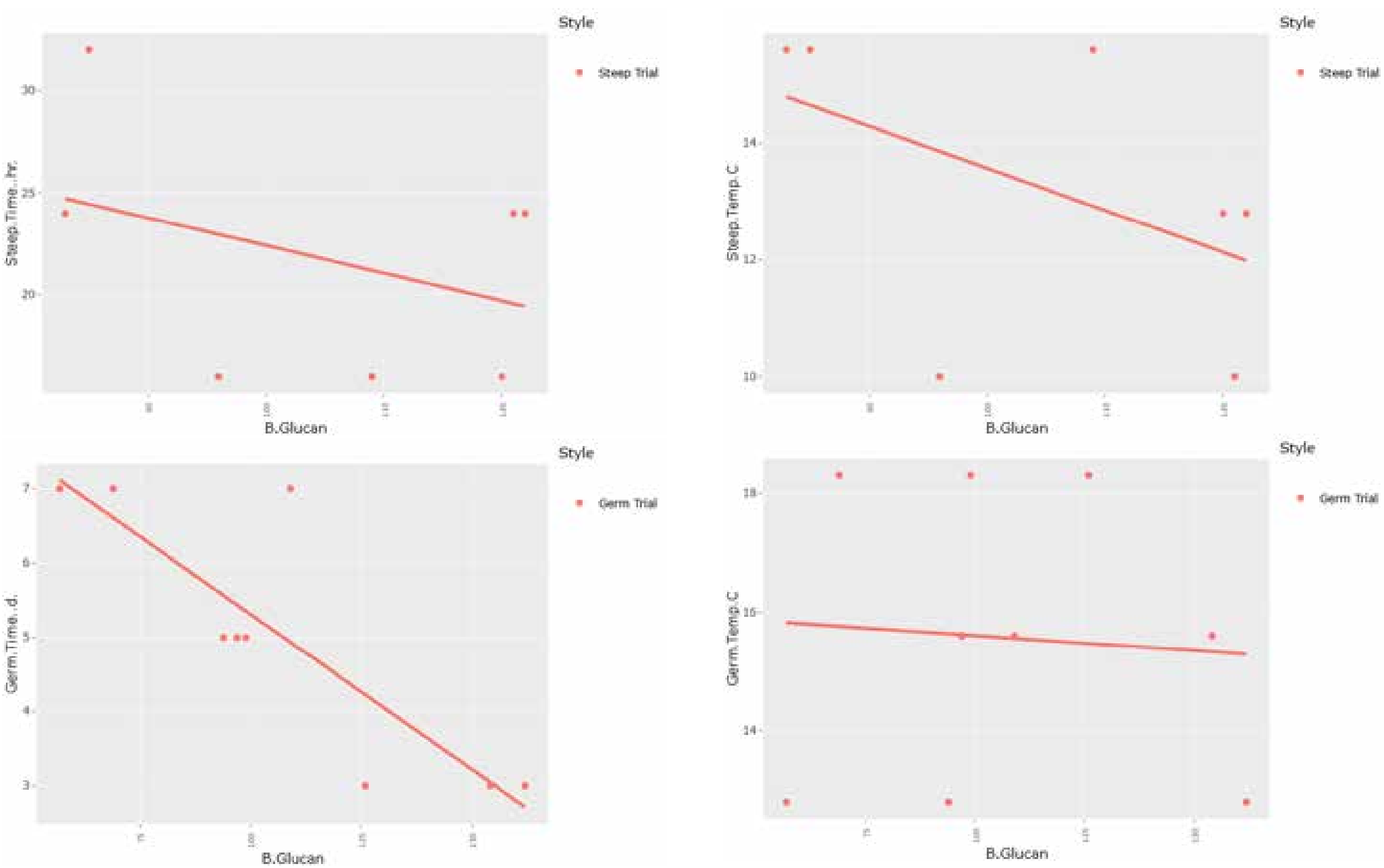
Average Moisture Percentage During Germination

The trends in these four graphs are strikingly similar to the graphs highlighting AA content: Concise correlation with steep time, less impactful but still consistent correlation with steep temperature, and an increasing range in value as the germination time increases. Moisture correlation with germination temperature shows a trend that is technically insignificant, yet still similar to that produced for AA: Germination at 15.6 C produced, on average, the lowest moisture content as well as the lowest AA content. These two variables together potentially show moisture content’s effect on AA as well as other variables upon continued reading.



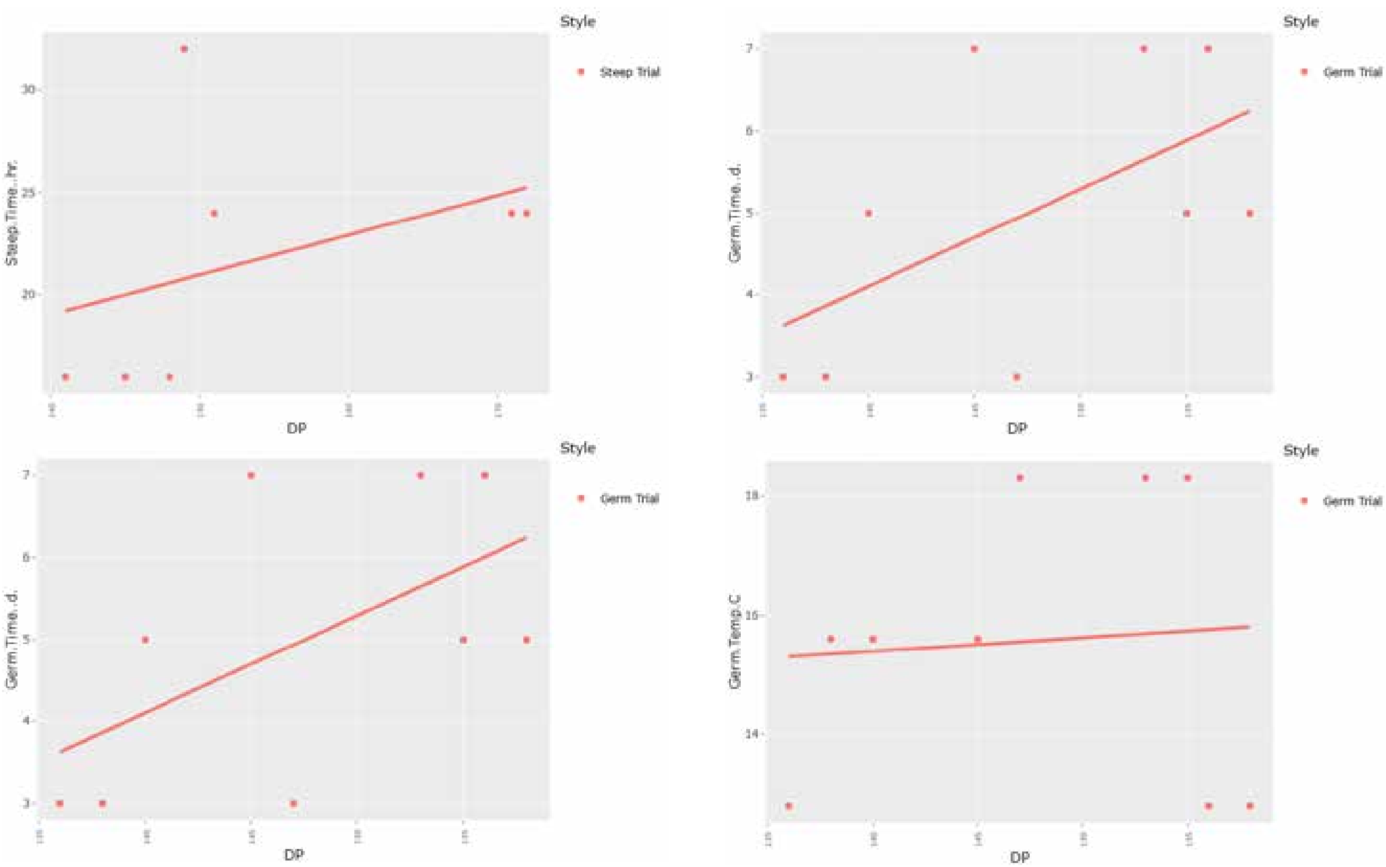
B-Glucan

Trends are less correlative here, but it looks as though time spent in germination has the most significant effect on lowering b-glucan levels. This makes sense, because breakdown of the beta glucan web is one of the first processes that occurs in the cascade of reactions that take place during the growth of a plant. Temperature trends are too inconsistent to draw any conclusions.



Diastatic Power

It is difficult to extract significant trends from these DP focused graphs. We previously thought that diastatic power and a-amylase content would correlate in relation to the same paramters, because a-amylase content makes up a portion of diastatic power. These graphs suggest something different, however. One thing to note is that, aside from a three day germination time, lower temperatures correlated with a higher diastatic power on average. Perhaps there is something to be said about diastatic power being present after a certain number of days, and it being produced more efficiently at lower temperatures versus higher temperatures.

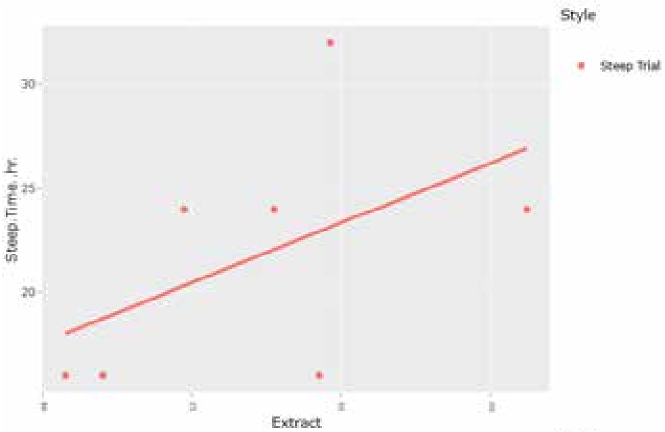


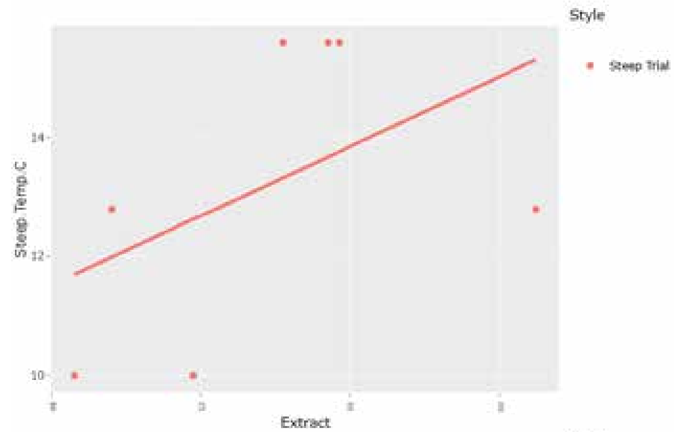
Extract: Coarse Grind dry basis (CGDB)

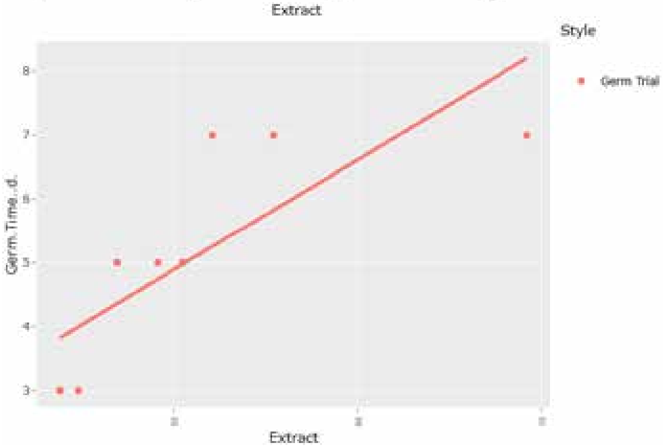
Extract is very important when it comes to malt specs.: A malt could have incredible diastatic power, alpha amylase content, and free amino nitrogen, but if it struggles with extraction, the effectiveness of each of these will be greatly reduced, because they will not be present in the mash and wort.

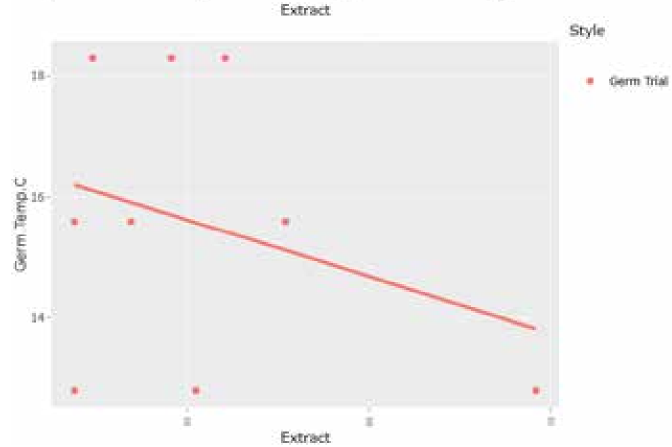
This set of graphs, again, does not produce precise correlations, but it looks like germination time and temperature have a stronger effect on final extract. Looking at the “Germ Time” graph, the most extract produced on average was produced during a 7 day germination. And those three data points, from left to right, correspond with high, medium, and low temperatures. A rough estimate: longer germinations at a lower temperature may facilitate optimal extraction.

There is another relationship amongst these variables that is also worth noting here: malt with decent diastatic power (115-150 in barley - our Kernza malt consistently produced DP over 135 during our steeping and germination trials) but low extract typically means the enzyme content present in each seed is good, but the starch content/ quality is low or poor. This insight aligns with the fact that Kerza seeds are very small in comparison to barley; their ratio of total starch is low.



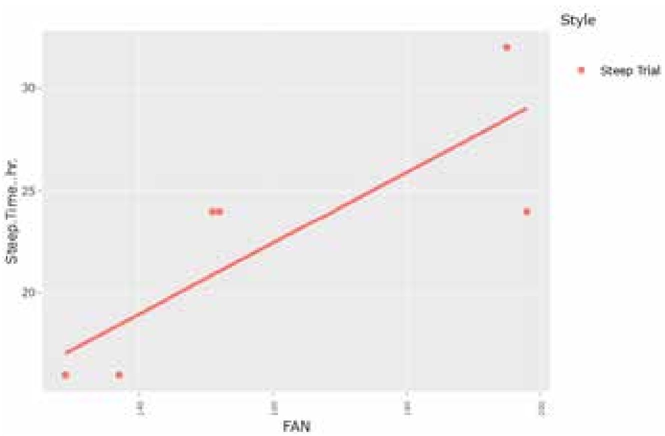


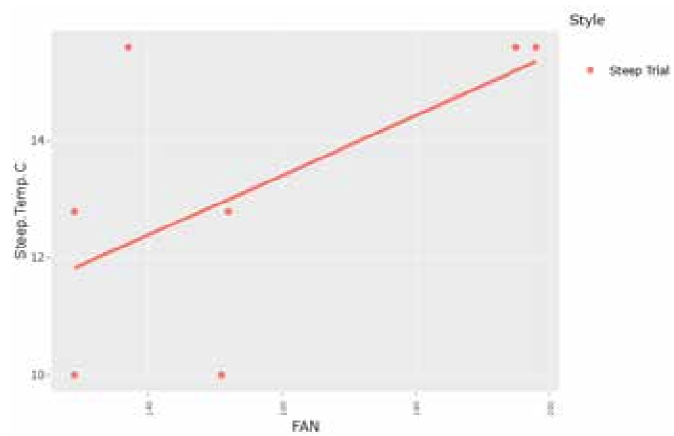


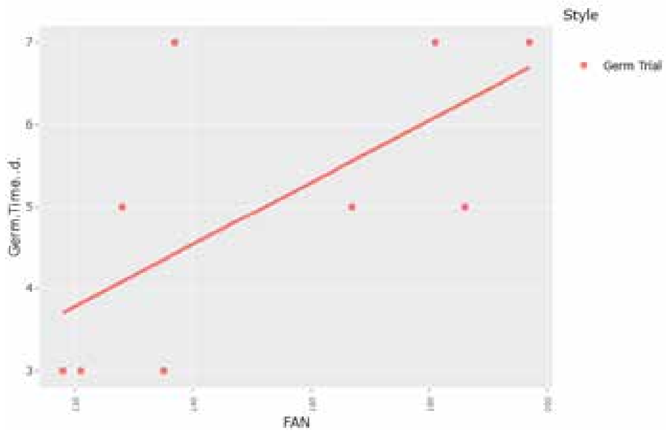


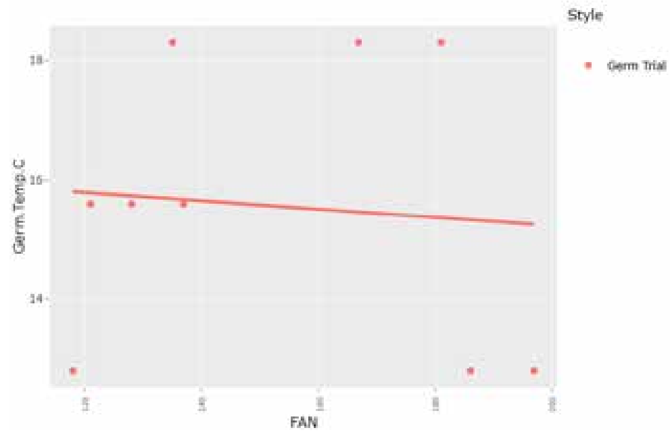
Free Amino Nitrogen (FAN)

FAN seems to lean in favor of both long steep and germination times. Again, there is not enough rigid correlation to state cause and effect, but when one understands free amino nitrogen it makes sense; it becomes more concentrated when soluble protein is broken down further. Because it begins appearing some time after the presence of soluble protein, it could mean that it takes longer to build up a significant amount. Ultimately, higher steep times lead to higher moisture content over germination time, which is what is required for this reaction to take place. Lower temperatures may also help boost the FAN amount.



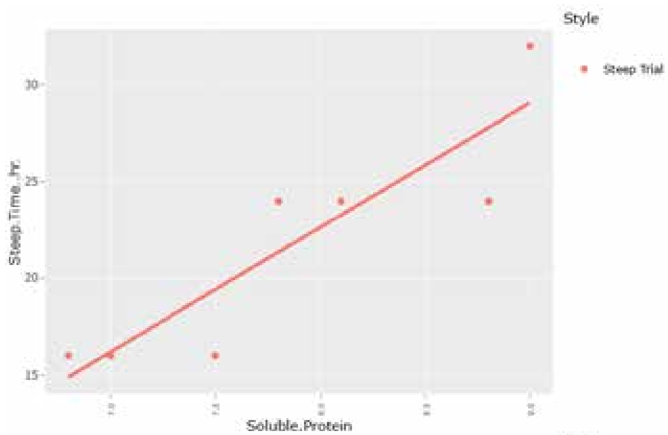


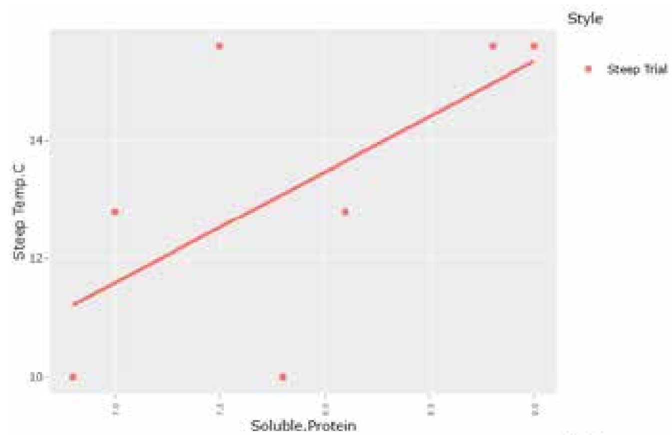


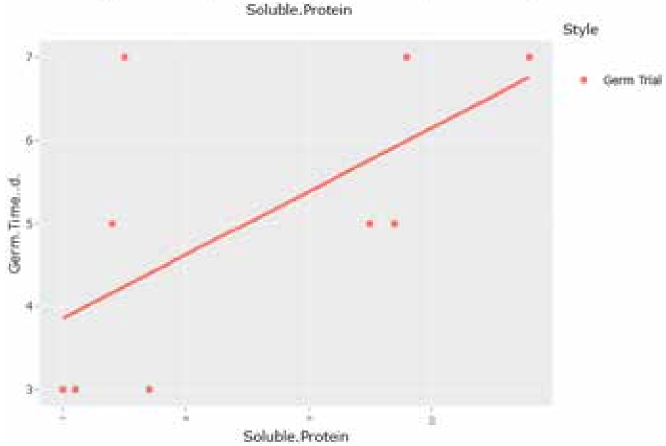


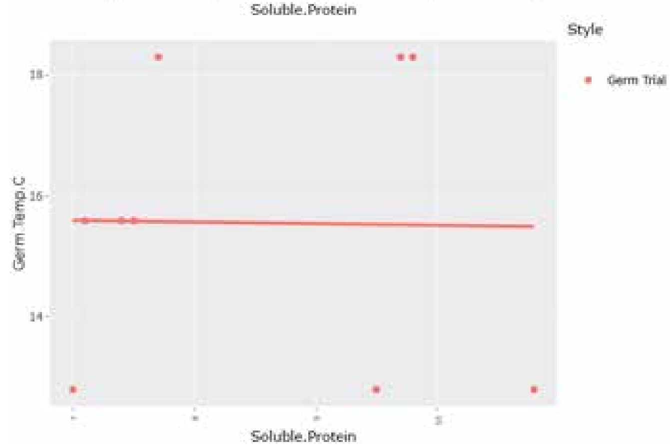
Soluble Protein

Much like AA, soluble protein seems to go up as steep time increases. All four graphs look close to those showing AA trends, for that matter. This is interesting and telling, because a higher AA content is desired, while a high soluble protein is generally not sought after. This depends on the beer, though. Hazy beers usually contain a higher soluble protein content. Most other beer styles call for less.





