Kernza® Perennial Grain

Building Sustainable Supply Chains, Enhancing Value-Added Uses, and Assessing Post-Harvest Handling Practices

August 2024

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For information on this report, please contact:

reports@auri.org

Agricultural Utilization Research Institute
510 County Road 71
Suite 120
Crookston, Minnesota, 56716
www.auri.org

Executive Summary

This project, supported by the Stearns County Soil and Water Conservation District (SCSWCD), focused on developing sustainable supply chains for Kernza® perennial grain, an emerging small grain crop being developed by The Land Institute in collaboration with the University of Minnesota and other research partners. Kernza is notable for its positive environmental benefits, providing deep-rooted, continuous living cover that can preserve soil health and water quality. Wider adoption of the crop by farmers requires the development of viable end markets.

Technical and commercialization staff at the Agricultural Utilization Research Institute (AURI) engaged in multiple activities supporting the goal of market development. This work included the identification and development of value-added uses for the crop, assessment and optimization of processing and handling methods, and engagement with private sector businesses and external research partners to build stronger commercialization and supply chain networks for Kernza.

Post-harvest handling of crops plays a critical role in market development by ensuring that agricultural products maintain their quality and value from the farm to consumer. AURI technical staff assessed cleaning, drying, and storage methods and conditions for Kernza. Information developed during these trials was aimed at filling gaps in knowledge and offering a foundation for ongoing assessment of on-farm storage conditions and post-harvest grain handling methods.

As part of its focus on technical assistance, along with product and process development, AURI partnered with multiple businesses and external partners to assess potential value-added uses by testing and demonstrating food and non-food uses for Kernza. Market development in the beverage industry was a focus, with pilot projects on malting, brewing, distillation, and flaking all providing promising results and a foundation for future product development by Minnesota businesses. The use of Kernza in other food applications was also assessed, providing additional information on flour quality and characteristics, production, and utilization of malt in food products, including baked products. Additional research included the use of Kernza straw in biocomposites and the development of several prototype products.

This work was underpinned by a strong focus on networking, outreach, and information sharing. While there are many potential opportunities for Kernza utilization, successful adoption will require the development of more mature, robust value chains, reducing barriers for end users to add Kernza to their product offerings. Events, meetings, information sharing, and outreach have

all been emphasized as paths to share information, identify potential stakeholders, and fill gaps in the value chain.

This final report summarizes the project's findings, providing a foundation for ongoing Kernza market development activities in Minnesota and beyond.

Acknowledgments

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Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR). The Trust Fund is a permanent fund constitutionally established by the citizens of Minnesota to assist in the protection, conservation, preservation, and enhancement of the state’s air, water, land, fish, wildlife, and other natural resources. Currently 40% of net Minnesota State Lottery proceeds are dedicated to growing the Trust Fund and ensuring benefits for Minnesota’s environment and natural resources.

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Project overview

The Agricultural Utilization Research Institute (AURI) partnered on a three-year project led by the Stearns County Soil and Water Conservation District (SCSWCD) to evaluate the effectiveness of aging Kernza® perennial grain stands on water quality and the development of sustainable supply chains, with a focus on post-harvest processing. Kernza® is the trademark name for grain from intermediate wheatgrass (IWG)[scientific name Thinopyrum intermedium], a perennial relative of annual wheat developed by The Land Institute. (The Land Institute, 2024) As a deep-rooted perennial crop, Kernza can provide multiple ecosystem services, including reduction of nitrate leaching, soil protection, carbon sequestration, and wildlife habitat. Expected project outcomes included profitability enhancement by maintaining mature Kernza stand yields, sustainable supply chain development, and identification of new value-added uses of the crop.

AURI led the efforts to build sustainable supply chains, enhance utilization, and assess storage and handling techniques for Kernza. Work on this activity included four key activities:

- Identify and evaluate methods for post-harvest handling, cleaning, drying, and storage of Kernza;
- Provide technical assistance to Minnesota businesses developing Kernza-based products and processing capacity;
- Disseminate information developed during the project through events, publications, and other outreach activities, and;
- Support grower profitability and sustainability through ecosystem services markets and continued supply chain development.

AURI's commercialization, technical, and outreach teams pursued this work in collaboration and coordination with a wide variety of partners in the private, public, and nonprofit sectors in Minnesota and beyond. These efforts were built on a foundation of research, partnerships, and stakeholder networks developed by AURI during previous LCCMR-funded Kernza projects (AURI, 2022).