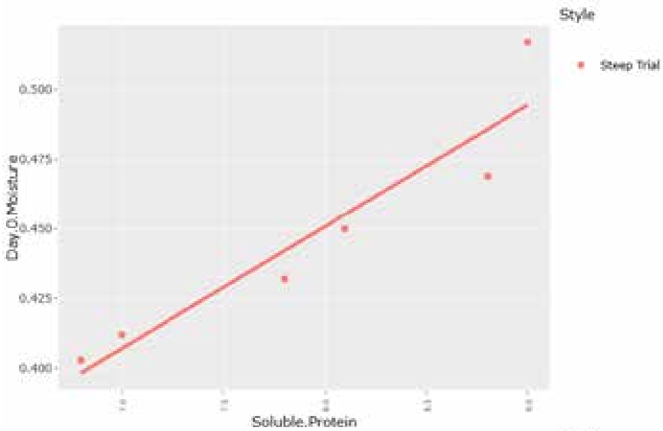


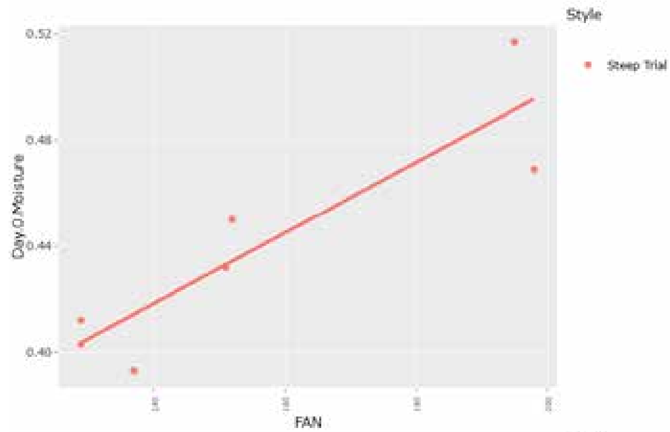


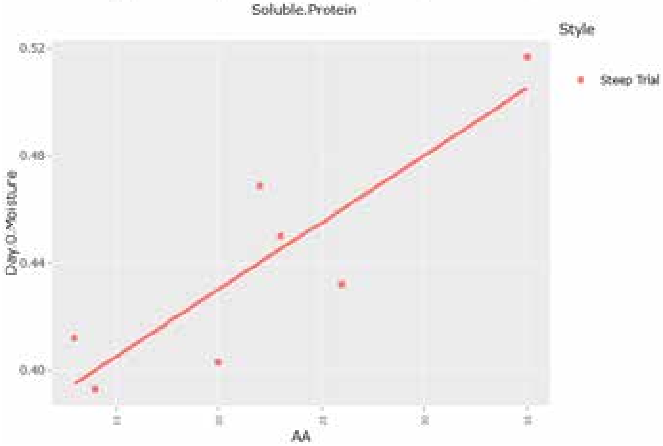
OTHER NOTABLE TRENDS AND INSIGHTS

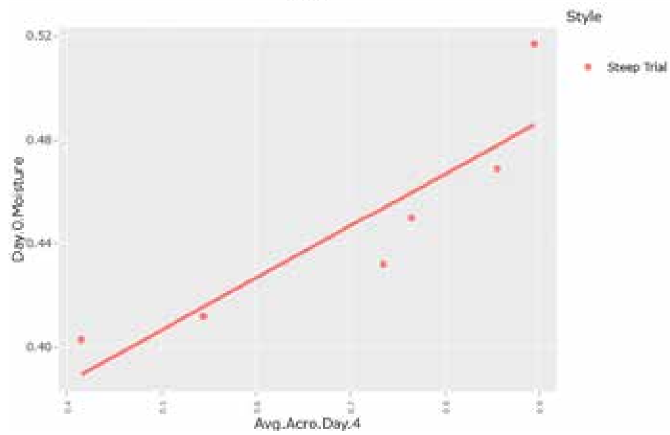
Day 0 Moisture and Acrospire Length: Steep Phase Benchmarks

“Day 0 Moisture” is a number that reflects the moisture percentage immediately after the Kernza malt sample has come out of its last steep. It is the most accurate indication of how much moisture was absorbed during the steep alone without external influence, and as one might expect, the amount of moisture present in this phase correlates directly with total steep time and has major implications for the remainder of the malting schedule. Therefore, much like the “Steep Time/Temp.” graphs shown above, day 0 moisture has a strong correlation with alpha amylase, soluble protein, and free amino nitrogen. An example of this is shown in the graphs here:



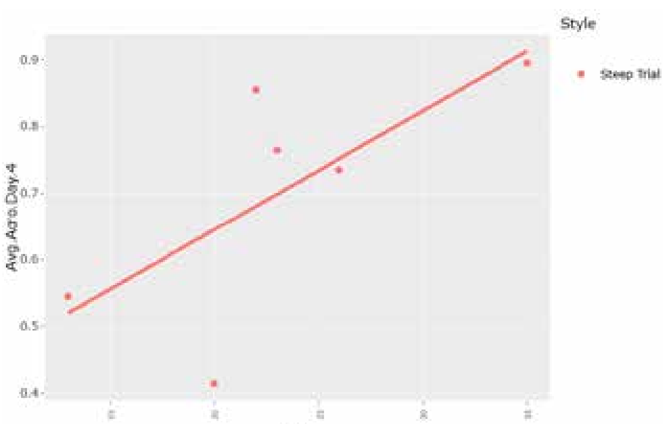


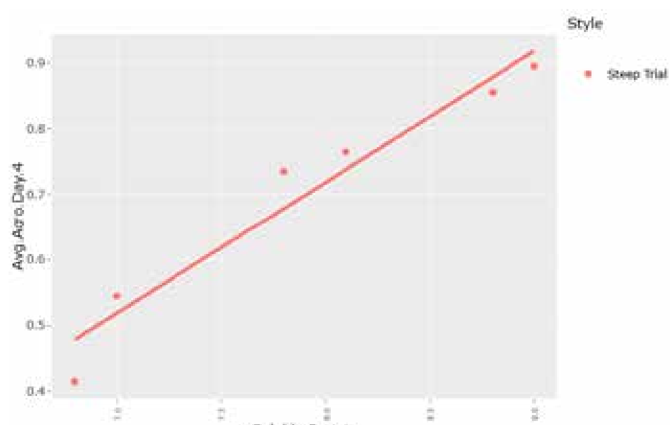


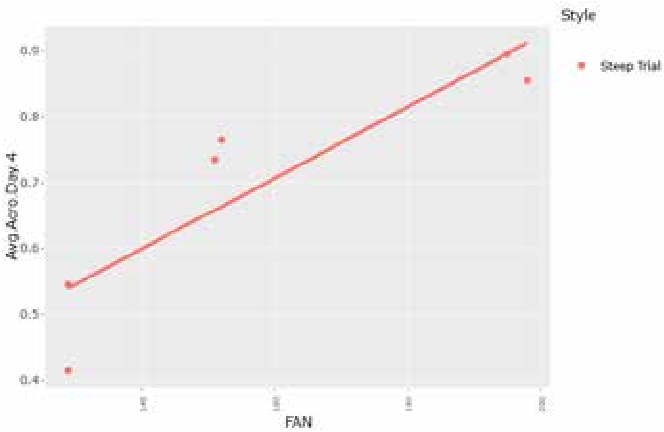


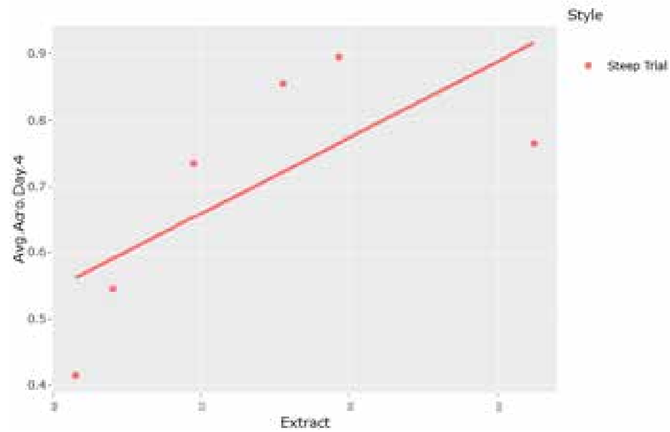
Interestingly enough, the day 0 moisture percentage also shares a strong correlation with the average acrospire length at day 4 of the germination phase throughout the entirety of the steep-centric-trials. This visual is also shown above right in graph form.

Given the connection between the day 0 moisture and the average length of acrospires in a representative sample on the fourth day of malting, it is possible that one may use these two parameters in tandem as somewhat of a check-and-balance system when malting Kernza. This may be a stretch, but the purpose of this notion is to merely provide a step in the direction of viable Kerza malt quality. Variables with a strong correlation to the acrospire length on day 4 are shown here:









Ideally, the length on any given day may be an indication of overall malt modification, but our specific data sets show consistency in regards to the length of the acrospire primarily on the fourth day. We are wondering if this specific time after germination has begun is significant outside of a malting setting; does this mark the transition from rapid initial growth to slower, consistent growth as the cycle progresses?

Ultimately, a thought experiment was entertained to see if we could determine "optimals" for the day 0 moisture and its corresponding acrospire length. The process was straightforward: What are the optimal numbers to shoot for in regards to major malt variables (AA, DP, sol. protein, FAN, and CGDB); What are the day 0 moisture and acrospire day 4 lengths of each of these optimals, and finally; What is the average between all of them.

The conclusion: If one aims for a moisture content of 46% by the end of the steep, and sees an average acrospire length roughly 76% as long as the seed itself, the malt quality, in an ideal setting, will look something like the list shown below. Please keep in mind that the four graphs shown above and the data used to come to this conclusion were all taken from the steep trial data. This means that as the steeping parameters changed, the germination parameters were consistent, making the correlations shown very valuable in regards to steeps effect on a consistent germination schedule

Total steep time: 24 hours
Steep Temp.: 13.8 C
Germination Time (Implied): 7 Days
Germination Temp (Implied): 15.6 C
AA: 26.3 D.U.
DP: 165.5 L
Sol. protein: 8.2 %
FAN: 170 mg/L
CGDB: 56 %

The schedule and extrapolated data show a potential malt sample with acceptable numbers. Consistent with most other tests, the alpha-amylase content is a little low, and the soluble protein is a little high, but on average, this malt would be usable in many recipes. We did not get a chance to test this concept, but perhaps the process to arrive at these numbers may be of benefit.

Optimizing Malt Schedule for Desired Quality

The graphs above provide a good example of the "give-and-take" of malting. When one trait is desired, odds are high that it will retract from a separate desired trait, or two traits may correlate positively when an inverse correlation is desired: alpha-amylase content and soluble protein, for example. The relationship between these two specific variables in Kernza may remain this way for years, because the raw grain itself contains very high amounts of protein and a small ratio of starch. Therefore, a maltster may end up deciding to target one specific variable at a time, regardless of a potential increase in less desirable ones. In considering this notion in malting, it became clear to us that "variable-specific" malting schedules might benefit someone reading this report, so we decided to compile the schedules containing the optimal numbers for six malt quality variables. Insights and a brief discussion follow the chart shown next.

Optimal Schedules per Parameter						
Isolated Parameter	Total Steep Time	Steep Temp.	Day 0 Moisture	Germination Time	Germination Temp.	Avg Acro Length Day 4
a-Amylase (35 D.U.)	32 hr.	15.6 C	51.70%	7 Day	15.6 C	89.5%
CGDB (69.2 %) & b-Glucan (57 mg/l)	16 hr.	15.6 C	45.50%	7 Day	12.8 C	78.5%
Diastatic Power (172 ° L)	24 hr.	12.8 C	45%	7 Day	15.6 C	76.5%
FAN (198 mg/l)	24 hr.	15.6 C	46.90%	7 Day	15.6 C	85.5%
Soluble Protein (6.8%)	16 hr.	10.0 C	40.30%	7 Day	15.6 C	41.5%

Using this template as a general guide, one could infer a shorter steep time at a low temperature may help mitigate the high protein content. If squeezing out as many enzymes as possible is the goal, longer, warmer steep times may be required.

Some interesting points to note when looking at this chart are the germination times and temps; a seven day germination time is consistent across each targeted parameter. The temperatures are also lower than the highest germination temperature tested. The “day 0 moisture” and “average day 4 acrospire length” were also added in to further test any correlative viability. It looks as though the “general optimization schedule” above fits nicely into many of these parameter specific schedules.

Final Malting Schedule

We needed to decide on one malting schedule before carrying out the remainder of the grant research. It was difficult to decide on the most significant parameter to target, but we eventually decided extract optimization would be the focus, because, when it comes to brewing, great malt quality can be rendered ineffective if only a small portion of it is present in the wort. The schedule is shown in the table above with “CGDB & b-Glucan” being the isolated variables: short steep, high temp., and a low temperature seven day germination. The full malt quality chart is shown here:

Analysis	AA (D.U.)	B-Glucan (mg/L)	DP (°L)	CGDB Extract (%)	FAN (mg/L)	Sol. Protein (%)	Day 0 Moisture (%)	Avg Acro Day 4 (%)
Final Schedule	33	57	156	69.2	197	10.8	45.51%	78.5%

The data from this batch of malt shows acceptable malt quality: The alpha amylase content is above 30 D.U.; The diastatic power is over 150: the high end of the targeted range for barley; And the free amino nitrogen concentration is well above the minimum benchmark of 130 mg/L. Limiting factors in this chart are soluble protein, and the extract itself. Though 69.2% extract was the highest we achieved, it is still quite far from optimal when it comes to base malts. Again, the insight on this was briefly mentioned above; high DP and low extract is typically an indicator of good quality enzymes and a poor starch composition, be it quality or quantity. There is little doubt here that Kernza’s average size is yet again, significantly impacting useability.

Genetic Line Comparisons

We were fortunate enough to receive some Kernza samples containing the newest genetic lines from the U of Minnesota and The Land Institute. These lines are each institution's most promising, and they have yet to hit the public domain. In general, these seeds are longer and wider than what is currently available at the moment. Seed size has and will come up a lot in this paper, as it is a major hurdle that is being tirelessly worked on in order to improve Kernza's utility in any setting. It was great to see this progress first hand. We malted the samples with the intention to compare the malt quality of each to that of "our malting schedule" malt shown above. We also had a

Batch #	AA (D.U.)	B-Glucan (mg/L)	DP (°L)	CGDB Extract (%)	FAN (mg/L)	Sol. Protein (%)	Day 0 Moisture (%)	Avg Acro Day 4 (%)
Final Schedule	33	57	156	69.2	197	10.8	45.51%	0.785
TLI New Gen	30	129	115	62.0	163	5.26%	N/A	N/A
MN New Gen	21	126	123	57.1	116	4.82%	43.72%	0.385
Kansas C5	30	146	125	58.3	138	4.85%	41.05	0.510

sample of the "Kansas C5" genetic line available to malt. This line, like MN-Clearwater, is available commercially. The results are listed here:

Aside from soluble protein, each parameter shifted in a less desirable direction. This does not discount the new genetic line's viability, however. One possible explanation as to why this parameter shift occurred has to do with moisture. The moisture content shown where available is lower than that of our ideal malting schedule's benchmark. There could be a number of reasons as to why this is, but a lower moisture content after steeping could have a greater effect on the remaining schedule if the seed is significantly bigger. Larger seeds may require a greater amount of additional moisture to ensure there is enough to efficiently carry out the entire malting process without getting too low. The fact that the average acrospire length on the fourth day of malting is significantly lower than that of our malting schedule even though the day zero moisture was relatively close could be evidence for this explanation.

The malt quality results of these final samples are intriguing: They indicate an opportunity to refine the procedures of this grant and carry them out again on the newer genetic variations of Kernza.

Final Conclusions on Malting:

Kernza has the ability to produce viable malt: one that can contribute to fermentation and provide nutrients to yeast as the brewing process is carried out. It does not need to remain an adjunct ingredient, and it will no doubt become more useful as breeding continues. This is a very significant finding given that the grain we were using was very water sensitive and produced sub optimal germination rates with dormant and dead seeds present.

Though we were able to produce a quality base malt, the process as a whole was tricky; many trends were hard to isolate. The variability in ambient temperature and humidity contributed to this difficulty. During the summer, the much warmer climate made it challenging to keep the grain bed at a low temperature during germination, and in the winter, there were instances where the grain bed could not be heated adequately. The air was much drier in the winter as well, which could have contributed to some of the fluctuations in moisture content. Along with environmental inconsistencies, the Acro machine itself presented another likely source of malt variability. For example, we went through a few versions of fogging setups in the attempt to maintain high humidity. Finally, our general availability when it came to physically handling each sample contributed to some variations, as we were not always able to be present during specific events in the malt's schedule.

With all of this taken into account, there are a few insights worth mentioning other than the fact that Kernza has the ability to malt successfully with acceptable quality. Mitigating the soluble protein content is a challenge. Raw Kernza itself is made up of about 17% protein, so right away it is obvious that protein is a hurdle. However, there are brewing methods to reduce protein content such as whirlfloc tablets that break soluble proteins out of solution and coagulate them, filtering the wort. We also saw correlations between protein content and alpha-amylase content. We considered this a problem, because we were continually attempting to boost alpha amylase while minimizing the soluble protein percentage. Perhaps with more brewing knowledge, this may not have been an issue worth emphasizing. Though alpha-amylase content struggled to exceed 30 D.U. throughout testing, the diastatic power consistently breached 130 degrees Lintner. This phenomenon has not been researched extensively by us, but we do know that beta-amylase (the other enzymatic contributor to diastatic power) is synthesized by the seed during grain development, whereas alpha-amylase is synthesized during germination. This could mean that the Kernza seed used throughout this grant was mature: already containing high levels of beta-amylase, while the synthesis of alpha-amylase during germination was a struggle. The relationship between these enzymes and diastatic power is significant, because, in theory, if there is an adequate supplementation of alpha-amylase (perhaps from barley base malt) Kernza's beta-amylase content will then contribute a very large amount of starch degradation into sugars.

Should Kernza malting proceed via other maltsters in an applied setting, it would be interesting to see a wider range of steep/germination times and temperatures. A controlled environment would be nice as well, but this is a rare commodity when it comes to malting and brewing. Honing in on this testing process and witnessing the same tests conducted on newer generations of malt should produce more consistent results and boost Kernza's malt quality to a point where it may be plausible to use it on a large scale with very little or no barley malt necessary to produce beer.

Chapter 4: Kernza Malt Flavor Analysis

To provide a bigger picture of Kernza malt applied in a brewing setting, three flavor analyses were conducted each consisting of a unique combination of malt roasted to specific temperatures. Though it is difficult to find legitimate flavor correlations between malt tea and the beer it ends up becoming, performing analyses on malt is a useful tool brewers use to ensure their progress is on the right track: It can reveal any off flavors that come about either from mistakes in the process or from low quality grain. The color of the malt also helps to determine the approximate final color of the beer. Between all three sessions, roughly 100 individuals provided us with data and feedback.