Post-harvest handling

Effective crop storage and handling practices are crucial to ensuring that processors and consumers have access to high-quality products. Adoption of best practices for storage and handling also helps farmers preserve the quality of grains, preventing spoilage and minimizing storage losses which if not addressed, can lead to significant negative economic outcomes. Proper post-harvest handling practices can extend grain storage life, maintain grain quality during transportation and distribution, improve stored grain quality, and minimize damage. Identification and adoption of quality storage and handling practices can enhance the quality of value-added products and support sustainable agricultural practices by reducing waste.

As part of its focus on identifying and evaluating methods for post-harvest handling of Kernza, AURI's technical team performed storage and drying trials, and offered information and technical assistance to individuals and groups interested in developing cleaning and dehulling systems.

In-Hull (L) and dehulled (R) Kernza perennial grain, AURI.

Cleaning and dehulling

During this and previous LCCMR-funded projects, AURI technical staff developed and refined processes for cleaning and dehulling Kernza, releasing publications with information on recommended equipment and processes. (AURI, 2022) This knowledge base served as a foundation for ongoing outreach and technical assistance efforts. AURI offered technical assistance to existing Kernza cleaning and dehulling entities as they worked to refine their processing methods and increase their capacity. Support was provided to the Perennial Promise Growers Cooperative (PPGC) as it developed a mobile grain-cleaning system. AURI's staff met with and provided information to individuals studying the market feasibility of offering cleaning, processing, and aggregation services in Minnesota for specialty small crops, including Kernza.

AURI and partners also developed an informational video on the Kernza cleaning process for potential processors. The video highlights the cleaning and dehulling process refined during this project and was featured during events in spring 2024, shared with Kernza supply-chain contacts, and uploaded to AURI's YouTube channel for ongoing dissemination.

Screenshot from "The Process of Cleaning Kernza® Perennial Grain," AURI 2024. Available online at https://www.youtube.com/@AURIMN

Drying

Grain drying "refers to the removal of some of the moisture from grain by mechanically moving air through the grain after it has been harvested" (Hellevang, 1994). While grain can dry naturally in the field prior to harvest, adverse weather may create conditions where farmers need to harvest grain at moisture levels that are too high for safe storage without additional drying.

Harvesting at higher moisture levels can also help reduce loss to shattering during harvest. Kernza ripens from the top of the seed head down, creating challenges in harvest timing. Delaying harvest until the entire head has matured and grain moisture levels are safe for storage makes the crop more susceptible to shattering, creating a situation where "waiting to harvest at safe moisture content" can result in yield losses (Jungers, 2019). The ability to dry grain harvested at higher moisture levels may offer opportunities to realize a higher yield and improve farmers' economic returns.

Agronomists currently recommend that "bin-grain should be <15% moisture at the time of harvest" (Tautges, Detjens, & Jungers, 2023). Current recommendations for on-farm post-harvest storage of Kernza call for the use of "either tube fans that can auger down into grain in totes or gravity wagons, or bins equipped with fans," and note that "full floor aeration is best, if possible." While these practices slightly reduce moisture levels, they are limited in their ability to dry grain harvested at higher moisture levels. In these instances, the use of heat and grain dryers may be required to reduce moisture to enable safe, long-term storage. Kernza researchers have recommended that farmers "proceed with caution" when using these methods to avoid potential grain damage, noting in a 2023 production guide that "not much is known at this point about heated grain drying with Kernza" (Tautges, Detjens, & Jungers, 2023).

To begin filling this knowledge gap, AURI performed Kernza grain drying trials at its Bioindustrial Innovation Center in Waseca, Minn. Prior to the 2023 harvest, AURI contracted with a Kernza producer in southern Minnesota to obtain grain harvested at moisture levels that would require drying. Unfortunately, hot, dry weather tied to an ongoing drought led to very dry conditions during the harvest window, making it impossible to obtain grain samples at harvest moisture levels that would enable mechanical drying trials. The moisture levels at harvest were dry enough for storage, so the Kernza was first used for storage trials. Following this storage period, water was added to the grain to raise its moisture level from 9.6% to 16%, and drying trials were performed. While the drying trials showed Kernza can be successfully dried, the volume of hulls may create issues with free-threshing and potential grain loss. A full report on these trials and their results can be found in Appendix A.

Storage

In previous research on post-harvest handling of Kernza, AURI reported that while "keeping the grain below 14% moisture should ensure Kernza maintaining its condition, drying the grain to 8-12% moisture is preferable." While making these recommendations, AURI also noted that further testing and research would be required to better understand the “storage of Kernza grain under ideal conditions” and what impact storage would have on grain quality. (AURI, 2020)

As part of its work on this project, AURI performed trials focused on assessing Kernza quality and stability when stored following its recommended guidelines. Grain for these storage trials was harvested in August 2023 in southern Minnesota and transported to the AURI Bioindustrial Innovation Center for preparation and storage. The grain was divided into two lots for storage, with one remaining in-hull and the other being cleaned and dehulled before storage, to assess what impacts, if any, this difference would have on quality metrics measured during the trials.

Grain in both lots was stored at a moisture content of 9-10%, and samples were taken for analysis every two months. Proximate data (protein, fat, ash, carbohydrates) varied minimally throughout the storage period in both lots, with no negative impacts to grain quality being noted. Observations of microbial activity (bacterial, mold, yeast) indicated that grain cleaned and dehulled before storage tended to show lower levels of microbial activity. Aflatoxin and deoxynivalenol/vomitoxin (DON) levels measured in both lots met federal standards for human consumption (National Grain and Feed Association, 2024). Appendix B provides a full report on these trials and their results.

Developing value-added uses

As markets are still emerging for Kernza, developing and assessing new value-added uses has remained a key area of activity for establishing a mature supply chain. Without continued development and refinement of Kernza-based products, sustainable supply chain expansion will be limited, and wider grower adoption, due to a lack of market opportunity, will be stymied. While multiple Kernza-based products (Kernza.org, 2024) and publications (The Land Institute, 2024) have been developed and released over the past several years, the volume of information on Kernza and its uses remains limited relative to other small grain crops.

Processing at all levels (primary, secondary, and tertiary) will play a key role in the future success of Kernza's market development. AURI focused a notable part of its activity over the past three years on these vital supply chain areas, pursuing pilot research aimed at developing information for processors and building connections in the vital intermediate stages of the Kernza value chain. Access to reliable sources of ready-to-use grain and processed ingredients will ease barriers to market entry for wholesalers and retail producers of consumer products. While early adopters may be more willing to deal with the challenges and uncertainty of an ad hoc ingredient procurement system, scaling of production will require the establishment of supply chains with predictability, consistency, and availability. In addition, access to information on how to use Kernza grain and ingredients to produce high-quality products will help reduce the risk of adoption for end users.

As part of its market development activities, AURI provided multiple companies and research partners in Minnesota and surrounding states with Kernza samples and technical information. The technical and material assistance enabled activities including ingredient assessment, product formulation, and evaluation of processing methods, as well as the development of pilot projects and new Kernza product launches in coordination with AURI.

AURI's commercialization and technical teams identified several value-added uses for heightened focus and effort, most notably in alcoholic beverages. Brewers and distillers have been early adopters of the grain in Minnesota and around the United States. Development and dissemination of information on the use of Kernza in malted ingredients and fermented beverages is aimed at reducing barriers to wider adoption, potentially streamlining the development of market-ready products by Minnesota businesses.

Distilling

Around the United States, a handful of pioneering distilleries have begun producing Kernza-based products, opening wider interest in the grain as an ingredient in whiskey. Early adopters highlighted the grain's flavor profile as a "major selling point." Distillers reported a "genuinely unique" flavor profile that, while holding some similarities to rye and wheat, also carries a "subtle nuttiness," along with "sweet and floral" notes. Most distillers working with the grain have used it in blends with other grains due to Kernza's relatively high price point (Brooks, 2023).

AURI partnered with the Rahr Technical Center (RTC) in Shakopee, Minnesota to perform distilling trials and prepare a report on their findings. (See Appendix C.) These trials included preparing a batch of malted Kernza and developing a malted Kernza American Whiskey. This whiskey was produced using 51% Kernza malt and 49% Rahr Distillers malt. A batch of whiskey using 100% Rahr Distiller's Malt was also produced for comparative purposes. As part of the trials, data was collected on the malting, mash, fermentation, distillation, and accelerated aging processes. Initial tasting notes were also compiled during the aging process, with Rahr noting that the Kernza Whiskey had a “very sweet flavor with a unique spiciness.”

Following the completion of aging, a tasting analysis of the final product was conducted. Tasting notes from this review can be found in Appendix D.