Malt Tea Methodology

Our malt teas were prepared in accordance with the ASBC Hot Steep method of producing teas from malt. An overview of the process follows:

1. Grind 52g of malt in an electric grinder for 10 seconds or until coarse flour consistency is achieved.
2. Add 50g of malt flour to a thermos
3. Pour 400ml of 65 C distilled water into thermos.
4. Cap and vigorously shake contents for 20 seconds.
5. Let sit for 15 minutes.
6. Shake again, and pour mash contents over a paper filter resting on a containment vessel.
7. Use collected wort for testing.

Kernza Fest and Prairie Fest Analysis Overview

We sampled malt teas with broad audiences at two events, Prairie Fest and Kernza Fest. We used Draught Lab's "Base Malt Flavor Map" as a template for testers in determining any flavor and aroma compounds present. Specific compounds were listed on a sheet, and testers would sample the wort making a tally for each compound they tasted or smelled. There was also a box where any additional notes could be recorded.

Prairie/Kernza Fest Sensory Analysis Results

The top five flavor compounds are listed here. They are in order of highest to lowest frequency. It should be noted that more than five compounds for each malt tea sample had at least one tally in them, but the top five for each were significantly higher than the remaining compounds that received anywhere from one to 4 tallies.

Kernza Fest: Kernza base malt: Grassy, bready, nutty, earthy, vegetal

Prairie Fest: Kernza base malt: Earthy, grainy, grassy, vegetal, nutty

Prairie Fest: 300F malt: Nutty, grainy, sweet aromatic, earthy, grassy

Prairie Fest: 400F malt: Nutty, smoky, earthy, woody, grainy

One important data point to note is no off-flavor compounds were listed in the top five of any malt tea sample. Though some were present, they were not overpowering when compared to favorable compounds. This provides a good indication of general viability of Kernza base malt strictly in relation to flavor.

The two base malts show four of five compounds being similar. Therefore, a good early description of a Kernza base malt is earthy, grassy, nutty, and vegetal. A few other interesting descriptors conjured up by the testers themselves include walnut, pasta water, squash, and maple syrup, which was written down separately by different testers in each location, suggesting maple syrup could be included in the top flavor compound descriptors.

The 300 and 400F malt samples begin to reveal flavor trends as roasting temperature goes up: more volatile fresh, grassy, living compounds, toward nutty, smoky, less volatile compounds. Again, very few unwanted flavors. Notable additions from testers include green tea, chocolate, toasted rice for 300F and caramel, tea, coffee, black pepper, graham cracker, toasted sesame oil, and even “old cigarettes” for the 400F sample.

Worts From Left to Right: Barley Base, Kernza Base, Kernza 300F, Kernza 350F, Kernza 400F, Kernza 450F

In House Analysis Overview

Our final malt analysis was conducted at Perennial Pantry. Colleagues at the University of MN as well as chefs from the twin cities area attended. Testers were asked to write a number from 1 to 5 based on how potent or detectable they felt each flavor compound was in the malt tea. The average was then taken from each box and recorded in a data sheet. Taking the average potency gives a much more precise example of what to expect in each malt style. In the other tests we performed without potency measured, a higher number of tallies may dubiously suggest higher potency, but it simply shows presence alone.

An overall preference for each malt sample was also included in this analyses; each tester ranked their preferred malt tea from 1 to 6. 1 being the most preferred and 6 being the least.

In House Sensory Analysis Results

Shown here is a list of the five most forward flavors for each malt. Ties in averages are lumped together with slash marks.

Barley base malt: Grainy, bready, grassy, sweet aromatic, floral

Kernza base malt: Grainy, bready, grassy, nutty, woody

Kernza 300F malt: Grainy, nutty, grassy, earthy/sweet aromatic/woody, bready

Kernza 350F malt: Nutty, grainy, grassy/sweet aromatic/vegetal, bready, earthy/smoky

Kernza 400F malt: Smoky, earthy, medicinal/sweet aromatic, grainy/nutty, woody

Kernza 450F malt: Medicinal, smoky, stale, woody, earthy

The results from this abbreviated list of flavor compounds reveal a few trends. The barley and Kernza base malts look very similar, and also show Kernza’s flavor profile veering in the nutty and woody direction. This is very telling and could provide a base malt with a profile more preferred to specific styles of beer.

Similar to the previous tea analyses, these nutty, woody, smoky flavors become more potent as roasting temperatures increase. Once 400F is reached, some off flavors start appearing, shown here as “medicinal.” These generally represent errors in processing, in this case, burning. Some professional brewers may find this profile useful, however. An overall preference for each malt sample was also included in the final analyses; each tester ranked their preferred malt tea from 1 to 6. 1 being the most preferred and 6 being the least. After the testers ranked the six teas, an average was produced, and from this overall preference was revealed. Here is the order from most to least preferred along with the averages of each:

1. 300F (1.22)
2. 350F (2.22)
3. Kernza base malt (3.00)
4. Barley base malt (3.77)
5. 400F (5.33)
6. 450F (5.44)

From this data table and discussions with the testers, 300F seemed to be an overwhelming favorite. Some testers that have worked with Kernza before mentioned it brought out the flavors they associate with Kernza the most. Additionally, though it was not recorded, we received a similar response from the Prairie Fest analysis group: testers loved the 300F Kernza malt sample. This is a great finding in the utilization of Kernza malt. Though diastatic power may be lower than that of the base malt, the flavor preference is high, which means this may be a good place to start if one is exploring Kernza malt in brewing for the first time.

Sensory Analysis Test Site

Chapter 5: Brewing with Kernza

Malt quality analyses are incredibly useful in revealing any Kernza malting trends. They help paint a picture of what one can expect in taking a grain all the way from raw seed to beer production. Correlations between malted barley data and its effect on a finished beer are well established, but they do not necessarily correlate with Kernza malt data simply because it is a different grain. For example, an ideal soluble protein content for barley may not work with Kernza. Therefore, fermentation of Kernza malt into beer is necessary.

Existing Kernza Use in Industry

At the start of this experiment, the vast majority of commercially produced beers containing Kernza utilized the raw grain (possibly toasted to some extent) as an adjunct at a very low percentage strictly to add a unique flavor. The Kernza itself contributed no enzymatic capacity. These beers use Kernza from 1%-15% on average. They have been a convenient use of Kernza, as the grain doesn't need to be as clean for brewing, and they don't negatively impact the beer. However, these are lower inclusion rates that don't highlight Kernza's flavor, and don't utilize Kernza's unique traits.

Kernza Brewing Milling Standards and Modifications for Malt

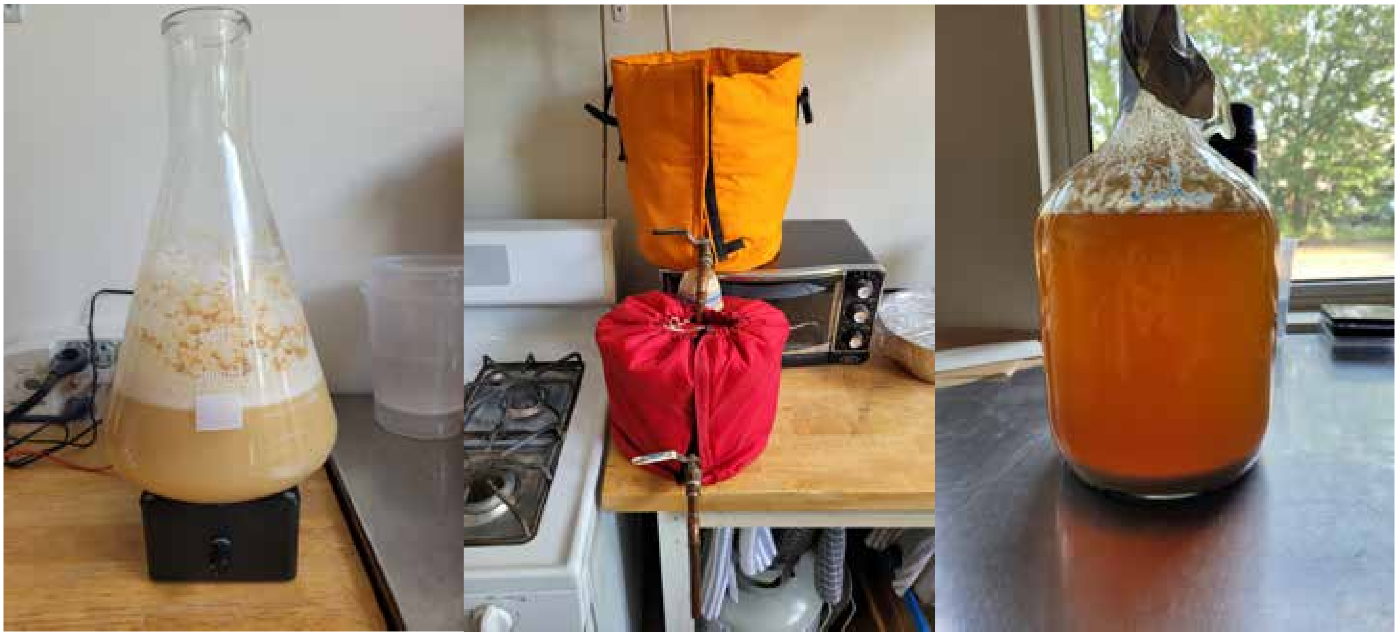
During the start of brewing trials, a few larger breweries reached out to us inquiring about Kernza malt. We sent out a few samples, and, after some feedback, realized that regardless of malt quality, a major issue in using Kernza at a large scale, once again, was its seed size. Barley is roughly three times larger and much more plump. This allows it to maintain a large particle size when milled before being used in a mash. The large particle size (along with the presence of hulls) prevents clogging and promotes efficient drainage. When Kernza is coarsely milled, its particle size is significantly smaller than milled barley. It was brought to our attention that this could pose a major issue during the sparge step of the brewing process. Additionally, many commercial malt mills cannot grind seeds as small as Kernza, with seeds passing untouched through rollers. If brewers cannot grind malt, there is no way to expose the enzymes contained within a seed to the mash water, thus rendering them ineffective. This hurdle was not an issue at the scale of our experiment, but if Kernza malt is to penetrate commercial brewing, it will need to be addressed.

Another issue with malted Kernza at any scale is its variability. The grain itself has not yet had a chance to be fully standardized during growing and harvest which creates inconsistencies in its composition. This means any batch malted with the same schedule could produce different results in the malt quality, which will eventually lead to an issue in producing a consistent end product.

We experimented with brewery roller mills and stone mills to develop a method for milling Kernza for brewing. Brewery roller mills were inadequate, and left many kernels untouched. Stone mills quickly turned Kernza to flour, which was too fine a particle size for brewers. We settled on a coarsely milled method using a stone mill to maximize larger particle sizes and increase ease of brewing.

Additionally, we've found brewer partners have had good success using Kernza hulls from the cleaning process as a replacement for rice hulls while brewing with Kernza. The extra hulls prevent stuck sparges from happening, and increase utilization of Kernza.

Our brewing experiments consisted of five unique trials. Each sample contained different inclusion percentages of Kernza base malt combined with barley base malt: Control (100% barley), 25%, 50%, 75%, and 100% Kernza base malt. Pseudo Helles Lager was the style of beer chosen, because it is a light malt-forward beer that can ferment quickly at higher temperatures. It is called Pseudo Lager, because ale yeast, rather than lager yeast, is used while mimicking the flavor of a lager without the long, low temperature fermentation required of most lagers. Omega Lutra Kviek yeast was used with Perle hops. One gallon of each beer was produced at a time, and it was a relatively simple process.



Brewing Process Photos

Beer specs:
Control (100% barley malt)
OG: 1.030
FG: 1.004

25% Kernza malt
OG: 1.038
FG: 1.006

50% Kernza malt
OG: 1.034
FG: N/A

75% Kernza malt
OG: 1.034
FG: N/A

100% Kernza malt
OG:1.029
FG: 1.006

Though the beers we produced did not have a very high ABV, it is difficult to determine to what extent this was due to Kernza malt versus our capability as brewers (we are not). That being said, beer was successfully produced in each trial, suggesting that Kernza has the potential to be used as a viable malt that will contribute some enzymatic function to the mash. As breeding progresses, its usefulness in brewing will increase.

Physical Attributes

Each of the five beers were very light in body and color, and this was to be expected given the style of beer we aimed for. As more Kernza was added, the color did get slightly darker. Where barley’s color was close to one, 75% seemed to approach 4 on the SRM scale. This is consistent with malt tea testing; Kernza generally has darker pigmentation than barley. Not only is the seed itself darker in color, but there is a higher ratio of the darker bran in relation to starch where the starch contributes the most weight to a barley seed.

Color Comparisons

Sensory Analysis Results

A beer sensory analysis was conducted with students from the University of Minnesota's Food Science Club. Using Draught Lab's "Beer Flavor Map," they were asked to smell and taste each beer and list three aromas and/or flavors they detected within the aroma and taste sections of the map. They were also given the option to record any additional descriptive notes. The top flavor compounds detected in each beer are listed below, along with a few additional notes.

Control (100% barley):

Fruity, sweet, strawberry, grainy

Addtl. Notes: Watery, minerality, bland, very light

25% Kernza Malt:

Sour milk, sweet caramel, barnyard, fruity

Addtl. Notes: Funk, metallic, musty, sharper flavor on tongue compared to control, don't really like, slightly skunky, didn't love

50% Kernza Malt:

Earthy, sweet, stale

Addtl. Notes: smells sour, dirt, more watery than control, not a fan, watery, stale

75% Kernza Malt:

Solvent, rotten, chemical

Addtl. Notes: Bad, sulfuric, tastes like soap or paint thinner, not for me kinda (no thank), not great, resin

Draught Lab’s Flavor Map

100% Kernza Malt:

Cereal, solvent, fruity

Addtl. Notes: smells like rotten milk, very light, I like the body and taste, neutrogena soap, smooth mouthfeel, tea, more viscous than others

None of the beers were very well liked. It can be assumed that this is somewhat due to the error of the brewer, who was a novice. It is also possible that the beer was not consumed soon enough after bottling, and it had started to oxidize. A lot of the aromas and flavors picked up are generally seen as signs of this. It should also be noted that the 75% sample was the most disliked. This is very telling, because an aluminum mash pot was used for this brew day. Some brief research has shown that using this material in brewing or cooking can produce off flavors. Generally stainless steel is used.

Though these brewing tests produced subpar beers, they suggest that given more experience, slightly better equipment, and perhaps a different recipe, brewing with Kernza malt is a worthwhile pursuit.

Additional brewing

Towards the end of the grant, we had a surplus of Kernza base malt, so it was decided that additional brew sessions would be useful. This time, with the help of our friend, Henry Yandrasits we upped the batch size to 7.25 gallons and used an entirely different recipe. The grain bill ended up being 5 pounds Maris Otter 2 row barley base

Kernza and Barley Grain Bill

7 Gallons of Kernza Beer

malt, 4 pounds Kernza base malt, 1 pound Kernza roasted at 350F for 30 minutes, and 0.5 pounds black Kernza malt which was roasted at 400F for 60 minutes. Ultimately, Kernza made up about 52% of the entire bill.

The beer turned out much better than the original trials: no off flavors, and a much more complex flavor profile. The fermentation was still lacking however; with an original gravity of 1.044 and a final gravity of 1.018, the final ABV was around 3.4%. It should be noted that two row barley was used. This generally has less enzyme capacity than a 6 row barley base malt. Further testing will take this into consideration. The main takeaway from this, however, is that after just two recipe iterations, end quality increased significantly.

Chapter 6: Milling and Sifting

Malt is not only used in beer production, it is also used extensively in culinary settings. Bakers frequently use malted barley powder to boost or standardize fermentation, add flavor, and alter the color of their products. Malted milk powder is also a staple ingredient in many products from malted milk balls to malted milk shakes. After developing malting schedules that resulted in a malted Kernza with utility, we explored the applications of malted Kernza in culinary settings.

With the goal of maximizing Kernza use in order to increase demand for the grain and impact of the cropping system, we developed several Kernza flours to analyze and compare the impact of malted Kernza powder. These included whole grain Kernza flour, sifted Kernza flour, and blends of Kernza and wheat to mimic the use of all purpose, whole wheat, and pastry flours.

This chapter covers all preparations necessary to explore a broad scope of applications in culinary settings. We started by developing standard practices for milling and sifting Kernza. Precisely adjusting milling and sifting parameters begins to reveal trends in how each component of Kernza flour affects a given culinary process. Optimizing processing parameters benefited the development of flour blends. For example, coarsely milled Kernza flour and finely milled Kernza flour each blended with the same wheat flour at the same percentage, will show a different outcome in the final product. The particle size and composition need to be similar amongst all samples in order to get more accurate results when applying testing to flour. Therefore, a barrage of milling and sifting tests were carried out in an attempt to standardize Kernza flours. Once this was achieved, additional culinary testing could take place. The entire process is laid out here.

General observations of Kernza flour

When it comes to Kernza flour, one can expect a few things. Kernza has a significant bran content that will affect dough behavior and flavor to some degree. The flour (excluding the bran) is very light, and can seem more like dust. It has a yellow tone that turns a much darker brown when hydrated. Dough with high hydration can become very sticky compared to wheat dough at the same hydration. Dough also seems to break down much more quickly than wheat dough. Fermentations should be fast with a high inclusion of pre ferment to maximize dough strength before this breakdown. An advantage of fermenting dough with whole grain Kernza flour (what is commercially available today), is it contains plenty of nutrients to keep yeast healthy. This will aid in boosting fermentation rate.

A large appeal of using Kernza flour is its flavor; it adds complexity to anything that is made with it, and expresses itself differently depending on the type of dough, how it is fermented, different baking temperatures, hydration, and so on. Below is a more precise bulleted list of Kernza specs taken from a culinary assessment published in 2022.

- Inclusion Percentage with Hard Wheat: 15-25%
- Inclusion Percentage with Soft Wheat: Up to 50%. 75% in some cases.
- Optimal Hydration Percentage (100% Kernza): 63-67.5%
- Optimal Hydration Percentage (Kernza/Turkey Blend): 66-70%Optimal Mixing Time: 6 minutes
- Has starch issues: not enough starch. Will not set loaves very well without inclusions.
- Gluten structure: Very viscous and somewhat extensible. Not very strong or elastic.
- Shares many similarities with soft wheat
- Struggles to keep fats emulsified. May benefit from cutting back in recipe.
- Sifting, oxidization, vital wheat gluten, ascorbic acid, or additional starch may help boost structure formation.
- Flavor profile: Honey, cinnamon, maple syrup, nuts, vanilla, butterscotch, almond extract, brown butter.
- Best applications: scones, pancakes/waffles, quick breads, some cakes, muffins, whole grain preparations, some crackers

Methods for identifying Kernza flour standards

In order to develop a standard Kernza flour, we looked at federal wheat standards and commercial wheat flour products to determine comparable ratios of flour particle sizes. We also examined the impact of grain moisture content on flour particle size ratios. Samples were milled on several different types of commercial mills, and finally a standard method was developed for flour production on a stone mill.

In aiming for one specific flour quality (particle size, moisture content), we looked to two sources for comparison: the Federal Code of Regulations, and commercially produced wheat flour. The FCR was useful in noting which sieve mesh sizes were generally used as metrics when determining particle size, but its regulations on said particle size were a little too broad. We found that most commercial wheat (whole wheat in particular), had particle sizes within a much narrower range, so we ended up using this general range as a comparison benchmark when running our own tests. Code of Federal Regs. standard flour particle size in relation to percentages passing through certain mesh numbers is listed here:

All Purpose Flour: “ Not less than 98 percent of the flour passes through a cloth having openings not larger than those of woven wire cloth designated 212 µm (No. 70)...”

Flour Sifter

Whole Wheat Flour: “Not less than 90 percent passes through a 2.36 mm (No. 8) sieve and not less than 50 percent passes through a 850 µm (No. 20) sieve...”

The photo of our sieve set above shows 6 mesh drums each with a designated number and corresponding µm size: 5 (4,000µm), 10 (2,000µm), 35 (500µm), 60 (250µm), 120 (125µm), and 230 (63µm).

It should be noted that due to Kernza’s recent entry into commercial markets, no federal regulations have been imposed on it yet. Using the regulations and benchmarks mentioned above is not an attempt to produce a Kernza flour compliant with wheat’s regulations, it is simply a means of comparison and viable quality standards to try and approach.

To get an idea of commercial flour’s particle size distribution, and hone in on a repeatable sifting technique using our sieve set, we sifted a number of samples taken from flour’s purchased at large scale grocery stores. Once a sifting technique was developed, the sifting data from each sample was recorded.