Malting

The RTC and AURI pursued malting pilot work throughout the course of this project. This work developed new information on processing, assessing the production of specialty ingredients, and providing malted grain for use in further project development work by AURI and external collaborators. Analytical data on the pale malt that was produced for use in these product trials was compiled into a malt information sheet, offering additional guidance to brewers and distillers about Kernza malt and its potential utility as an ingredient. (See Appendix E)

While the RTC has successfully produced multiple batches of Kernza malt, its report on the malt process associated with the whiskey development trials noted that “working with Kernza in the malthouse and the brewhouse requires patience and adaptability” to manage the small kernel size appropriately (Rahr Technical Center, 2023). Kernza kernels can be broken during the dehulling process, which negatively impacts germination rates and may lead to the production of under-modified malt. Kernza producers seeking to sell grain to maltsters will need to take care to limit seed damage during cleaning. Separation and removal of broken kernels can also improve results during malting but may require special equipment. During the whiskey development trials, an indent separator was used to remove broken seeds prior to malting.

In addition to pale malt production, AURI also partnered with RTC to develop and assess the use of Kernza in specialty malts. This work moves beyond the production of pale malt to explore the use of Kernza in malts that are kilned to produce darker colors and different flavor profiles for use in the brewing and distilling industries. Two types of specialty malt, Vienna and Munich, were successfully produced as part of the pilot. A wort produced with the Munich malt was formally analyzed by a trained sensory panel. Panelists were impressed, with RTC reporting that the flavor and aroma of the wort “stand apart from any other worts ever tasted by this panel.” Comparative descriptors used by panelists included sweet, spiced, fruity, nutty, and bready. RTC described the overall results of the trials as “very encouraging,” noting that the “very unique and prominent attributes” that were observed should “increase the appeal and justification for malted Kernza as a specialty ingredient in brewing." RTC also noted that "there must certainly be more flavor and aroma to be unlocked with even higher color malts," and that the trials could serve as a foundation for further incremental work on darker malts (Rahr Technical Center, 2024). For a full report on this work and its results, see Appendix F.

Table 1: Selected Kernza Malt Trials

Pilot Partner(s) (Name/Type)	Trial Product(s)	Trial Notes
Rahr Technical Center	Kernza Malt	Grain was malted and distilled into whiskey (See Appendix C)
Rahr Technical Center	Kernza Malt	Produced a pale malt (9 SRM) for use in brewing, distilling, and malted flour pilots (For analytical details on this malt, see Appendix E)
Rahr Technical Center	High Color Kernza Malt	The development and assessment of high-color specialty malts (roasted, kilned) for use in the brewing and distilling industries. (See Appendix F)
Beth Dooley's Perennial Kitchen	Grain Bowls	Demonstrate malt Kernza as an ingredient in grain bowls at the 2023 Minnesota State Fair.
Fermented Food and Beverage Producer	Sake	Initial assessment of use as an ingredient in sake.
Modist Brewing	Saison	Development of a barrel-aged, wild-yeasted saison. Beer to be released as part of a Kernza-focused event in October 2024, hosted by AURI and project partners.
Clean River Partners, Imminent Brewing, Chapel Brewing	Beer	AURI partnered with Clean River Partners, a Northfield, Minn.-based water conservation nonprofit, to provide samples of Kernza to breweries in its region for use in product development. Imminent Brewing (Northfield, Minn.) piloted a brown ale and Chapel Brewing (Dundas, Minn.) produced a pilsner.
Craft Distillery	Bourbon	Sample provided to a Minnesota-based distillery for ingredient assessment.

Flaking

While malting Kernza may provide brewers and distillers with a unique and potentially interesting ingredient, production to date has been limited to small-scale pilots. A lack of commercial processing means that malted Kernza will remain limited in availability and high in price until wider production begins. Even once adopted by maltsters, the cost of malting coupled with Kernza's high-cost relative to other grains used in brewing and distilling, will likely lead to a product being sold at premium prices in the initial stages of commercialization. Brewers and distillers wanting to use Kernza are likely to look to clean, dehulled grain as their main option for the foreseeable future.

While unprocessed grain kernels can be a particularly useful ingredient for alcoholic beverages, they offer some challenges to end users. Milling is often required to allow enzymes and water to penetrate and efficiently convert the grain. Unmalted grains tend to be "somewhat plastic" and can be more "difficult for normal brewing roller mills" to process than malted grains, which are more "crisp and friable." Distillers working with Kernza noted that it can be difficult to mill due to its small size (Brooks, 2023). Flaking provides a grain ingredient that may be used without milling, offering brewers and distillers an additional option when formulating products. (Hansen, 2022)

To assess Kernza's utility as a flaked ingredient, AURI worked with the Northern Crops Institute (NCI) in Fargo, N.D. to perform Kernza flaking trials. Six samples of Kernza were flaked using a variety of heat and moisture treatments. The process included moisture tempering, warming the seeds before flaking, and moisture treatment after flaking, and was found to produce "very nice flakes," with "low flour" levels. More details on the methodology and outcomes of these trials can be found in Appendix G.

After processing, the six sample batches of Kernza were sent to the RTC for analysis of their potential utility as a brewing ingredient. A wort analysis included the appearance, extraction, viscosity, and taste of each sample. NCI identified one sample as having "very nice flakes" and the same sample was singled out by RTC as the "clear choice for preferable flake" for use as an ingredient for brewers and distillers. More details of RTC's analysis are included in the analytical report found in Appendix H.

Following these trials, NCI prepared additional flaked Kernza to enable further assessment of the ingredient by Minnesota-based brewers and distillers. While trials remain underway, one brewer who received a sample for assessment provided positive feedback, noting good results during the mashing and brewing process.

Flour analysis

To provide more information to bakers, AURI contracted NCI to perform a selection of tests assessing the flour and dough qualities of Kernza. This rheological analysis was performed on a sample of Kernza harvested in August 2023. These tests offer more data points on the quality and utility of Kernza flour, complementing previous work in Minnesota by AURI (AURI, 2021), artisan bakers (Perennial Pantry, 2021), and university researchers (Ismail, Schoenfuss, & Marti, 2017).

In addition to measuring the moisture, wet gluten content, gluten index, and falling number of the Kernza, NCI performed the following dough quality tests (Wheat Marketing Center, 2004) as part of its analysis:

- Farinograph (flour water absorption and dough strength)
- Extensograph (dough extensibility and resistance to extension)
- Alveograph (dough strength)
- Mixograph (flour water absorption and dough mixing characteristics)

In assessing the results, NCI technical staff noted that wet gluten content in the Kernza samples was "significantly lower compared to Hard Red Spring Wheat (HRSW)," which reflects Kernza's "minimal gluten-forming proteins. The falling number was also "close to the minimal desirable level," for wheat, indicating enzymatic activity that could "cause quality issues during baking." Previous research by Perennial Pantry had also identified relatively low falling numbers in Kernza flour but noted that the numbers "provide 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" (Perennial Pantry, 2021). Low falling numbers (and their associated enzymatic activity and impacts on starch quality) are caused by pre-harvest sprouting damage and are influenced by harvest timing and weather conditions (Brouilette, 2020).

The NCI dough quality tests showed a "stability comparable to that found in soft wheats." While weaker and less extensible than HRSW, the NCI research team noted that Kernza flour "still presents numerous applications and opportunities." A full report with detailed results of NCI's tests can be found in Appendix I.

Malt Flour

Malted barley and wheat flours are specialty flour products produced by milling grain that has undergone malting. To assess the viability of Kernza as a malt flour product, AURI partnered with a Minnesota-based milling company to mill a sample of the malted Kernza produced during malting trials with the Rahr Technical Center. As part of these pilot tests, the miller worked with both whole-grain and sifted-grain and provided feedback on both processes.

For the whole grain milling analysis, the malted Kernza was stone-milled with granite stones using the miller's "standard" settings for most wheats. The miller reported "significantly fewer issues" compared to their experiences milling malted barley and noted that the "ease of milling" might be attributed to low moisture levels in the Kernza (4%). The final product texture was described as "fluffy/light, with relatively even particle size for the flour and bran/germ layers." The miller noted that when milling malted barley, they "often must slow down the auger speed to allow the grain to have more time between the millstones and produce a finer flour with a more even particle size. This was not the case for the malted Kernza."

For the sifted milling analysis, the miller made use of a stone mill with a gyro sifter to sort and screen the malted Kernza grain. The screening process used two 8MF (180 Microns/53% open area) screens and one 30GG (670 Microns/53% open area) screen to "separate the coarse bran from the medium-sized germ." The miller reported an "exceptional" extraction rate of 93.9%, which exceeded the 75-85% target for most wheats. Bran and germ layers were reported to be "clear and distinct," showing a "great separation" of the grain components. The miller described the final flour as "very fluffy and light and yellow/tan in appearance with a few darker flecks of brown."