As briefly mentioned, the #60 mesh drum was our focal point in both all purpose and whole wheat comparisons. Initial commercial flours sifted included: Bob’s Red Mill (BRM) whole wheat, BRM whole wheat pastry, BRM all purpose, King Arthur whole wheat, and Baker’s Field whole wheat. The average amount of flour that passed through the #60 mesh from each of these samples was 86%. Percentages ranged from 84.42% (King Arhtur whole wheat) to 87.26% (BRM whole wheat), a very narrow range. These data provided us with our comparison benchmark for Kernza flour standardization.

Evaluating moisture content impact on milling

Moisture is a very important factor when milling; it can have effects on particle size as well as the mill itself, even causing damage. For us, moisture was a relatively simple variable to manipulate: a matter of placing a high moisture grain sample over a fan and running a moisture analysis, 5g at a time, until four separate moisture levels were achieved. As shown in the table below, the four samples had moisture percentages of 11.91%, 10.03%, 8.20%, and 6.48%. Each sample was milled in succession, and sifted. Flour remaining on the surface of each sifting layer was weighed and recorded. This test shows a relatively clear advantage when sifting flour at 10.00% moisture. 61.56% of the flour passed through the targeted #60 mesh sieve. The 11.91% sample was close, but the moisture content was very close to 12%, which was the limit of acceptance according to the federal regulations of wheat flour.

Comparing Kernza milled on different commercial mills

Additional samples were sent out to various milling operations to get an idea of flour quality differences when milled with other equipment, including a “Hippo” hammer mill and a 36” stone mill.

The moisture content of our samples was 7.6%, fairly low for what was deemed preferred when milling Kernza. With that in mind, the percentages of flour that passed through the #60 mesh were 50.41% and 38.02% from the 36 inch mill and hammer mill respectively. This may seem undesirable, but when compared to Kernza flour’s data in this range of moisture, it seems that the hammer mill produces similar results, while the 36” stone mill produces more preferred flour (smaller particle size). This is consistent with research: larger stone mills generally produce finer flour, because the grain stays between the stones for a longer period of time. This is because the stones are horizontal, and have a much wider diameter.

Methods for identifying Kernza flour standards

With federal regulations, sifted flour data from other milling operations and various commercial flours, and a preferred moisture content, our stone mill adjustment trials were ready to begin.

We have an 8” stone mill, and conducted standardization using this mill. Early Kernza commercialization has been aligned with the growth in regional mills, many of which rely on stone mills. These types of mills produce whole grain flours and have increased in accessibility in recent years. Our focus on stone milling was based on analysis from exterior flour, ease of access, and the likelihood of sharing milling information with regional mills who could begin offering Kernza.

Standardization with a stone mill requires almost daily adjustments. More specifically, most stone mills are completely analog pieces of equipment. They do not have presets, screens, even physical notches to mark settings. The reason for this is that a stone mill is always changing. Each time grain passes through and is ground into flour, the actual shape of the stone changes shape: it gets worn down. This is a very minimal change that, at times, takes months to show a noticeable effect on the flour, but the stones are consistently morphing and becoming more dull. Since the stones themselves are changing, the dial adjustment that sets gap width is also changing, and will change its set position depending on when the stones touch.

Though this fact led to reduced consistency in experimentation results, the data collected is very useful in an applied setting, because it provides a practical methodology and template for any stone mill user.

Trials were run on the mill gap and grain flow rate to evaluate best practices for milling Kernza. Mill gap is the distance between the stone mills and grain flow rate is the rate of adding kernels into the mill.

We ran 150 gram samples of Kernza through the mill, testing 7 flow rate settings for each new mill gap size. Each sample was then sifted and particle size ratios were determined. The determined setting produced flour with 51.65% passing through the targeted #60 mesh sieve.

Settings Across Grain Varieties

One trend revealed from all of the milling/sifting trials was optimal mill gap/flow rate settings on the stone mill were consistent across each grain tested. This remained true even when blending Kernza with multiple wheat varieties. This finding is significant, because one mill setting for all grains and blends means increased product consistency as well as production efficiency. It also provided enough evidence that a standardized Kernza/wheat flour blend could be produced and applied to baking trials. These trials are covered in the next chapter.

Though the optimal mill settings remained consistent across all varieties and blends, blending Kernza and wheat at different percentages did affect the final flour quality. The blends showed an increase in particle size quality compared to Kernza flour unblended, but a drop in quality when compared to the wheat used in the blend.

Variable Moisture Rate Sifting Results									
Sample was contained in, and did not pass through #(x) mesh sieve									
Moisture = 11.91%	#5 Mesh	#10 Mesh	#35 Mesh	#60 Mesh	#120 Mesh	#230 Mesh	Bottom Tray	Total	Total Loss
Weight (grams)	0	0.15	26.65	12.24	17.28	40.29	1.69	98.3	1.7
Percent of Total	0.00%	0.15%	27.11%	12.45%	17.58%	40.99%	1.72%	100.00%	1.70%
% thru #60 Mesh	58.57%								
Moisture = 10.03%	#5 Mesh	#10 Mesh	#35 Mesh	#60 Mesh	#120 Mesh	#230 Mesh	Bottom Tray	Total	Total Loss
Weight (grams)	0.00	0.07	24.24	13.63	33.31	27.00	0.45	98.70	1.30
Percent of Total	0.00%	0.07%	24.56%	13.81%	33.75%	27.36%	0.46%	100.00%	1.30%
% thru #60 Mesh	61.56%			74.91%	61.10%				
Moisture = 8.20%	#5 Mesh	#10 Mesh	#35 Mesh	#60 Mesh	#120 Mesh	#230 Mesh	Bottom Tray	Total	Total Loss
Weight (grams)	0	0	23.07	37.53	31.65	7.06	0.09	99.4	0.6
Percent of Total	0.00%	0.00%	23.13%	37.63%	31.73%	7.08%	0.09%	100.00%	0.60%
% thru #60 Mesh	38.81%								
Moisture = 6.48%	#5 Mesh	#10 Mesh	#35 Mesh	#60 Mesh	#120 Mesh	#230 Mesh	Bottom Tray	Total	Total Loss
Weight (grams)	0.00	0.00	26.07	46.28	21.67	4.74	0.00	98.76	1.24
Percent of Total	0.00%	0.00%	26.40%	46.86%	21.94%	4.80%	0.00%	100.00%	1.24%
% thru #60 Mesh	26.74%								

Chapter 7: Developing Kernza and Wheat Blends

With milling and sifting data among flour blends collected, it was time to test blends in a baking application. As mentioned toward the end of chapter six, consistent mill settings produced consistent flour quality (in terms of particle size distribution) amongst nearly all grain varieties and blends. Given these results, developing blends utilizing Kernza flour was attainable; milling with optimal mill settings produced the most desired results in the flour, which would pose an advantage when seeing how each blend would perform in applied baking settings. Our aim in blend testing was not only to see effects of blending Kernza flour with other wheat flour varieties, but also to develop blends that could act as substitutes for flour types already in production, specifically: whole grain, pastry, and all purpose flour. These blends could then be used in assessing malted Kernza powder utility. Processes for each flour type follows:

Whole Grain Flour with 0-75% Inclusion Rates

The first round of whole grain blend testing involved baking a simple sandwich loaf with four different inclusion percentages of Kernza blended with Turkey Red wheat milled in-house: 0 (Control), 25, 50 and 75%. Observational data was collected from mixing, proofing, and baking stages.

As Kernza percentage increased: More water was required for successful mixing, dough became more sticky, volume expansion in proofing and baking decreased, final volume decreased, final height decreased, and color got darker.

Whole Grain Bread: 0-75% Kernza Flour

Ultimately, it was decided that an inclusion rate somewhere between 1% and 25% Kernza would align with the goal of our outcome for this blend: An acceptable whole wheat flour substitute with a significant percentage of Kernza included. Subsequent testing was carried out in a similar fashion: 0 (Control), 10, 15, and 20%. Photos of these tests are shown below, and they provide great visual examples of general expectations when it comes to baking with Kernza.

Whole Grain Bread: 0-20% Kernza

Kernza/Turkey Red Blend Vs. Commercial Whole Wheat Flours

A whole grain flour blend consisting of 15% Kernza and 85% Turkey Red wheat was deemed an acceptable stand-in for this initial iteration of a whole grain flour. With a viable whole grain flour at our disposal, further testing was carried out for the sake of comparing this blend with commercially available whole wheat flours. Though it was not expected to perform in the exact same way, if our blend produced products that were similar enough to those made by commercial flours, we would have a viable whole grain flour containing Kernza. In total, six samples were made, and the testing procedure was the same as above.

Flour Samples:

- Turkey Red Control
- Whole Wheat King Arthur Control
- Whole Wheat Bob's Red Mill Control
- 15/85% Kernza/Turkey Red Blend
- 15/85% Kernza/King Arthur Blend
- 15/85% Kernza/Bob's Red Mill Blend

Taste Test Trial

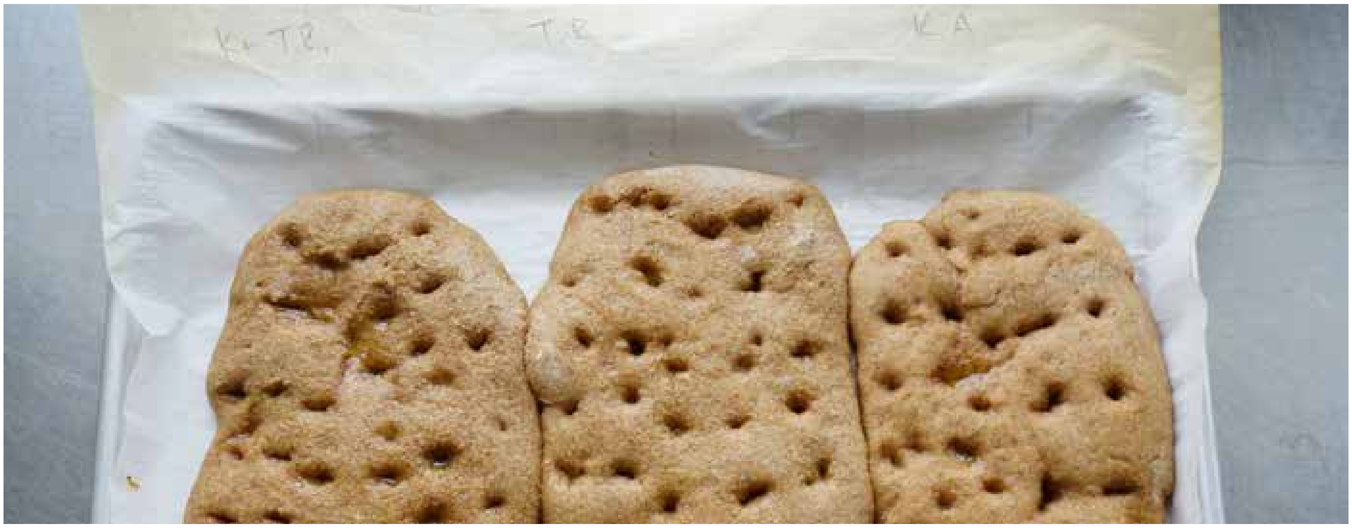
The goal here was to determine whether or not our blend could produce comparable results (better, equal, or slightly less desirable) to popular commercial flours in order to deem it an acceptable substitution. Though the commercial flours we tested had a smoother texture, and produced bread slightly larger in size, comparative differences were slim. It was even said that the crumb of the pure Bob's Red Mill loaf was too tight, or toothy. Aside from visual comparisons, the combination of Kernza and Turkey Red wheat generated a more desirable flavor overall (according to a few testers available). Ultimately, it was determined that the Kernza Turkey Red blend was a viable substitution for whole wheat flours.

Consumer Facing Bake Trial (Focaccia)

The final phase of whole grain flour blend testing involved more consumer facing bake trials. The recipe for the loaves above was used specifically because it was simple and would allow for easy observational testing. Though helpful, a broader range of dough styles had to be considered in order to determine the true versatility and utility of the Kernza/Turkey Red blend. Focaccia was the chosen bread style; it required different ingredients, fermentation time, hydration, and baking parameters.

Three flour samples were used in the final phase:

- Whole grain Turkey Red Wheat
- Kernza/Turkey Red blend
- King Arthur whole wheat flour (chosen due to preference over Bob's Red Mill)



Foccaccia Test Bakes. From Left to Right: Kernza/ Turkey Red Blend, Turkey Red, and King Arthur

Results

Fermentation/proofing took relatively the same amount of time amongst all three samples. Post baking, King Aruthur focaccia was the most firm, and had a conventional whole wheat smell. The crumb of each of the samples was fairly tight, but this was to be expected using whole grain flour and a very simple recipe. The Kernza/Turkey blend focaccia had the softest crumb, and it smelled “lively and floral.” The volumes of each were similar. One notable difference of the blend focaccia was that it seemed to lose a little more oil during the bake than the other flours. This is consistent with other high fat doughs made in the past.

Whole Grain Pastry

The process for developing a whole grain pastry flour followed the previous tests. Again, the focus here was to not only observe effects of Kernza flour blending, but to create a whole grain pastry flour using Kernza and wheat that can be substituted for commercially produced whole wheat flours, for use in analyzing malted Kernza powder.

We used a soft white wheat from Meadowlark Mills to perform scone trials. As before, the trials began with Kernza inclusion percentages of 0, 25, 50, and 75%, allowing us later to hone in on a tighter range. Mixing and baking revealed minimal differences in each dough. As the percentage of Kernza present in the blend went up, however, a little more water was required, and the brown color deepened. When baked, each sample spread out significantly, but the control held its shape the best. More Kernza present caused

Kernza Scones 0-75%

slightly more flattening out of the scones, and the heights of each were very similar. The differences were far less drastic than the differences in the whole grain loaves at the same inclusion range from the previous trial.

Results

Due to fewer expectations when it came to structure, noteable flavor observations were taken into account. When tasting the control next to the scone with 25% Kernza, it was pointed out that a much more complex flavor had developed; Kernza seemed to turn the sweetness of the sugar into a flavor profile closer to honey. This occurred without sacrificing the structure and softness of the scone.

Upon mixing, the pure wheat dough remained fairly wet and increased in dryness as the amount of Kernza increased. This makes sense, because our Kernza flour had a more prominent bran inclusion, causing it to soak up more water. While baking, the pure wheat scone seemed to hold its shape the best and 75% Kernza, the least. It spread out a noticeable amount as well. None of the scones fell flat, though, and only slight differences in height were observed. Each sample developed a very nice top crust, too. As the scones approached 75% Kernza inclusion, the crumb got a little denser and the color a little darker. None of the samples were unpleasant, but 75% was ultimately just

Scones: 0-50% Kernza

outside of what we would consider an acceptable soft white blend substitute.

The inclusions percentages of phase two were 0% (control), 20, 30, 40, and 50%. Round two revealed similar results in comparison to the first round: hard to distinguish substantially, but the biggest jump in flavor happening between the control and the scone with 20% Kernza. At 30% we noticed a "brany-ness" coming through in the flavor. It was not unpleasant, just intriguing. In fact, we deemed the 30% inclusion to be our favorite, because its flavor was the most balanced between the two flours; both were recognizable and seemingly boosted the flavor of their counterpart.

Final conclusion was that 30% Kernza flour and 70% soft white wheat flour blended together produced an acceptable substitute for whole wheat pastry flour.

Versatility, Comercial Comparisons, and Conclusion

Commercial flour comparisons and versatility testing were done at the same time in this final phase. Our blend was tested alongside Bob's Red Mill whole wheat pastry flour and 100% Meadowlark soft white wheat flour. This time, shortbread would be used as the baked good for comparison: different processes, ingredients, structure, flavor, etc.

Kernza's effect on the shortbread cookies was fairly standard; the cookies came out of the oven a little darker, and a little structure and height was lost. The flavor of the Kernza/Meadowlark blend, however, was considered the favorite amongst the three. Some testers even disliked the flavor that the Bob's Red Mill flour expressed. With slight but noticeable physical changes, and a preferred flavor, it was concluded that our blend was an acceptable replacement for commercial whole grain pastry flours.


Shortbread Comparion From Left to Right:
Kernza/Turkey Red Blend, Meadowlark, Bob's Red Mill

FLOUR COMPOSITION DATA

Flour Analysis

The blending trials provided a lot of insight on what one can expect when using Kernza flour (and its blends) in practical settings: Home, restaurants, etc. This information is, for the most part, observational, though. To satisfy home cooks and food scientists alike, we sent two flour samples to the Great Plains Analytical Laboratory in Kansas City, MO. to conduct some rheological flour tests for us. This testing would provide compositional data and reveal quantifiable dough behavioral characteristics. We sent whole grain Kernza flour and our Kernza/Turkey Red blend in for testing. Concise descriptions and results of each significant data point follow.

Moisture:

Amount of water present in the flour expressed as a percentage by weight.

Ash content:

Refers to the mineral content of a sample. It is obtained by incinerating a small portion of flour and weighing any remaining ash. Minerals do not fully combust and are, therefore, left over after burning. Everything else gets vaporized. The higher the ash content, the more minerals are present in a sample. In grains, the majority of minerals (nutrients) are stored in the bran and small germ. Very few minerals are present in the starchy part (endosperm) of a grain seed, making it, among other things, less nutritious. For example, all purpose flour contains almost no bran or germ. Its ash content is usually between 0.5-0.6%, whereas Kernza's is 2.218%. More ash equals a higher mineral content, which equals more bran/germ presence, which ultimately means more nutrients.

Protein:

Protein is typically an excellent indicator of bread quality. Two proteins, glutenin and gliadin, when allowed to combine in the presence of water, form gluten. It is gluten that provides structural capacity in bread. In most cases, a higher protein content will yield a stronger dough that still has the capacity to stretch and expand. This is revealed in a loaf of bread that has an excellent rise and a high final volume. These guidelines are mainly relevant to wheat, however. When in relation to Kernza, protein content alone is not as sufficient of a bread quality indicator.

Our Kernza flour sample has a protein content of 15.39%. If a wheat variety were to contain that level of protein, it would most likely have the capacity to develop an extremely strong dough. High gluten bread flour (wheat) usually contains around 13% protein. Unfortunately, the protein listed needs the right combination of glutenin and gliadin proteins to form high quality gluten. While Kernza has both, along with somewhat acceptable amounts of each, there are functional and less-functional forms of both proteins. Any glutenin present needs to be "high molecular weight glutenin;" the weight of each individual molecule determines whether or not that molecule will carry out the desired function. Kernza's glutenin is predominantly "low molecular weight glutenin," so it does not perform with the rigor of glutenin present in a high-protein wheat. Instead, its structure is a little less stable. It is partially due to this that we recommend using it in structure deficient baked goods such as quickbreads. Another contributor to the high protein content is the relatively high number of "albumins" and "globulins." These proteins are not stored where glutenin and gliadin are. They reside in a thin layer of cells just underneath the bran, while glutenin and gliadin are contained in the starchy endosperm. Again, due to the high area of bran in comparison to endosperm, the ratio of albumins and globulins will go up, contributing more to the total protein percentage; contributing more of the "wrong" proteins, as they do not serve a strong function to desirable baking properties. A wheat seed is larger, because it contains more endosperm. Making it safe to conclude that an overwhelming amount of its protein comes from (high molecular weight) glutenin and gliadin.

Falling Number:

Provides an indication of the starch quality in a grain. The method used to produce this number utilizes a machine that operates by heating a mixture of flour and water in a small vial to make a thick slurry. Once heated and allowed to thicken, a small plunger is placed just on top of the slurry, and allowed to fall through it until it reaches the bottom of the vial. The falling number itself is literally the amount of time, in seconds, it takes the plunger to reach the bottom of the vial. Every falling number is greater than 60, because the mixing and heating time is taken into account for each test. As you may have guessed, thicker slurries are more viscous and produce more resistance to the plunger. So, the thicker the slurry, the higher the falling number.

A general sweet spot for wheat and a few other grains is a falling number around 200-250 seconds. In a few cases, a falling number at or just slightly over 300 is acceptable as well. Too weak of a slurry (low falling number) typically means there is a significant amount of damaged starch or enzyme activity already present in the grain. Damaged starch usually occurs during milling, and a literal breaking of starch granules causes a decline in their stability during hydration and heating. A high enzyme activity can also involve damaged starch, but it usually begins in the field before, during, or immediately after harvest. If a grain begins to germinate too soon, before it has had a chance to dry down to a storage moisture content, enzymes present in the seed will begin breaking down the starch, again causing a loss in stability.

On the other end of the spectrum, too high a falling number can also be detrimental. From what we've gathered, this is usually above 350, and this typically means there is not enough damaged starch. A certain percentage of damaged starch (around 8-10%) is incredibly helpful during baking; the starch chains are broken down enough to become food for the yeast when it is added, increasing its vigor. The falling number is usually a very reliable predictor of potential flour performance.