AURI provided malt flour samples to several Minnesota-based food businesses for assessment and product formulation tests. Participants used the samples in a variety of products (see Table 2) and some provided additional feedback following their trials.

Table 2: Kernza Malt Flour Trials			
Pilot Partner Type	**Malt Flour Type(s)**	**Trial Product(s)**	**Trial Notes**
Artisan Bakery	Sifted, Whole Grain	Bread	
Artisan Pizza	Whole Grain	Pretzels, Bagels, Pizza	Not ideal for their pizza crust recipe- impacted rise.
Coffeehouse/Bakeshop	Sifted, Whole Grain	Waffles	Waffles were "really delicious." Tested recipes with 50/50 and 60/40 ratio of all-purpose to Kernza malt flour. Worked similarly to regular whole wheat flour.
Bakery	Whole Grain	Bagels	
Restaurant	Whole Grain	Cookies, Cinnamon Rolls	
Artisan Bakery	Whole Grain	Shortbread Cookies	
Chef, Food Educator	Sifted	Crackers, shortbreads, breads, pie crust, other baked goods.	A "very nice" flour. Fat absorption creates a delicious "toffee-like firm crust" in shortbread. Great when mixed 50% with pastry wheat flour in pie crust. "Best attributes are its flavor – malty and nutty – and the way it absorbs butter."
Artisan Bakery	Sifted, Whole Grain	Sweet and Savory Baked Goods	Requires less hydration in breads, more time to rise/rest. Was "wonderful" in their sweet cake recipe. "Nutty, good crumbly texture."

Biobased Materials

The development of value-added uses for non-grain Kernza biomass represents another opportunity to build more sustainable markets for the crop. Typical straw yields for Kernza can range between 1.4 and 4.5 tons per acre (3 to 10 Mg ha−1), with some researchers reporting yields over 5.3 tons per acre (12 Mg ha−1 a). While this straw "has the potential for use in total mixed rations for dairy cattle as animal bedding or as a biomass feedstock," (Hunter, Sheaffer, Culman, Lazarus, & Jungers, 2020) identification of higher-value uses may provide more economic opportunities for producers.

One potential application explored by AURI was the use of Kernza straw in biocomposite materials. Working with c2renew, a North Dakota-based material designer and custom compounder, AURI piloted the use of Kernza straw as a natural filler in polylactic acid (PLA) resin based biomaterials. As part of these trials, c2renew produced PLA/Kernza biocomposite pellets (nurdles) for use in injection molding. The pellets were then sent to third-party molders for the production of several prototype products including cups, plates, bowls, and golf tees. A report from c2renew, including more details about its compounding trials, the molding process, and a technical data sheet offering specifications for injection molders, can be found in Appendix J.

Injection molded products made with biocomposites incorporating Kernza straw, AURI 2024

Supply chain development

Over the past three years, the Kernza supply chain in Minnesota has continued to develop. While markets for the crop remain in a nascent state of development, organizations and companies are engaged at all stages of the value chain, offering the potential for continued growth and scaling.

Kernza supply chain development remains a work in progress, but wider market trends may offer support for maturation over the coming years. A 2023 report from Archers-Daniels-Midland (ADM) states that nearly three-quarters of American consumers "agree that the majority of their food and beverage options would ideally be sustainably sourced," and "expect companies to sustainably source their ingredients and products." Its survey of executives in the retail and consumer packaged goods (CPG) industries found that the "overwhelming majority" believe that regenerative agriculture programs can have a positive impact on their company's reputation and performance, with most CPG companies already having a program in place (ADM, 2023). This move toward more sustainable practices to meet consumer demands may support expanded market attention for crops with positive environmental profiles, including Kernza.