In the context of 100% Kernza flour, and our Kernza/Turkey blend, the blend has a falling number of 340, while 100% Kernza flour is 152. A drastic difference, and a potential indication that Kernza has a starch deficiency. The blend may also seem fine for practical uses, but other factors need to be taken into account - whole grain flours in particular, because there is so much variability from product to product - before one can definitively say "this is a completely acceptable flour to use in most applications." One final point: The falling number provides data on a specific sample, and falling numbers produced by grain taken from the same plot can vary year to year due to the heavy influence of environmental factors. We suspect the falling number taken from this specific sample may represent the low end of Kernza's range, and we believe that subsequent generations of Kernza may reveal an increase.

Wet Gluten:

An indicator of pure gluten quality and quantity in a given sample of flour. It is expressed as a percentage, by weight, of the gluten network remaining after a dough has been formed, and all of the water soluble components of it have been washed off. The higher the percentage of wet gluten, the higher the quality and quantity of gluten forming potential is present in your dough.

The results we obtained from each of our samples were <10% wet gluten content from pure whole grain Kernza, and 28.83% from our blend. As a benchmark, most strong hard wheat flours have a wet gluten content ranging from 30-45%. This range of percentages represents the highest quality/quantity, however, and does not mean anything below is unacceptable. Additionally, most soft wheat's wet gluten content (that we've seen) are around 19-22%. Judging by Kernza's wet gluten percentage, it is pretty clear that it needs a little help should one need a boost in baking performance. It also seems that the addition of our Turkey Red does just that.

Rheological Testing

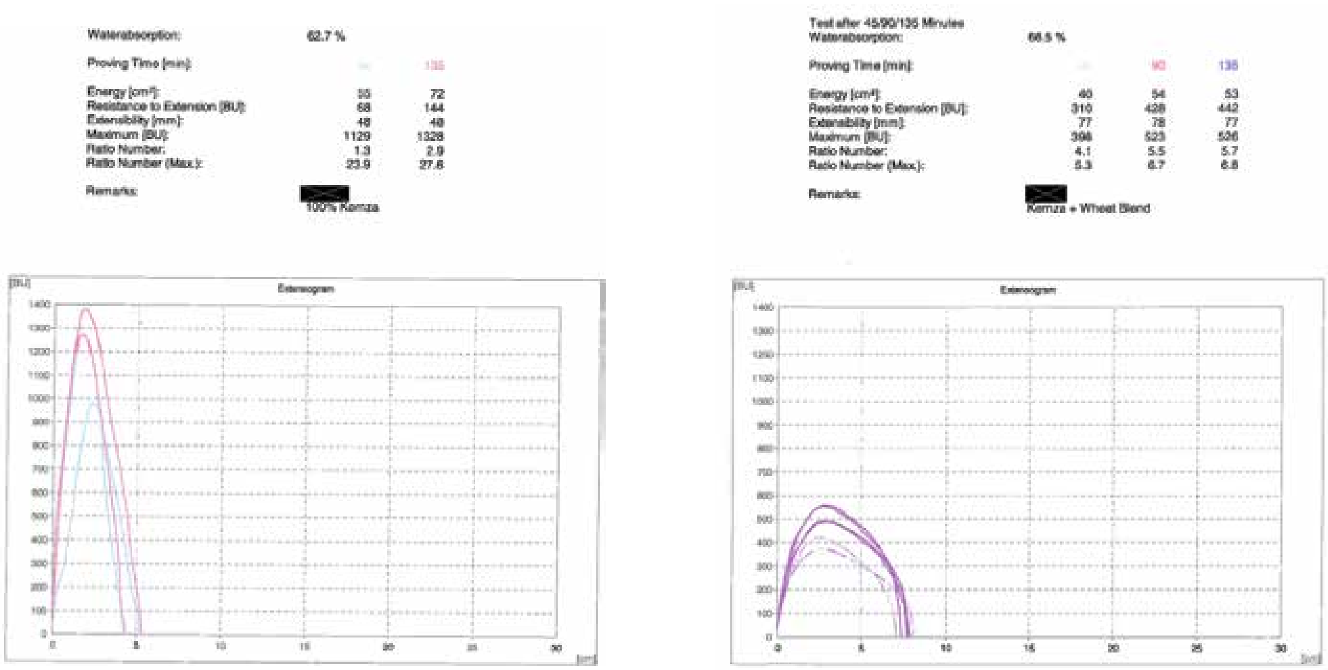
Rheological tests reveal structural and mechanical properties of dough when force is applied. This provides more insight of how a dough will behave under the stress of kneading, fermenting, baking, and so on. Multiple tests were conducted with a variety of specialized equipment. Explanations follow.

Extensograph:

Provides insight on dough behavior before baking. This information can, in turn, be used to predict what will happen when baking actually does occur. Generally, the shape of the graph reveals how positive the interplay is between glutenin and gliadin (the two proteins that form gluten). It also reveals a potential hydration to consider when baking.

Take a look at the graph below depicting an extensogram (the graph made by an extensograph) of 100% Kernza flour. It is a tall, thin spike. Its height is around 1400 BU, or “Brabender Units,” which are a unit of force: in this case, resistance to extension. The horizontal axis depicts length in centimeters. Seeing as the extensograph literally stretches a piece of dough, imagine what would need to happen to produce a graph like this: A lot of force would be applied to stretch the dough a very small amount before it snapped. In other words, the dough cannot stretch without breaking. This is not ideal for a loaf of bread. Instead, an extensogram depicting more of an upside down “U” or rainbow shaped curve is a sign of a dough that resists extension just enough to stretch a little farther.

The extensogram produced by our Kernza/Turkey Red blend, however, looks much more like what one would desire when making a loaf of bread. Although, when compared to the extensogram of a high quality, high protein dough (bread flour), it is still lacking. Imagine the graph being pulled to the right and slightly upwards, and you have just pictured a more ideal extensograph.



Extensogram Charts. Kernza on the left and Kernza/Turkey Red Blend on the right

Farinograph:

Reveals many dough quality properties that arise specifically during the process of mixing flour and water. As two paddles mix the dough, they are measuring the force of resistance. Continued mixing increases the dough’s strength until a peak viscosity has been reached. After this point, continued mixing will slowly begin to break down the structure that had formed. The results from this process give bakers an idea of how much water to add to a given flour, the amount of time it takes for optimal consistency to form, the extent to which it breaks down after peak consistency is reached, and how quickly it will do so.

Though all of this information is very helpful, it does not always paint a full picture of how your flour will actually perform. As it was explained to us, it is just a strength reading; it determines how strong isolated components in a flour can become, but does not correlate to the total quantity of said components in the flour. It is for this reason that farinographs and extensographs should be used in tandem to give a broader picture of a flour’s performance.

With that being said, the 100% Kernza farinograph reveals some important information on how one should generally treat the dough.

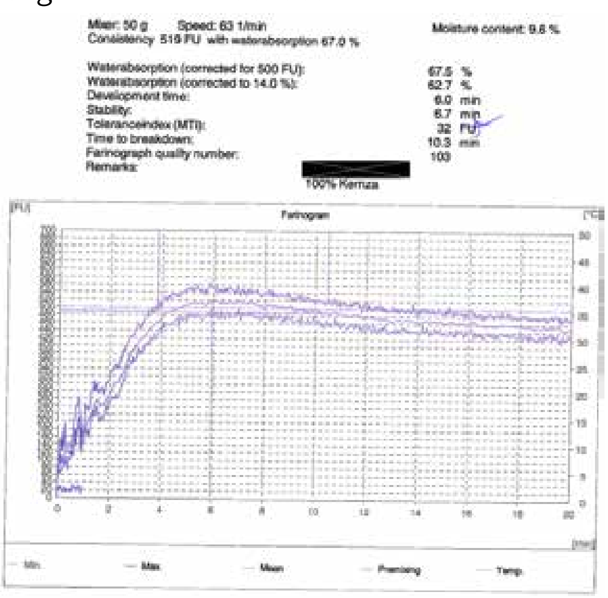
Water absorption: a straightforward data point; start with 62.7 - 67.5% water to flour by weight. Each of the two numbers represents an optimal percentage corrected for different variables, so creating a range between the two should be alright.

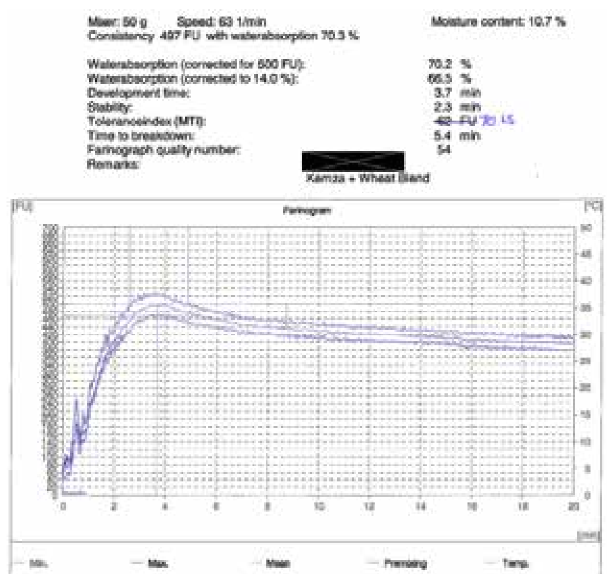
Development time is the amount of time it takes for a given dough sample to reach peak resistance i.e. maximum strength. There is usually a direct correlation between the development time on this test, and the actual mixing time when one makes a loaf of bread. Our Kernza sample’s time was six minutes. Generally one looks for longer development times, because it can be an indicator of a more stable dough. A dough that peaks too quickly is more likely to break down faster, as well. Stronger flours usually sit around 8-11 minutes of mixing before reaching maximum strength. While mixing your own dough, be very aware of what it is looking like at the six minute mark. Once this point is reached, overmixing is approaching very quickly if it hasn’t happened already.

Stability indicates the “endurance” of your dough in minutes. Longer stability time is equivalent to a longer period of time in which your dough holds near maximum strength. A longer period of time is, again, more desirable in this case. A stable dough will be more versatile in ever changing circumstances: humidity, room temperature, differing fermentation times, inconsistent mixing, etc. It gives the processor more “wiggle room.” To, once again, compare Kernza to a relatively strong wheat, notice its stability is 6.7 minutes. On the graph, this is the range where the curve breaches 500 FU (or BU in some cases), and subsequently falls back below it. FU and BU are units of force or strength. 500 BU is used as a standard for characteristics of a desirable dough. In stronger wheat flours, I have seen stability times of up to 23 minutes, and suspect an even greater number of minutes may be possible.

Though there are more data points on this graph, the three mentioned above are typically the most helpful. They will tell you how to treat your dough, and how it will behave in an unpredictable environment. However, it should be reiterated that this graph is not the sole indicator of flour quality, and a comparison between the results produced by each flour provides a great example as to why. The Kernza/Turkey Red blend results show a very short development time, an even shorter stability time, and a short breakdown time. Short farinograph times are usually undesirable; longer development, stability and breakdown are traits of strong, resilient doughs. The results produced by 100% Kernza flour look much better, but as we know, the performance of Kernza flour cannot compete with wheat in a baking application. This is precisely the reason why a farinograph needs to be considered amongst a range of other tests in order to get a complete picture of flour quality and performance.

As to why the blend produces such short time intervals, we predict it has to do with the introduction of more (and potentially stronger) bran contributed by the wheat. Because this dough is being mixed throughout the entire procedure, the bran’s effect may take hold sooner, thus causing a more rapid dismantling of the gluten/starch network. This is a simple explanation, and there is always more at play, but we feel it is significant nonetheless.





Farinograph Charts. Kernza on the left and Kernza/
Turkey Red Blend on the right

Rapid Visco Analyzer:

Measures viscoelastic properties of a dough: how viscous and/or elastic it is. The RVA is designed to bring out behavioral characteristics of starches present in grains. It works by mimicking a standard baking process, and records the viscosity of hydrated starch along the way. There are three temperature phases: heating, holding, and cooling, and the starch's behavior throughout each phase has the potential to reveal an aspect of the final bread quality.

Two important roles of starch in baking are: providing food for yeast, and preventing the structure (formed by gluten) from collapsing. In other words, starch is responsible for “setting” the dough in the final moments of a bake. The type of starch also determines how rapidly the bread will harden as it sits in storage. Starch works hand in hand with gluten; it helps trap water and CO2 and eventually sets the structure after a certain amount of cooking. A dough without starch (just gluten, and assuming yeast had something else to eat) might still rise while baking, but would collapse immediately after baking. Therefore, starch quality/content is in direct correlation with loaf volume.

The red line on the RVA graph represents temperature changes, while the blue line represents the real time viscosity of the hydrated flour. There are six variables along the blue line to take into account: Pasting Temperature, Peak 1 (peak viscosity), Trough 1 (hold viscosity), Breakdown (viscosity), Setback, and Final Viscosity.

The pasting temperature represents the minimum temperature required to cook the starch in a given flour. It is at this point that the viscosity of the mixture begins to increase. This is caused by the swelling of individual starch granules due to increasing temperature. And should be noted when considering heating/cooking options for your dough. In many cases, it can be used to predict final loaf volume. A delayed pasting temperature is generally preferred when a high final bread volume is sought after, as it is a sign of higher amylose content. More on this in the following paragraph.

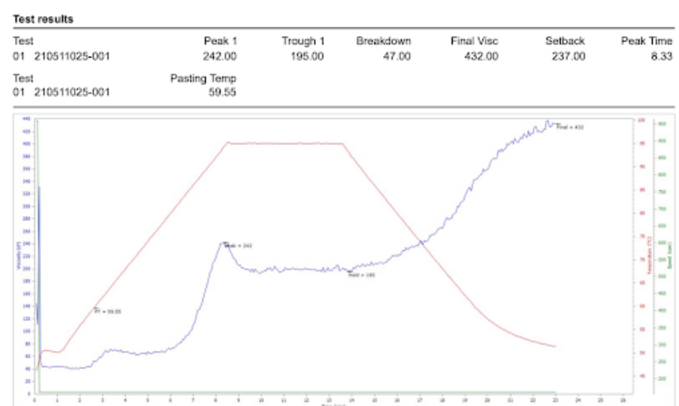
Peak viscosity represents the point during heating at which a dough has the highest viscosity, or thickness. It may seem counterintuitive, but a high peak viscosity does not necessarily mean a higher quality of starch. Starch is composed of two molecules: amylose, and amylopectin. Due to their difference in size, weight, and shape, they behave differently when hydrated and exposed to heat. In this hot wet environment, starch granules begin to swell, and amylopectin is the main contributor to this attribute. It is this increase in size that causes the increase in viscosity. During this phase, the amylose molecules begin to “leach” out of the granule and into solution. This event counteracts and reduces the rate of granular swelling. This is an important step, because a delay in starch swelling increases its stability. If starch granules swell too much too quickly, they will rupture and degrade earlier in the baking process, losing a portion of their contribution to the bread.

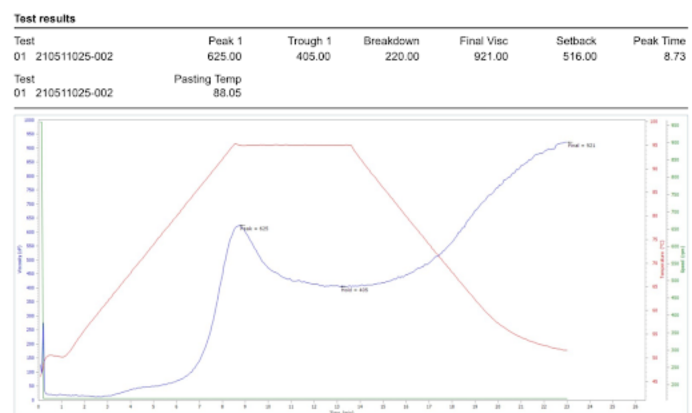
A comparison between hard and soft wheat provides a good example of amylose's role in peak viscosity. Hard wheat has a higher percentage of amylose than does soft wheat, and in many studies we've come across, soft wheat has a significantly higher peak viscosity, meaning less amylose is leeched, and amylopectin is able to swell freely (gliadin is also partially responsible for an increase in viscosity). With the quick swelling of soft wheat flour comes an early structural failure (revealing a low starch integrity) and, ultimately, poor bread volume. This is a major reason soft wheat is rarely used when a large loaf of bread is a desired outcome.

Breakdown viscosity is the value given to the difference in “peak” and “hold” viscosity. At a certain point (with enough heat), all starch will rupture, and its structure will be compromised. After this rupture, viscosity will drop to a certain point and remain there for a certain period of time. This post-rupture constant viscosity is the “hold viscosity,” and it occurs at some point after the RVA machine reaches a temperature of 95 degrees celsius. The degree of loss in viscosity is yet another indication of starch content and stability, and, again, it is the relationship between amylose and amylopectin that determines the level of breakdown. A more substantial drop in viscosity could mean a high peak viscosity which is an indication of a lack in amylose. In addition to preventing granular swell, amylose is also responsible for setting the dough during baking. Not enough amylose and your bread will collapse regardless of how strong the gluten network is. So, the more the viscosity drops (higher breakdown value) during this phase, the less stable the starch content is said to be. This is an interesting point, because our 100% Kernza flour saw a significantly smaller drop in viscosity (proportionately) than the Kernza/Turkey Red blend. However, digging into research publications studying similar topics, We've found this to be a common occurrence. Kernza's starch may be more stable than wheat's. As to why, there could be a number of reasons: higher minerality provided by the bran, high lipid (fat) content, or the ratio of amylose to amylopectin all contribute dough conditioning like properties to the starch. We have yet to find an exact explanation.

The overall viscosities of each RVA parameter (from 100% Kernza flour) are very low, implying, again, that there is not enough starch for it to really contribute anything substantial to the flour's integrity. Something this information may allude to, however, is the potential of a starch isolate from Kernza: being that it seems to be stable and resilient, it may be a practical starch to use in cooked products that require thick texture after prolonged cooking (sauces, soups, pudding, etc.).

The *final viscosity* and *setback viscosity* are parameters that typically correlate with the way a flour will behave while it is cooling after cooking. Where final viscosity is, aptly named, the final viscosity reading taken during the analysis-after cooling and time have expired, the setback viscosity is the difference in viscosity between peak and final viscosity. Depending on the type of starch, the viscosity during cooling will increase substantially or nominally. A substantial increase in viscosity corresponds to a high amylose content relative to amylopectin. Amylose is the portion of starch that has the ability to quickly form thick gels upon cooling. It is this quick action that is responsible for setting the dough. Though it contributes positive attributes during baking, a high concentration can lead to products becoming too firm as they cool. However, a higher concentration of amylose along with fat and minerals derived from the bran will contribute to the bread maintaining its quality in the long term as opposed to drying and solidifying even more as the amylopectin retrogrades. Where amylose sets quickly, amylopectin "recrystallizes" days after cooling, and it is the main contributor to bread staling. Again, this is all about the balance between amylose and amylopectin. Too much or too little of each can have a positive and negative effect. Not only that, the average shape and size of each of these molecules will cause even more changes in dough characteristics. For example: Amylopectin consisting of longer than average branch chains can mimic the effect of amylose.





RVA Graphs. Kernza on the left and
Kernza/Turkey Red Blend on the right

Flour Analysis Conclusions

With all of this information, it is still difficult to draw many solid conclusions when it comes to cooking and baking with Kernza. The graphs and data points may allude to something, but carrying out actual baking may tell a different story. One thing that may help in experimenting with Kernza at home or in the kitchen is the fact that the individual seeds are so small. This fact is really the foundation to what throws everything off. It increases the bran to endosperm ratio, which means it has a high protein content; it's just the wrong type of protein. If Kernza were a larger seed, the starch characteristics may show some promise, but there isn't enough per gram to contribute much at all. No number on the RVA graph got very high when compared to wheat, even though the shape of the pasting curves look similar (perhaps even better) at a glance. More starch per seed may also help mitigate the undesirable gluten characteristics to a certain degree. For a while, the seed was even too small to remove the bran for a refined flour, though a study published in 2019 determined the size in some strains was finally to a point where tempering and bran removal were possible. Refined Kernza flour does show more promise across the board when it comes to ease of cooking and usability. That being said, whole grain Kernza is what's available for now. So, it will need a little boost. A little boost from a little (or a lot of) extra wheat flour, although certain dough conditioners, hydrocolloids, perhaps some refined starch might help out as well. It is also important to keep in mind that a lot of the properties mentioned above are what is required for a higher quality loaf of bread or something of similar nature. Quick breads, cookies, and no-structure-necessary baked goods are usually a great fit for Kernza.

All Purpose Blend

The data and insight gained from each section of this chapter eventually led us to consider the possibility of making an all purpose flour substitute. Prior to experimentation, it was thought that Kernza simply did not have enough beneficial properties for it to be used effectively in a AP flour blend unless the inclusion percentage was extremely low. We felt that too low of an inclusion percentage (below 15%) would not effectively boost or promote the use of Kernza in applied settings. After the results from milling, sifting, blending, baking, and flour composition analysis were compiled and absorbed, though, we decided to give it a shot. An all purpose flour substitute with a substantial inclusion of Kernza flour would prove to be extremely beneficial and practical over a wide range of consumers.

Dough conditioners

After researching dough conditioners used to improve bread quality, a list was compiled to begin testing. This initial round of testing was to be performed on 100% sifted Kernza flour (SK). The flour used had passed through a #60 mesh screen. In all, four rounds of testing were carried out to fully understand any potential benefits of using the dough conditioners listed below.

List of Compiled Dough Conditioners:

- Ascorbic Acid (AA)
- Vital Wheat Gluten (VWG)
- Wheat Protein Isolate (WPI)
- Wheat Starch (WS)
- Expandex and Gluten Replacement (modified cellulose)

These dough conditioners would act as small inclusions in a bun loaf dough. The recipe was extracted from a research paper out of the University of Minnesota. Kernza was the flour used in this paper.

Round 1 A.P. Test Buns

Round 1 AP Testing:

It was decided that Ascorbic acid would be included in each trial due to findings that it is generally a beneficial conditioner to use. It generally does not affect volume or height, but improves crust and crumb texture. The rest are generally volume and height improvers. Sample labels and conditioners used follow:

A.P. Control (commercial AP flour): No inclusions
Commercial all purpose flour with no conditioners added

IWG Neg.:
(Negative control) Sifted Kernza flour (SK) with no conditioners added

IWG Pos.:
(Positive control) SK with 10.8g Expandex and 1.14g gluten replacement added

IWG 1: AA
SK with .015g ascorbic acid

IWG 2: AA + VWG
SK, 0.105g ascorbic acid, 2.25g vital wheat gluten

IWG 3: AA + WPI
SK, 0.015g ascorbic acid, 2.25g wheat protein isolate

IWG 4: AA + WS
SK, 0.015g ascorbic acid, 4g wheat starch

Once the samples were baked, the following measurements were collected from each: Pre-bake weight (g), post bake weight (g), pre/post bake height (mm), volume (ml), and density (g/ml). Photos are shown below.

In short, the conditioners added to sifted Kernza flour benefited the flour overall, but not very much. A few interesting takeaways: Each of the Kernza loaves showed less height, less volume, and had a greater density than the all purpose flour control. In analyzing only Kernza loaves: The post bake height of each sample increased in relation to the negative control (SK with no conditioners added). The positive control saw the largest increase in height followed by IWG 2: ascorbic acid and vital wheat gluten. IWG 4 was the least dense loaf with the largest volume other than the negative control.

Round 2 Dough Conditioner Buns

Round 2 AP Testing: Refined Dough Conditioner Inclusions

Round two sought to refine inclusions and trial samples with different ratios of fewer conditioners. Ascorbic acid was to be eliminated in this round, and added back in round three after the best performing samples were revealed.

In this round, wheat starch was selected to be the constant inclusion. It was to be combined at multiple ratios with either vital wheat gluten or wheat protein isolate. These conditioners were selected to work in tandem, because wheat starch seemed to improve density and volume and vital wheat gluten and wheat protein isolate improved height, albeit slightly. It should be noted that the combination of flour and conditioners always added up to 90 grams. As the conditioner inclusion went up, flour weight went down.

The quality gap between Kernza buns and the all purpose flour control shrank slightly but not quite enough to show promising signs of a potential substitution. Overall, samples containing vital wheat gluten showed slightly more improvement than samples using wheat protein isolate. VWG 4 (#4 in the photos) was closest to the AP control in terms of height, and even showed an improvement in density. All Purpose Kernza Testing - Google Sheets

Round 3 AP Testing:

VWG group from round 2 with ascorbic acid. In comparison with the SK control in round 2, each of these samples saw an improvement in the variables listed: Greater post bake height (except for #1 which saw no change), volume, and lower density. When compared to IWG 1-4 from round 2, there was slight change, but not necessarily an improvement: closer to simply different and inconclusive. The post bake height dropped slightly, the volumes went up overall, and the densities were relatively the same; samples 1 and 2 were a little less dense. The main point of consideration is that these combinations of conditioners still did not produce results comparable to the AP control sample from round 2.

Other interesting things to note: VWG 4 (4) had a very soft crumb. This was consistent from round 2. The dough was very sticky when kneading. This could be attributable to the ascorbic acid, but we are uncertain. The crumb visually looked more like sandwich bread than "quickbread" in that it had distinct alveoli (air pockets). The crust was smoother. 1 was the most smooth and 4 was the most rough. The crust itself - in all rounds, for that matter- was much thicker than the AP control's crust.

Round 4 AP Testing

Testing Kernza blended with commercial all purpose flour at different inclusion percentages. Samples will include the preferred conditioner blend from round 3 (VWG 2) along with controls for each. Includes updated AP control.

Significant change in results: Improvements in volume and density all the way up to 40% Kernza flour.

- Tallest bun: 20% W
- Greatest volume: 20% W/O and 40% W/O
- Lowest Density: 20% W/O and 40% W/O

Throughout the entire range, the most comparable samples to the AP control were the samples containing either 20% or 40% Kernza flour. The 20% samples actually overshot the all purpose control characteristics in every category, showing that conditioners can really make improvements even when weak flour is present. Though the 40% samples showed slight reductions in height compared to the control, the volume and density of each improved.

Dough Conditioner Trial Conclusions:

Conditioners show improvements in weak flour, but when it comes to Kernza flour, the conditioners tested in many different quantities and combinations did not improve the end result enough to satisfy a flour blend that was an apt substitute for all purpose flour. Conditioners present when Kernza flour was blended with wheat flour showed vast improvements in the end results. This suggested that blending may have a much greater impact over bread quality than conditioners in the presence of just Kernza.

The pursuit of an all purpose flour substitute would continue with a priority on blending different varieties of flour rather than using dough conditioners. Though there was some potential in the use of dough conditioners, not needing to use them would be much more practical with no refined ingredients or additives and less cost.

Round 5 A.P. Test Buns

Round 5 AP testing

Five strong wheat varieties were compiled for this round of testing in an attempt to boost Kernza's gluten content: Rouge de Bordeaux, King Arthur High Gluten flour, Yecora Rojo, generic hard spring wheat, and Red Fife (hard red winter wheat). Sifted Kernza flour was blended with each of these flours (also sifted) at a rate of 40%. Baking trials were conducted as before. There was a control for each wheat variety used along with an all purpose flour control.

King Arthur flour showed the highest percentage passing through the #60 mesh, which was expected due to it being a highly refined commercial flour. All other flours were milled in house, and their sifting characteristics were similar to other wheat varieties (around 85% passing through #60). Red Fife had a noticeably lower percentage of 67.48%. It was unclear why.

Results were inconsistent, but it seemed as though Rouge, Yecora, and HG were all candidates to move forward. In some cases, Kernza flour seemed to increase post-bake height. In others, it decreased it. Each blend produced results in height comparable to our AP control other than the Red Fife samples: 49 and 50mm vs. 63 mm. 40% Kernza blended with Rouge de Bordeaux surpassed the AP control at 67mm. It also had the softest crumb, and most preferred flavor - similar to a baguette.

Round 6 AP Testing

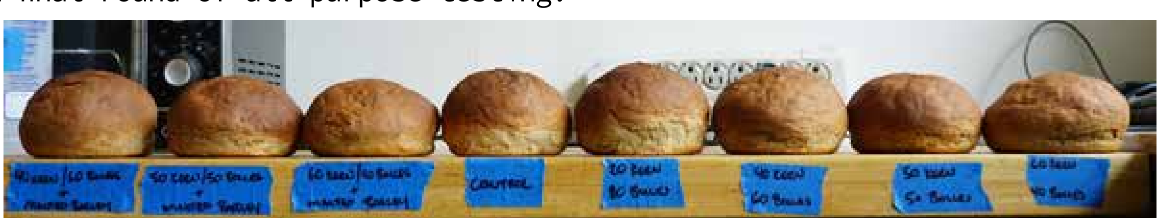
Pushing the Kernza inclusion percentage beyond 40% in blends with Rouge de Bordeaux and commercial high gluten flour. Inclusion percentages are 50, 60, 70, and 80%. Each 10% increase in Kernza flour saw a reduction in bun height. The only blend to match the AP control was 50%/50% Kernza/High gluten flour (63mm), followed by 60/40 Kernza HGF (61mm). 50/50 Kernza/Rouge reached a height of 58mm which could be considered viable for substitution as well. The crumb of each sample was nice. It was noted that the crust of the Rouge samples were slightly thicker than those of the high gluten samples.

Round 7 AP Testing

This round of testing utilized malted Kernza powder (MKP) for the first time in a culinary application. It was decided that Kernza flour blended with Rouge de Bordeaux would be the blend used to form an AP flour substitute over King Arthur's high gluten flour. Our aim was to make a substitution flour that could be processed in house: useful information to share amongst small producers and consumers should we find success.

50/50 Kernza/Rouge samples were baked: three using MKP, and three using malted barley powder (MBP) for comparison. Inclusion percentages for MKP were 1, 2, and 3%. Inclusion percentages for MBP were 1.7%, 2.7% and 3.7%. The reason behind the different inclusion percentages between Kernza and barley malt had to do with the barley malt's package recommending 1 tsp. of powder per cup of flour. This volume was kept consistent, and malted barley powder weighs more than Kernza malt powder. In a completely scientific context, they would be tested in equal weights, but we wanted to keep it as consumer focused as possible, and used the package recommendations as a benchmark.

There was not much of a noticeable benefit to using MKP. Though very similar to no malt inclusion, each post bake height was lower. Samples containing BMP showed a height increase at 1.7%, and decreases in height as BMP inclusions increased. When compared to similar samples with no malted barley inclusion, height, volume, and density each saw improvements. This inclusion of barley malt powder showed a practical potential inclusion for future all purpose production. It was considered and used again in the next and final round of all purpose testing.



Round 8 A.P. Test Buns

Round 8 AP Testing

During AP testing, Ben Penner, one of our Kernza suppliers, sent us a sample of his high protein “Bolles” wheat. We wanted to see what would happen if we tried this in our tests. In this round, we made samples using Bolles with 0, 20, 40, 50, and 60% sifted Kernza included. We also made three additional samples using 1.7% malted barley powder. Kernza inclusions in these samples was 40, 50, and 60%.

Alone, roughly 85% of Bolles flour passed through the #60 mesh sieve. This is consistent with other wheat varieties sifted. Bolles and Kernza flour sifted together showed 68% of the flour passing through #60: a promising amount.

With 63mm in height from all purpose flour as our benchmark, the results from blending Kernza flour and Bolles wheat flour were very promising. Inclusion rates were up to 60%, yet no sample dipped below 61mm. This shows that Bolles wheat can handle a very large amount of Kernza flour and still produce good results. The samples including barley malt showed improvements as well, specifically when it came to volume and density. Height improved slightly except for the 60% inclusion sample.

Conclusion:

After milling, sifting, and blending many varieties of wheat with Kernza flour, and testing Kernza and barley malt powder, an all purpose flour substitute was created. Mixing whole Kernza and Bolles wheat berries together in equal parts by weight, and milling and sifting them together was the most efficient method of producing a substitute without any additional non-flour inclusions. Milling them together in equal parts meant the final flour contained roughly 43% Kernza and 57% Bolles wheat. This is a very high Kernza inclusion percentage, and potentially a very practical flour blend. The only further vetting to be done was to use it in a number of applied culinary scenarios, to determine the scope of its “all purpose” title. We used it to bake brioche, croissants, biscuits, gougeres, pizza, and bagels, and it would also be tested in a few different varieties of pasta.

A list of each test with photos and a brief summary follows.

Croissant

Aside from being slightly stickier during mixing, the croissants turned out very well. From the cross section, one can see clear signs of lamination: open and separate air pockets. They are slightly smaller than its commercial flour counterpart, but they are also more uniform. The crust was light and flakey, and the flavor was great.
Pass

Brioche

The brioche turned out to be incredible. During the pre-bake process, it behaved very similarly to the control dough. It was easy to work with and proofed nicely. After baking, it came out smooth, uniform, fully cooked, and delicious. It had a smell similar to marzipan. The all purpose control ended up splitting on top.
Pass

Pizza

Pizza dough made from our AP blend again produced acceptable results when compared to a dough made from commercial APF. It was noted that the dough was more extensible and easier to work with than the control’s, which was harder to spread out due to elasticity. Both pizzas tasted very good after baking. Our AP blend pizza revealed larger air pockets in the crumb compared to the control. Some may see this as a positive trait. It was also noted in this trial, that the AP blend seemed to have positive characteristics of strong and weak dough manifest simultaneously: The dough was extensible, yet it produced large air pockets and formed a strong gluten structure.
Pass

Gougere

Gougeres call for “pate au choux” dough. This is a unique dough that contains a lot of fat and is cooked twice. Gougeres should be mostly hollow in the center, soft throughout, a little crispy on the outside, and have a nice chew. Our blend checked all

of these boxes. It set a touch firmer than the control, but aesthetically, it made a great gougere.
Pass.

Biscuit

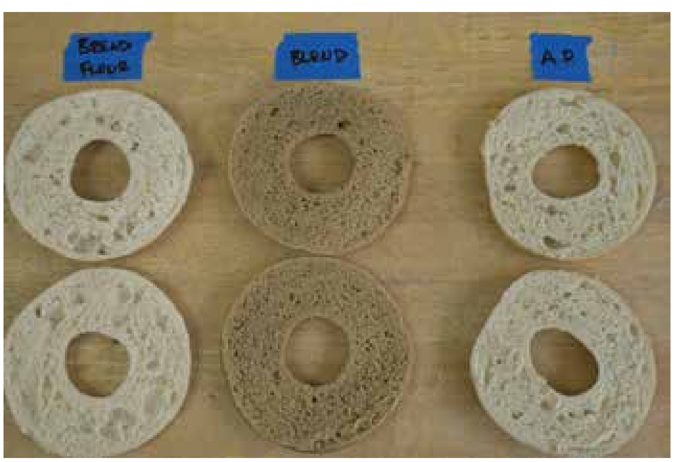
Another success. Our blend achieved a higher rise and showed more distinct layers in the biscuit. It was not quite as soft as the control biscuit, but it was soft enough to still be considered an acceptable biscuit.
Pass

Bagel

Bagel trials revealed the first instance where our blend may not be the preferred flour to use. Commercial all purpose flour is also not the preferred flour either, however. Typically, a strong bread flour is used for bagel dough. A strong bread flour, commercial all purpose flour, and our blend were all tested. Our blend made a very sticky extensible dough. It seemed to remain sticky throughout the entire pre-bake process. The crumb was tight with small air pockets. The bread flour made a porous, soft, yet chewy crumb, and the commercial all purpose flour was somewhere in between. Though the blend still successfully produced a bagel, it is difficult to state that it is an acceptable one to one replacement with all purpose flour in this instance.
Pass, but not ideal.







From Top Left, Clockwise: Croissants, Gougere, Pizza, Brioche, Bagels, Biscuits

Pasta

Six samples of pasta were compared for this final in-depth trial. Both water and egg dough were made from our blend along with commercial all purpose flour. A separate water dough was made with durum flour, and a final egg dough was made with “Caputo” brand 00 flour. The durum and caputo samples represent appropriate flours for the specific pasta type being made. Two styles of pasta were made with each sample. Due to the number of samples in total, notable data points will be listed below:

Dough

- Commercial AP flour was difficult to work with from start to finish: very elastic and incapable of forming long gluten strands
- Our blend in an egg dough was extensible and laminated nicely. It was a little tacky, however.
- Caputo samples were also difficult to work with.
- Our blend’s water dough was weak and soft.

Cooked Pasta

- None of the pastas turned out to be amazing.
- Our blend produced the best flavor
- Our blend was not the most ideal flour, but it was usable and the flavor put it ahead of the others.
- The blend was much more suitable for an egg dough.

Pass when used in the appropriate pasta variety.

AP Conclusions:

After sifting, testing inclusions, blending, and seven different in-depth baking trials using our all purpose flour substitute, the results showed that this blend provided a completely acceptable alternative to a commercially produced refined all purpose flour. In some cases there may be differences in density or firmness of a given loaf, but the flour produces dough with enough structure to give them just the right amount of lift. It also works well in doughs with a lot of inclusions such as fat or eggs. Kernza flour alone has struggled with these inclusions. Along with the ability to produce structurally sound dough, the all purpose blend consistently yielded great flavor. The most noticeable case being the brioche. We aren’t sure what it was about the combination of ingredients used in this recipe, but the bread had an incredible aroma and flavor.
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Chapter 8: Kernza Malt Culinary Applications

When Kernza flour is blended with other flours, it generally impairs the final outcome when structure and height are required: in a loaf of sourdough bread, for instance. Our research aimed to understand whether or not malted Kernza powder had any potential to improve bread characteristics rather than impair them. This chapter provides all of the context surrounding Kernza malt in a culinary setting along with the entire regiment of testing done in the pursuit of a culinary application for Kernza malt.

Understanding Malt Powders

Malt powder is generally the same malt referred to early in this report: partially germinated barley (or Kernza, in this case) that has been dried until enzymatic processes have ceased. When ground into a fine powder with the consistency of flour, malt becomes a very useful tool in the culinary world. It is typically included in some flours to improve bread quality: volume, fermentation time and rigor, flavor, and color. To get a good grasp on malt powder, one should first know there are two varieties:

Diastatic Malt Powder

If there is still enzymatic capacity in the malt, it is diastatic malt powder. The powder has starch degrading properties, and will convert as much starch from the flour as it can into fermentable sugar. This is useful in flours with an extremely high falling number. High falling numbers can indicate that there aren't enough fermentable sugars present to undergo a successful fermentation. An example: the Bolles flour we used in testing had a falling number over 400. Introducing enzymes to the flour will break down some starch and properly adjust fermenting characteristics. In other words, it is a useful flour standardization tool.

It does not have to be used to standardize. In some cases, a fermentation boost is generally helpful. Malt powder can decrease the fermentation time by increasing fermentation activity and rate. Enzymatic digestion of starch can also relax doughs and increase their extensibility, making them easier to work with.

Non-diastatic Malt Powder

Non diastatic malt powder also utilizes malted grain, but the enzymes have either been killed off or used up in the grain itself. It will not contribute any starch degrading properties to dough. It does, however, usually contain some fermentable sugars, and also has the capability to improve fermentation. The sugars present also contribute color, sweetness, and malty flavor to baked goods.

Overlap

Though each type of malt powder has different applications, when it comes to small-scale non-commercial baking, they can typically be used interchangeably. Non-diastatic malt is generally used for additional color and a slight increase in sweetness, however.

Developing a Kernza malt powder

Developing a Kernza malt powder was relatively straightforward, as we had an entire collection of malt data to draw on. As mentioned above, when it comes to diastatic malt powder, enzymes are important. Therefore, our malting schedule that produced the highest alpha amylase content would be used to develop the powder. Turning the malt into powder was simply a matter of finely grinding it.

The schedule: Short Steep, High Temp. - Long Germ, Low Temp. - Standard base malt Kiln.

Targeted Relevant Data: a-Amylase: 33 DU. Diastatic Power: 156

We used the malt made with this schedule for brewing tests as well, so produced a larger batch. Unfortunately, producing on a larger scale caused the malt quality to change, but we had to use it due to various constraints.

Actual Relevant Data: a-Amylase: 13 Du. Diastatic Power: 104

For the non-diastatic Kernza malt powder, we kilned a portion of this malt at 110 c for a few hours. This was to ensure that the enzymes would be deactivated without over-toasting the malt itself.

Creating a Comparison: Investigating Barley Malt Trends Alongside Kernza Malt in Culinary Applications

During three phases of malt powder testing explained below, Kernza malt powder and barley malt powder were tested alongside each other in the presence of a control using no malt inclusion. Similar inclusions were used in the first two steps, while the third step (In-Depth Bake Trials) isolated the inclusion percentages that lead to optimal outcomes for a final comparison. In other words, what worked best for barley malt powder was compared to what worked best for Kernza malt powder. Methodology, relevant data, trends, and conclusions are laid out after the following overview of each phase of testing.