Figure 1: Kernza Value Chain Map

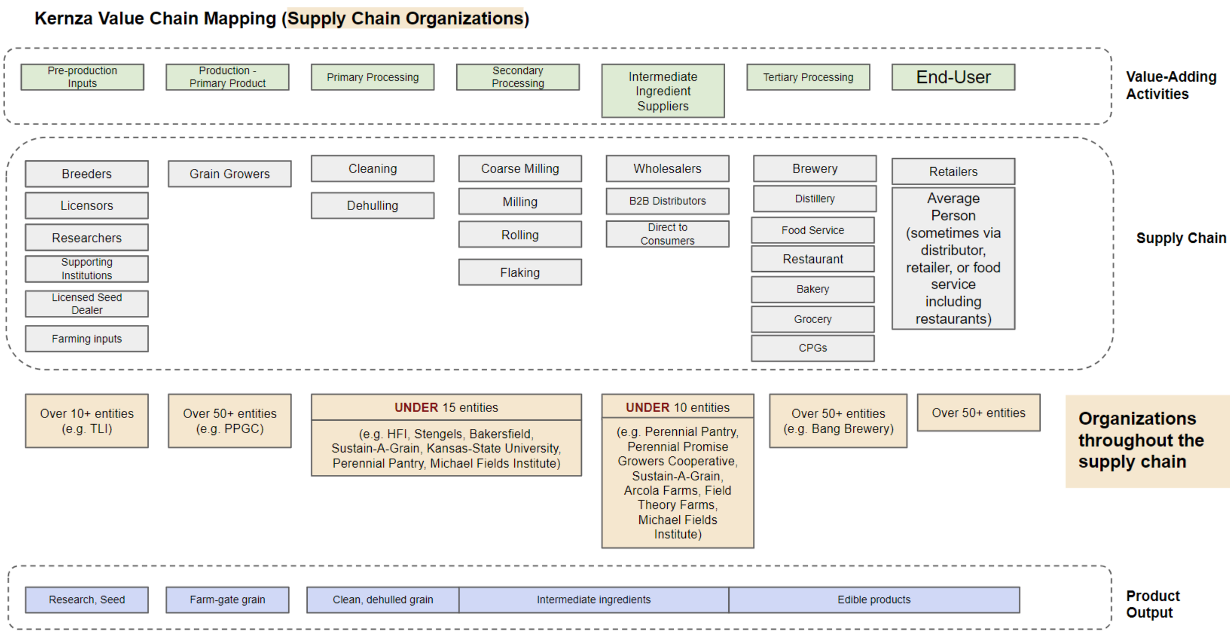

Figure Credit: This figure was adapted by The Land Institute from the supply chain map in "2024 F.G.I Kernza Market Scan" which was supported by AFRI Sustainable Agricultural Systems Coordinated Agricultural Project (SAS-CAP) grant no. 2020-68012-31934 from the USDA National Institute of Food and Agriculture. This work is also funded in part by the Walton Family Foundation.

Source: The Land Institute. Used with permission.

While there are now multiple millers handling Kernza, and there have been "significant investment in supply chain, sales, operations, and manufacturing" by several "early supply chain Kernza® businesses," a 2023 analysis by the Forever Green Initiative notes that "much more investment is needed" (Chute, 2024).

Table 3: Minnesota companies with Kernza-based products (Feb. 2024)		
Producer	**Product(s)**	**Location**
Artisan Naan Bakery	Naan, pita pockets, pizza crust	St. Cloud
Baker's Field Flour and Bread	Cookies, flour, grain	Minneapolis
Bang Brewing	Lager, Farmhouse Ale, IPA	St. Paul
Beaver Island Brewing	Kernza Saison	St. Cloud
Doughp Creations	Sourdough boules, maple Kernza hearts (baked good)	Granite Falls
LocAle Brewing	Farmhouse Style Cream Ale, Pale Lager	Mankato
New London Food Co-op	Flour	New London
Perennial Pantry	Whole Grain, Flour, Flour Blends, Crackers, pancake/waffle mix, pasta	Northfield
Perennial Promise Growers Cooperative	Grain, Flour	Statewide Cooperative
River Rock Kitchen & Baking	Shortbread, sourdough	St. Peter
St. Peter Food Co-Op	Whole grain Kernza	St. Peter
Sturdiwheat	Honeyed Kernza muffin mix, pancake mix	Red Wing
Tattersall Distilling	Whiskey	Minneapolis and River Falls, Wis.
(Chute, 2024)		

Developing processing capacity

As an emerging crop undergoing ongoing improvements to grain size, yield, and other breeding attributes that affect grain consistency and quality, working with Kernza can prove challenging for existing seed cleaners and initial ingredient processors.

Additionally, because scaling Kernza adoption continues to fluctuate with market demand, right-sized aggregation, cleaning, and initial processing are important factors enabling ingredient market access to Kernza. Development in this part of the supply chain will not only improve the timeliness of getting grain to market but also the ability to aggregate larger quantities of cleaned grain for larger buyers. Based on conversations with project collaborators and industry stakeholders, there are currently several types of facilities that deserve further focus for supply chain development. These include seed cleaning, storage, and grain processing (toll processing for flaking and organic/conventional malting) that can accommodate specialty crops.