Overview:

1. Ferment Trials: Testing the rate and rise height (mm) of a yeast fermented sample of dough with three different inclusion percentages of barley and Kernza malt (diastatic and non-diastatic) across three flour varieties: Commercial All Purpose Flour, Bolles wheat, All Purpose Blend (Kernza and Bolles).

I Commercial AP
- Kernza Diastatic malt (KDM) at 0.5, 1.5, and 3% inclusion
- Kernza Non diastatic malt (KNDM) at 0.5, 1.5, and 3%
- Barley Diastatic malt (BDM) at 0.5, 1.5, and 3% inclusion
- Barley Non diastatic malt (BNDM) at 0.5, 1.5, and 3%

II Sifted Bolles Wheat
- KDM
- KNDM
- BDM
- BNDM

III P.P. AP Blend
- KDM
- KNDM
- BDM
- BNDM

2. Bake Trials: Testing malt powder’s effect on buns: post bake height, volume, and density. The same inclusion percentages that were used in the ferment trials are used in the bake trials:

I Commercial AP (KDM, KNDM, BDM, BNDM)
II Bolles (KDM, KNDM, BDM, BNDM)
III P.P. AP Blend (KDM, KNDM, BDM, BNDM)

3. In Depth Bake Trials: Malt inclusions from either ferment or bake trials that produced the most beneficial results were determined and tested in an applied setting using bagels and hamburger buns. The list below shows chosen samples from barley and Kernza malt testing. It should be noted that some samples contain two malt inclusion percentages. This is because what was optimal during the ferment trials was different from what was optimal for the bake trials. They were both used in the third phase of testing, and the optimal sample from the bake trial is labeled.

I Commercial all purpose flour
- Barley Diastatic Malt Powder (3%)
- Kernza Diastatic Malt Powder (1.5%)
- Barley Non Diastatic Malt Powder (0.5% Bake) & (3%)
- Kernza Non Diastatic Malt Powder (0.5%)

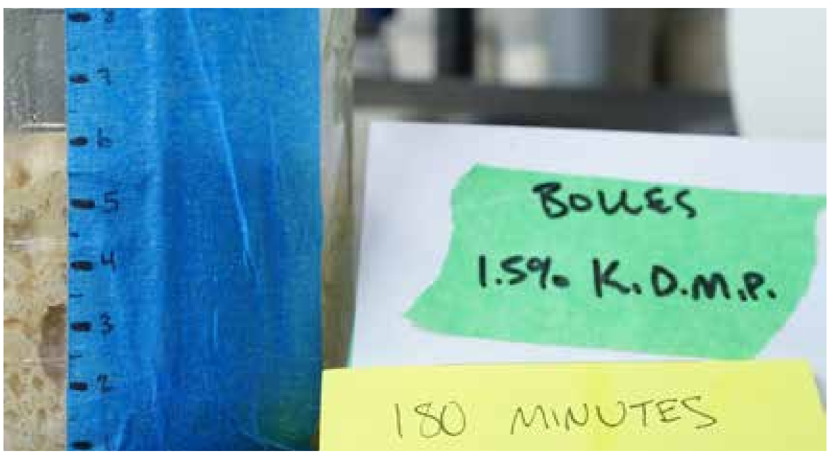
II Bolles wheat flour
- Barley Diastatic Malt Powder (3%)
- Kernza Diastatic Malt Powder (1.5%) & (.5% Bake)
- Barley Non Diastatic Malt Powder (1.5% Bake) & (3%)
- Kernza Non Diastatic Malt Powder (.5%)

III Perennial Pantry all purpose blend
- Barley Diastatic Malt Powder (3%)
- Kernza Diastatic Malt Powder (1.5%) & (3% Bake)
- Barley Non Diastatic Malt Powder (3%)
- Kernza Non Diastatic Malt Powder (1.5%) & (.5% Bake)

METHODOLOGY, RELEVANT DATA, TRENDS, AND CONCLUSIONS

Ferment Trials

To conduct fermentation trials, the same bun dough used in the all purpose development trials from chapter 7 was used here. This set of testing required no baking, however. Instead, each dough sample was placed in a greased mason jar with tape indicating length in millimeters running from the bottom to the top of the jars. A photo was taken of the dough inside of the jar once every ten minutes until 180 minutes had elapsed. Once all fermenting was done, the heights for each time interval were compiled in spreadsheets.



Fermentation Trial

Noteable Data Points

- Barley malt (diastatic and non-diastatic) powder did not seem to have much effect on commercial all purpose flour.
- For each flour type, a barley malt inclusion of 1.5% performed the worst in terms of peak ferment height and length of time to reach it.
- When it came to our all purpose blend and Bolles flour, both diastatic and non diastatic seemed to help boost fermentation at an inclusion of 3%
- Between commercial all purpose flour and our all purpose flour blend, Kernza malt powder inclusions showed little benefit: either slowing fermentation or maintaining constant fermentation.
- Kernza malt used with Bolles flour, however, did show slight boosts in fermentation rates

Bake Trials

Bake trials were conducted using our standard method for testing doughs baked in an oven. The same malt inclusion percentages used in the ferment trials were also used in the bake trials.

Notable Data Points

- Kernza diastatic malt had little to no effect on quality.
- The 0.5% KDMP inclusion in the Bolles sample showed the only slight improvement across each parameter
- Though lacking in volume/density improvements, KDMP did seem to increase total change in height.
- Generally non-diastatic Kernza malt powder led to a more significant drop in quality or no change.
- Barley diastatic malt powder generally led to a boost in most traits. Especially with a 3% inclusion.
- In Bolles flour, each BDMP inclusion boosted quality.
- Barley non-diastatic malt powder had no effect or a small positive effect.
- It produced extremely small increases in density, but overall did not decrease quality.

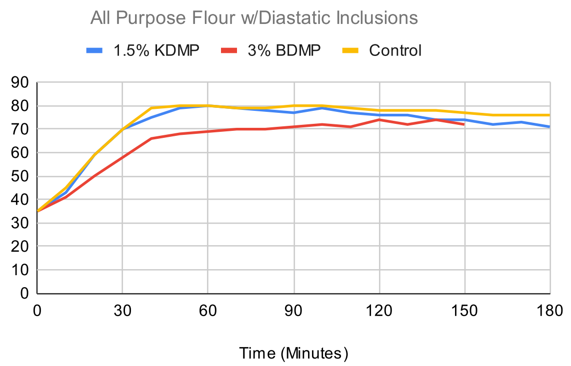
Comparing most significant data results:

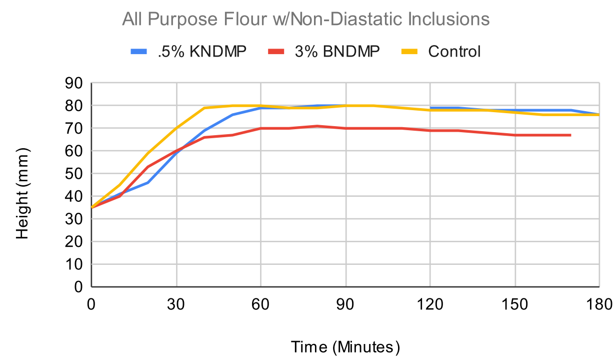
Before getting into the results of the in depth trials, it is worth taking a look at direct comparisons between each selected, most promising, Kernza malt recipe and its barley malt counterpart along with a control across all three flour blends. There are two graphs for each flour type: one showing diastatic malt comparison, and the other, non-diastatic comparisons.

Note: A new control which was an average of two controls used in barley and Kernza malt testing above was used in the charts below.

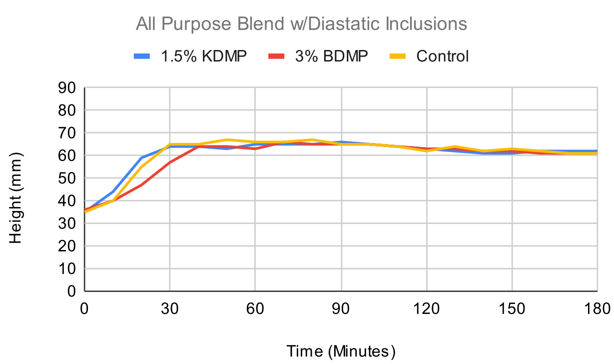
Fermentation Trial Comparisons

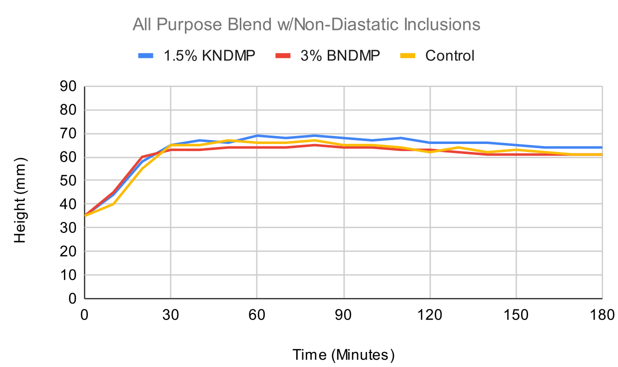
Commercial All Purpose Flour



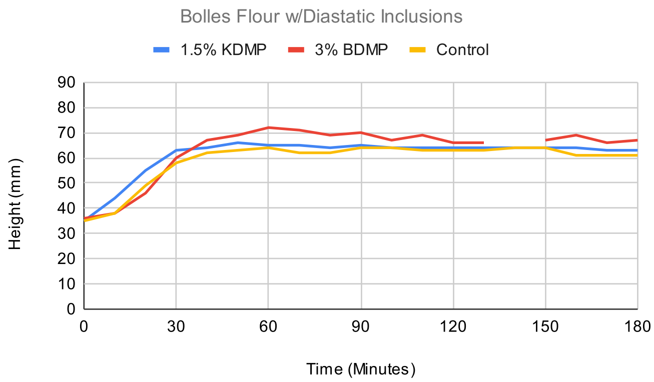


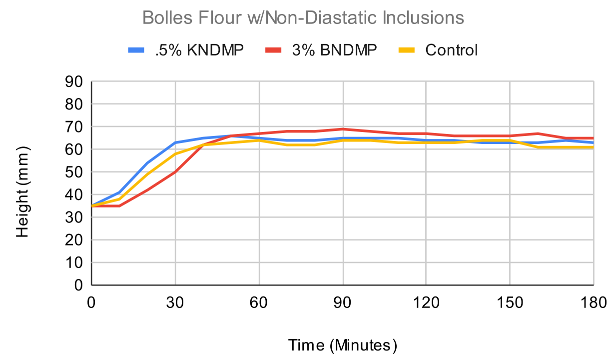
Perennial Pantry All Purpose Blend





Bolles Wheat





Results Discussion

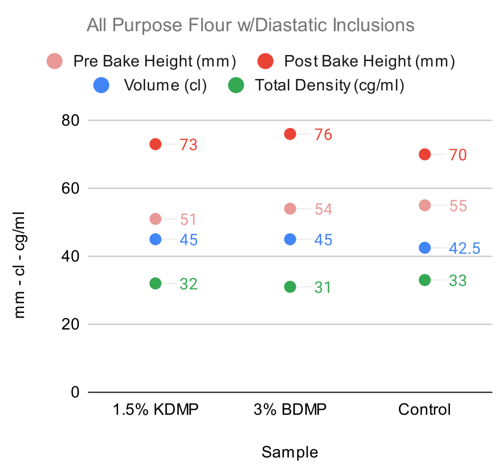
When compared to the control, it seemed both Kernza and barley malt powder failed to provide much benefit to fermentation until they were added into the 100% Bolles wheat dough, where both seemed to have a positive effect: Kernza malt powder seemed to boost initial fermentation rate, while barley malt powder seemed to boost overall fermentation.

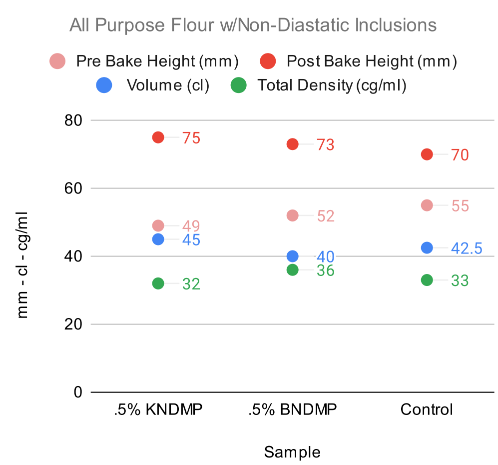
When Kernza and barley malt were compared to one another, Kernza shows promise: it outperformed barley malt in the all purpose samples, was equal to (NDMP) or slightly more preferable (DMP) when used in the all purpose blend, and was slightly advantageous during different parts of the fermentation when used in Bolles flour. Overall, it seemed to have the greatest effect on initial fermentation (within 30 minutes).

Bake Trial Comparisons

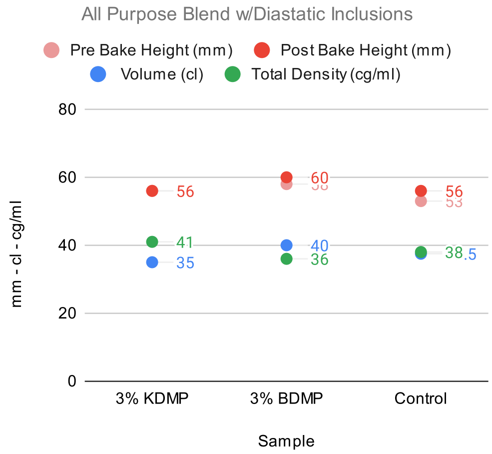
Note: In the Bolles samples, 0.5% KDMP showed an increase in quality. 1.5% KDMP inclusion is shown here, because this is the inclusion percentage that was used in the "In-Depth Bake Trials" shown below.

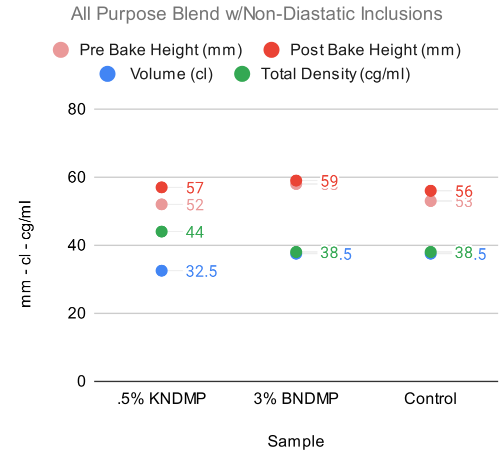
Commercial All Purpose Flour



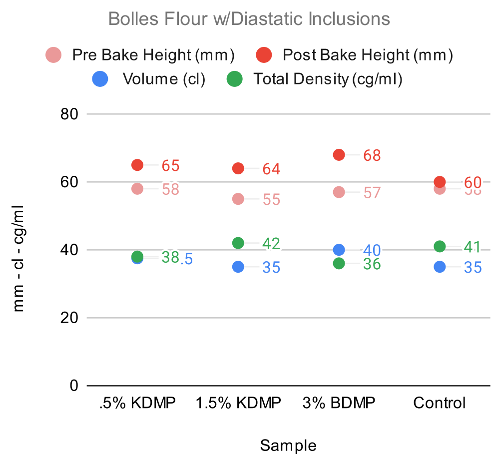


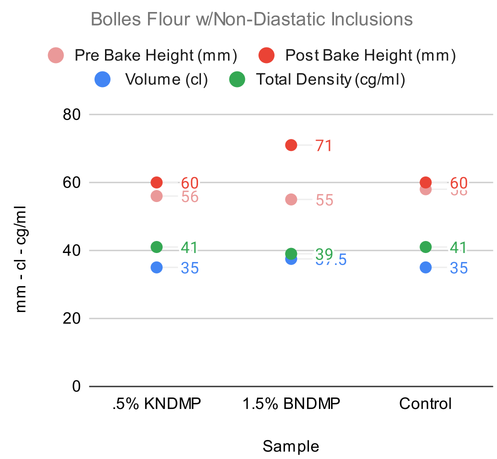
Perennial Pantry All Purpose Blend





Bolles Wheat Flour





Results Discussion

Given the way these graphs are laid out, an improvement in bread quality would show a higher number for “Post Bake Height” (red) and “Volume” (blue) with a decrease in “Density” (green). There would also be a greater distance between “pre” (light red) and “post-bake” heights. In other words, the cluster of dots representing each sample will expand in relation to the control.

There are a few things to note when comparing samples containing Kernza malt to the control samples. The overall effects were minimal. Aside from the commercial all purpose samples and the Bolles “.05% KDMP” sample, density went up consistently while volume either remained the same or dropped. This indicates that the malt had little effect on outcome: more elements were put into the dough which led to insignificant changes after baking. Same size but heavier. It may also show that KDMP is more effective at a lower inclusion rate. Both of the commercial all purpose samples, however, showed slight improvements in each parameter. Additionally, though some samples did not end up much taller than the control, it seemed that Kernza malt boosted total growth between pre and post bake heights.

Overall, there may be some indication of benefit when Kernza malt is used in commercial all purpose flour, and a decline in quality in hardier wheat flour varieties. When the Kernza and barley malt samples are compared, the graphs indicate much more consistent performance boosts on the side of barley. One slight diminish in quality is shown in the 0.5% BNDMP sample using commercial all purpose flour where the volume dropped and density increased. Overall, however, barley malt seems to boost height and volume significantly in all wheat flours. The boost generated in the all purpose blend was less dramatic.

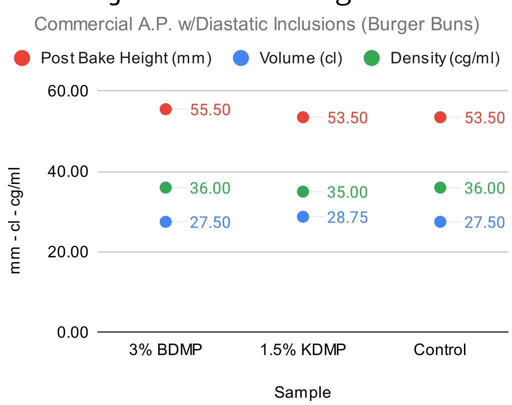
There are a few caveats in this analysis. It should be noted that each sample was baked only once. More accurate data would arise from compiling averages of each. Also, the environment and baking procedures were not standardized, so variables like pre-bake height and pre-bake fermentation rate most likely varied. If so, this would affect the post bake variables.

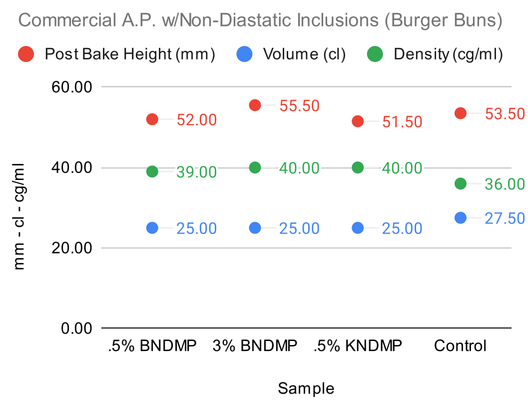
In Depth Bake Trials

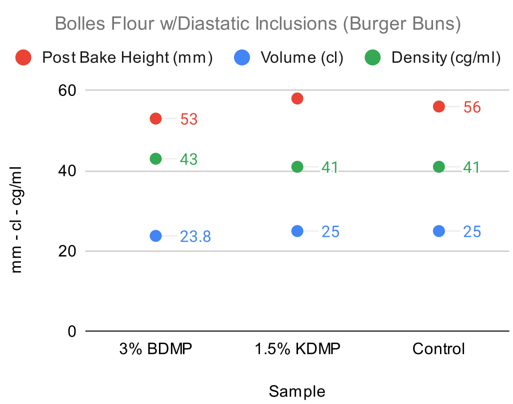
Much like the in depth bake trials conducted during the all purpose blend development (chapter 7), further applied testing was conducted using malt powder to gain an even broader understanding of the effectiveness (or lack thereof) of Kernza malt in an applied setting. This time, the selected baked goods were Burger Buns and Bagels. Take note that the previous section looking at most significant results varied slightly between the ferment and bake trials. For the in depth trials, every optimal malt inclusion percentage was tested, which is why some charts show four samples rather three.

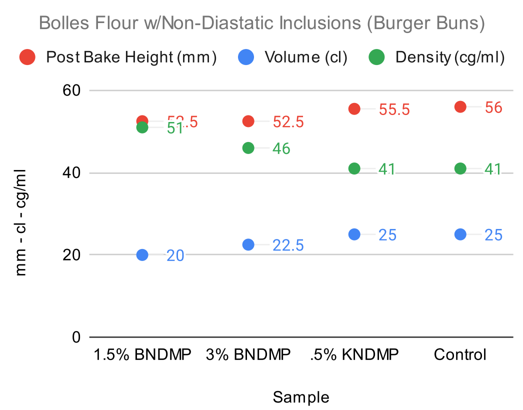
Burger Buns

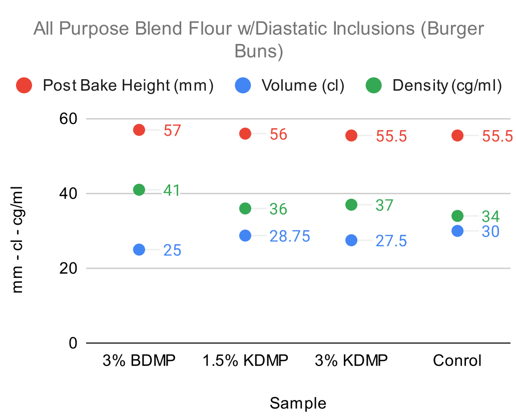
The burger bun recipe was acquired from Serious Eats and is shown below as well as in data charts similar to the previous bake trials. An additional inclusion contains very brief subjective tasting and observatory notes.

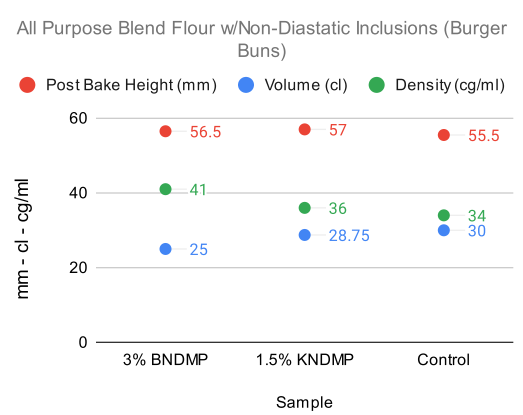












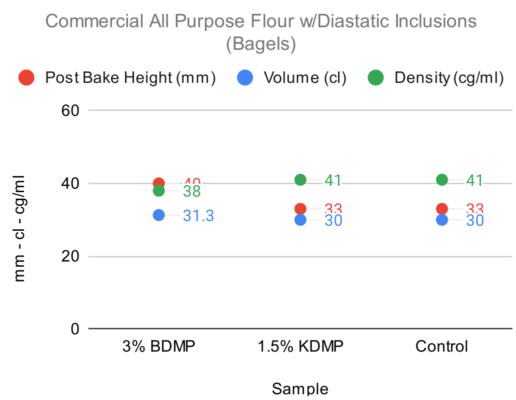
Results Discussion

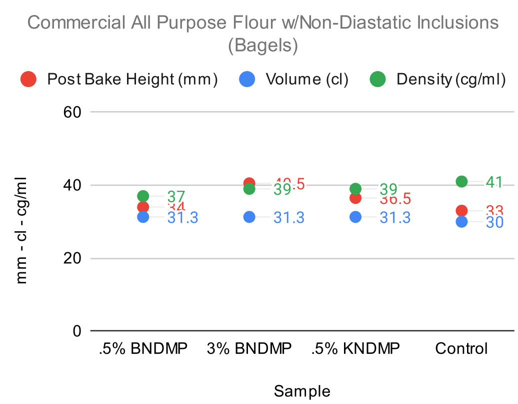
Mimicking the analyses in the previous trials. The Kernza malt powder samples will be compared to the control samples first. A slight improvement was seen in density and volume when diastatic Kernza malt powder was added to the commercial all purpose samples while the non-diastatic powder seemed to reduce quality. Each diastatic inclusion in the all purpose blend samples showed diminishing quality as well. 3% KDMP seemed to have a much greater negative effect than 1.5% KDMP. The non-diastatic inclusion only showed a slight increase in height. In the Bolles flour samples, the changes were too insignificant to draw any valid conclusions. However, there was no observable reduction in quality.

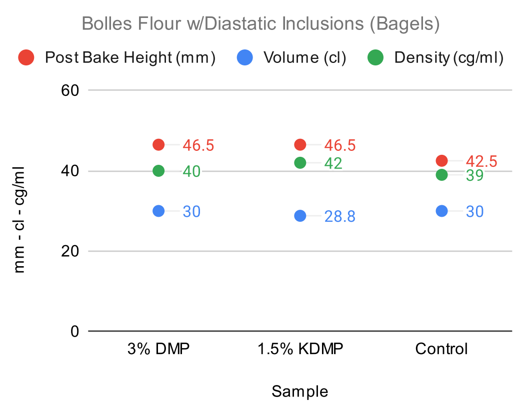
Comparing Kernza and Barley malt inclusions in commercial all purpose flour samples showed surprisingly similar results; they both seemed to diminish quality. In the all purpose blend samples, though showing a slight increase in height, the volume and density of the barley malt samples were much more negatively affected than those containing Kernza malt powder. This is also the case in the Bolles samples.

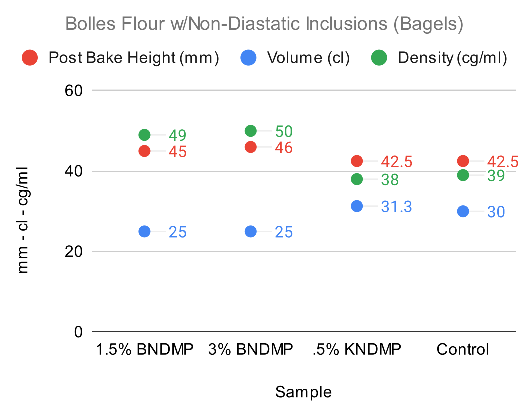
There are a few observational trends worth mentioning when it comes to Kerza malt powder inclusions: Kernza diastatic malt powder generally produces a more desirable flavor with more depth. Some control samples had a dry crumb, and it seemed that the Kenrza malt powder helped to retain a little moisture. The color was also darker. These subjective results also correlated with those of barley malt samples, but it was noted that barley malt lends a little more sweetness to the baked good.

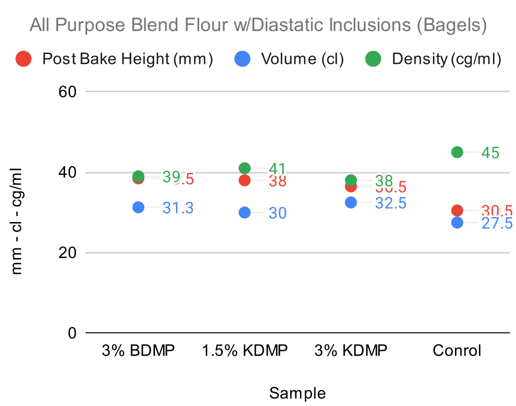
Bagels

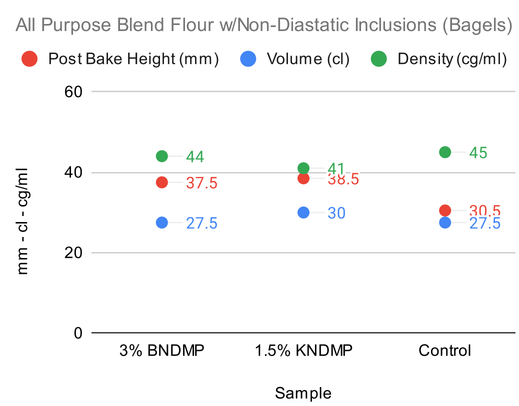












Bagels Results Discussion

Samples containing Kernza malt powder showed noticeable benefits to all purpose blend samples: Both diastatic samples improved post bake height, density, and volume. 3% KDMP showed the greatest change. The KNDMP sample also showed an improvement in each of the three parameters. Even compared to the barley malt inclusions, Kernza malt was roughly equal to or more beneficial than barley malt. Kernza malt in commercial all purpose flour had much less effect, but it also did not greatly diminish quality; it was either equal, or very slightly less desirable. This is somewhat consistent with barleys inclusions also. In the Bolles samples, KDMP only showed a significant improvement in height, and the other two parameters dropped in quality in comparison to the control. This was similar to the barley samples. In the non-diastatic Bolles sample, Kernza malt performed relatively the same as the control, showing little effect. The non-diastatic barley samples showed a much more significant drop in quality amongst the three parameters.

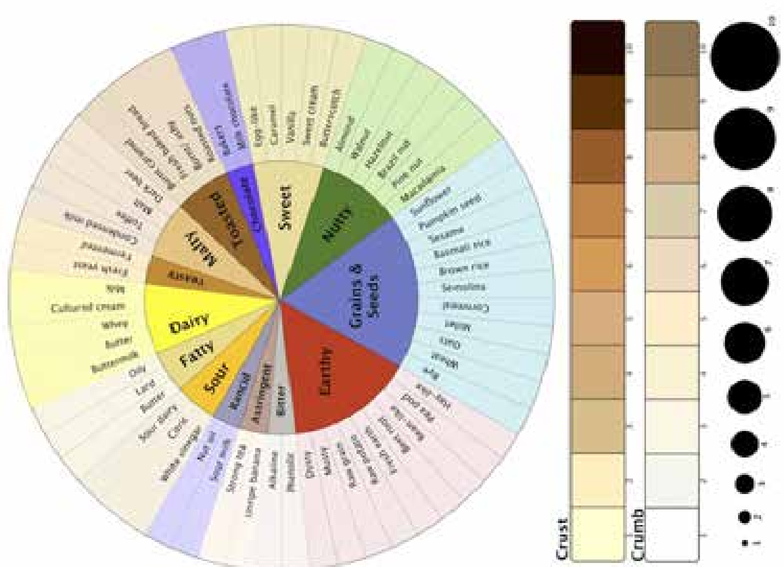
As far as tasting and observation goes, Kernza malt powder affects the baked good similarly to its effect on the burger buns. The color darkened and flavor was boosted. It also seemed to make the crumb noticeably softer with more distinct air pockets in some cases. A 3% KDMP inclusion produced the most significant changes in this regard. Again, the barley inclusions produced similar results with the addition of a boost in sweetness via the diastatic malt. A comment was also made involving both burger buns and bagels that dough containing malt powder (specifically diastatic) was easier to work with; it was a little less elastic and still maintained structure.

In House Sensory Analysis

Once all fermentation, baking, and in-depth baking trials were completed. A sensory analysis was conducted to expose Kernza malt powder to a broader audience. This analysis was conducted simultaneously with the malt tea sensory analysis mentioned above where students from the U of M and local chefs visited Perennial Pantry for a tour and testing. The analysis focused on subjective differences between bagels and shortbread made with commercial all purpose flour, Kernza malt powder, barley malt powder, and no inclusions.

Due to some advantages being seen amongst diastatic and non-diastatic Kernza malt powder, a special blend was made combining the two. For the shortbread, the Kernza malt powder blend was combined with milk powder to create a malted milk powder. This was pitted against a store bought barley malted milk powder. It should be noted that while our malted milk powder contained two ingredients, the store bought malted milk powder had sugar and other flavor enhancing ingredients added.

Each analysis used the chart below as a reference for color and detectable flavor compounds. The flavor wheel is similar to the flavor map used in malt tea and beer tasting.



Flavor Wheel

Bagel Results

Crust
Color averages:
Control: 2.8
Barley: 3.5
Kernza: 4.2
Texture notes written down by testers
Control: Nice, dense, slightly soft
Barley: Soft yet chewy, more chew
Kernza: Soft but dense

Crumb
Color notes written down (numbers were not used for this)
Control: A little dark, egg shell, off white/some yellow, tan
Barley: Off white, white/tan, tan
Kernza: A little dark, brown yellow, amber
Texture:
Control: soft, slightly crumbly
Barley: soft and chewy, tighter
Kernza: Chewy

Bagel Top 3 Flavors Detected			
Sample	Highest Potency	Middle Potency	Lowest Potency
Control	Grains & Seeds	Toasted	Sour
Barley	Fatty	Malty	Grains & Seeds
Kernza	Grains & Seeds	Fatty	Nutty

Bagels (BMP on the left, KMP in the center, and Control on right)

Shortbread Results: (Crust and crumb are not separated for this)

Whole Cookie
Color Averages:
Control: 1.4
Barley: 1.8
Kernza: 2
Texture notes:
Control: Crumbly
Barley: N/A
Kernza: Smoother, creamy

Shortbread Top 3 Flavors Detected			
Sample	Highest Potency	Middle Potency	Lowest Potency
Control	Fatty	Sweet	Yeasty
Barley	Malty	Astringent Toasted	Fatty
Kenrza	Bitter Nutty	Toasted	Astringent Chocolate Grains & Seeds Malty

Additional Notes/Comments:

Kernza malt has sweeter notes: banana or warm spice.
Kernza shortbread tasted very different/had more flavor - was good!

Sensory Analysis Takeaway:

In both bagel and shortbread analyses, Kernza malt powder had a few effects: the color deepened, flavor was boosted and more complex, and the baked goods were a little softer. It was noted that the bagel crust was a little dense overall, but it was still soft and palatable. It also seemed to have a positive effect on the bagel's crumb, taking a crumbly and somewhat dry crumb to one that was chewy; chewy, in this case, was a positive trait. Though present, the effects malt powder had on the bagels were not extremely dramatic.

When volumetric traits were less of a concern, as in shortbread, it seemed Kernza malt's effect was much more significant. The shortbread caramelized easier to produce a more golden color, the cookies were noted to have a smoother texture, and the flavor, again, was much more complex. Banana, and warming spice were among a few flavors detected. The flavor change can also be seen in reference to the chart provided above. The control had a more simple combination of flavors, while Kernza had a range from nutty and bitter to toasted, chocolatey, and malty.

Though Kernza malt may have slightly boosted texture in the bagels, it seems a more appropriate use for inclusion comes through if one should desire a more complex flavor with more even and darker coloration.

Sensory Analysis Event

Final takeaways

- Fermentation: Kernza malt powder may be beneficial in boosting fermentation rate in the early stages: around 30 minutes.
- Non diastatic malt powder (Kernza and barley) consistently increased density. In some cases height was increased.
- Diastatic powders showed the most significant boosts in quality in samples containing only Bolles flour
- This aligns with the role of diastatic powders: Bolles had a falling number of over 400, which, in some cases, there was an extremely low level of enzymatic activity in the flour. Supplementing enzymes from the malt mitigated the lack of enzymes present in the flour and aided in starch breakdown.
- Additionally, BDMP may have diminished quality in some commercial AP samples because increased enzymatic action is not needed as much.
- Kernza malt data loses some correlation when “most significant” trials are compared to previous trials: it seems to boost only the commercial all purpose flour samples.
- Post bake height and the difference between pre and post-bake heights consistently increased, however.
- Overall quality diminished when malt was added to burger buns. The more Kernza malt that was included, the greater the negative effect
- Kernza malt had generally significant positive effects on bagels; It improved physical measurements, and contributed to softness in the crumb.
- Effects were less significant in all purpose blend and Bolles flour samples.
- Perhaps diastatic malt powder shows more promising results in doughs that require a lot of strength development
- It was noted that diastatic malt inclusions made strong doughs easier to handle during the kneading process
- Kernza malt consistently boosted flavor, made crumbs softer and less crumbly, and deepened the color of baked goods.
- The most positive flavor attributes were revealed when Kernza malt powder was combined with milk powder and used in shortbread.
- Overall: the data is inconsistent: Kernza diastatic malt powder at an inclusion of 1.5% may help fermentation rates, but generally does not consistently improve final baked good quality.
- There is also significant overlap between Kernza and barley malt powders; across all trials, there were instances of Kernza malt powder adding more, an equal amount, or less benefit compared to barley malt powder. This may indicate potential to continue exploring the use of Kernza malt in baking settings as breeding continues. It is also important to keep in mind that the Kernza malt powder used in these trials was not of the highest quality seen in previous Kernza malt samples. Using a malt with better enzyme capacity could lead to an increase in benefit.

Chapter 9: What's Next?

A diverse array of organizations are working to scale up Kernza. Some focus on premium prices and large companies, others on basic research, still others on product development and awareness. The first several years of commercial availability have had more supply than demand, with uncleaned Kernza sitting in bins, awaiting markets. How will this crop move onto the landscape with clear demand, increasing impact, and continued improvement?

We believe this research has shown that researchers and industry should focus on Kernza's unique traits, not on its similarities with existing grains or possible impacts. Kernza is often billed as a cousin of wheat, but its low molecular weight gluten prevents wheat-like utility. Kernza can be malted, yet its lack of starch can't compete with barley's high starch content when it comes to extract production. Excitement around carbon sequestration abounds, yet research is still ongoing, and a perceptible benefit in this form will likely depend on location, soil type, climate, and more. Yields remain low, cleaning takes longer, and awareness is low. Despite these challenges, we believe there are enough demonstrated strengths and opportunities to focus on, which can create real impact on Minnesota agriculture.

What currently defines Kernza? It has wonderful flavor, a lot of bran, and a tangible impact on water quality. Flavor is a powerful lever for product adoption, and a compelling selling point for Kernza. Observed flavor impacts appear higher in baked goods than beer and spirits, in part because higher utilization rates work in baked goods.

Kernza's bran is a challenge. It makes sifting Kernza economically impractical, can contribute negative flavors, and limits baking utility. However, it also offers incredibly high dietary fiber, an important component of microbiome health.

Minnesota's investments in Kernza research and deployment have led to early acreage on Drinking Water Source Management Areas (DWSMAs). One planting in Edgerton, MN has reduced city drinking water nitrate levels 30-40%. With low acreages and many rural communities facing drinking water pollution from agriculture, targeted deployment of the first tens of thousands of Kernza acres should be focused on DWSMAs and areas of maximal impact on watersheds. This can materially benefit greater MN, provide a return on state investment in the crop, provide more affordable Kernza for markets, and establish this new industry.

Malting Kernza

Cleaned, dehulled Kernza has been selling for \$4-6/lb, a price significantly higher than any other grain. This is an immediate barrier to malting Kernza commercially. Small maltsters typically buy barley for \$0.10-0.50/lb, and sell malt for \$0.85-1.25/lb. Depending on margins, Kernza malt could be prohibitively expensive to malt.

A potential market with more willingness to pay for Kernza malt is the distillery industry. We supported research by Jeff Bradford at Heriot-Watt University into a single malt whiskey made with 100% Kernza malt. His paper is forthcoming, but he successfully distilled a single malt with Kernza.

Malting for distilling markets could also be fruitful based on malted Kernza's ability to contribute more enzymatic capacity than extract. Distillers could work with maltsters on high enzymatic Kernza malt, and use this to convert adjunct grains to create unique, compelling spirits with real utility being offered by Kernza.

The small percentages of malt powder used in baking could also make high prices tolerable. With a meaningful flavor contribution, some bakers may find malted Kernza powder a novel new ingredient.

For brewers unable to afford malted Kernza, roasting Kernza may be a preferred strategy for increasing the flavor contributions of the grain.

Future Research

We believe continued focus on flavor during breeding is essential to expanding Kernza's adoption. Integrating supply chain trials early on during breeding to ensure flavor isn't lost should be prioritized. Additional food science research into understanding Kernza's flavors could be important to safeguarding it during breeding.

Additional food science and nutrition research into Kernza's high dietary fiber levels would benefit potential health claims for products made from the crop by providing an expanded understanding of how Kernza's unique nutritional profile impacts human health, especially within the framework of the microbiome. Characteristics of Kernza that are considered limiting factors when compared to wheat (high bran, low starch, poor structure forming protein), should be considered positive traits unique to Kernza: high fiber, low gluten, high protein overall. Additional research into the development of compelling products highlighting these traits will greatly benefit Kernza.

Conclusion

Kernza is a new technology for an existing industry. Much like renewable energy, it offers the opportunity for a superior product without negatively impacting the environment. Solar and wind energy took decades of research and development and state investment, but are now growing incredibly fast and offering a superior economic opportunity in comparison to traditional energy. Solar installers for private homes typically lead with an economic argument for how to save money on your utility bill, and see the environmental benefit as a secondary reason to install panels.

Kernza needs to have additional reasons beyond the environmental impact of the crop to gain traction and use. With yields still low, what is the value proposition that meets the price needed to convince growers to plant it? While some consumers will pay this price for the environmental impact, other reasons are needed to create real market momentum. Those active in boosting Kernza's commercial impact must play to its strengths to communicate real value and grow sustained demand. Pursuing research and development around the crop's novel flavor, high bran content, and demonstrated water impacts are the most compelling opportunities we have uncovered in this research, and the direction we believe future work should take.

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