Even when processing capabilities exist, the number of companies offering processing may be very limited. Issues with location, capacity, pricing, and timing may create bottlenecks and imbalances in the supply chain (Chute, 2024).

While addressing these challenges will take time, there are initial signs of progress. The Perennial Promise Grower's Cooperative, which has collaborated with AURI during this project, is exploring opportunities to produce and sell ingredients made with Kernza grown by its members. AURI also made connections with other entrepreneurs who are looking at opportunities to offer Kernza processing and aggregation services. AURI will continue providing information to interested parties as part of ongoing efforts to support market development for the crop.

Ecosystem services markets

Kernza's array of positive ecosystem benefits is a driving force behind the excitement for the crop's development and market potential. With its deep roots and ability to provide continuous living cover, Kernza perennial grain offers a unique value proposition compared to non-perennial and/or traditional cropping systems. The past several years have seen a pronounced focus on highlighting these attributes in marketing and product differentiation efforts.

While the notable environmental profile of Kernza has generated public interest and enabled a limited number of producers to adopt the crop, finding ways to more directly monetize the crop's positive ecosystem impacts remains a challenge. This involves recognizing and assigning economic value to the various environmental benefits provided by its cultivation. With the implementation of payments for ecosystem services (PES) programs, farmers could receive financial incentives for growing Kernza. Monetizing these benefits would help boost the economic case for Kernza production, improving its competitiveness versus higher-yielding crops in well-established marketing channels. Monetization of ecosystem services may also offer Kernza farmers more flexibility in pricing and marketing their grain, providing an alternative revenue source less tied to yields, grain prices, or the impacts of weather on crop outcomes.

While there have been signs of progress, challenges remain. Farmers who were early adopters of sustainable practices may find themselves excluded because their actions predate the establishment of markets, and they lack baseline data to show the improvements they have made. Currently, carbon markets for reducing indirect emissions lack standardized protocols for measuring soil carbon changes, limiting the market size and value. No formal marketplaces exist for trading credits for other ecosystem services like soil health, water quality, or other environmental attributes besides carbon or greenhouse gases (GHG). These metrics could have greater environmental impact, permanence on the landscape, and measurement accuracy, but the development of credits in these areas is lagging.

With the rise of these and other programs, agricultural stakeholders have increased their collaboration and communication efforts. As part of its market development work tied to Kernza and other new and emerging crops, AURI has sought to engage these emerging groups to stay involved and informed as new opportunities arise. This includes regular participation in meetings of the Minnesota Farmers Union coordinated Minnesota Working Group for Climate-Smart Commodities, which first convened in May 2023 (Minnesota Farmers Union, 2024).

While efforts to develop markets remain piecemeal, some notable programs have been launched. In Minnesota, programs such as the Minnesota Agricultural Water Quality Certification Program (MAWQCP) (Minnesota Department of Agriculture, 2024) and the University of Minnesota-led Environmental and Economic Clusters of Opportunity (EECO) pilot (Forever Green Initiative, 2023) are providing new ways for Minnesota farmers to monetize their positive environmental practices.

Pricing trends

While the regional Kernza supply chain has evolved over the past several years, the overall development of markets for the crop is a work in progress. Minnesota led the nation in acres of Kernza in 2023, but producers reported challenges in finding buyers for their crop, forcing farmers to store the grain while they seek buyers (Bjorhus, 2023).

High grain prices have likely slowed the development of sustainable markets for Kernza, creating a barrier for end users who might otherwise be interested in using the crop in their products. Interviews with end users by University of Minnesota researchers have highlighted interest in the crop and its potential, (Teller, 2024) but also concerns about the price of Kernza compared to alternative grains (Chute, 2024). Minnesota Kernza producers appear to have responded to these concerns and have been reducing prices for their grain, hoping to precipitate new opportunities to market their crops. In late 2023 and early 2024, prices quoted to AURI dropped by approximately 20% to 50%, depending on classification.

Table 4: Quoted Prices for Kernza in Minnesota, 2023-2024		
Type of Kernza	**Original Price ($ per lb)**	**New Price ($ per lb)**
Conventional	$3.75	$1.75-2.00
Organic	$5.00	$3.75
Regenerative Organic Certified	$5.50	$4.50

Source: AURI Contacts with Minnesota Kernza Producers

Outreach, dissemination, and stakeholder engagement

Throughout the three-year project period, AURI team members actively focused on organizing, attending, and participating in events and collaborating with partners to develop and share informational materials. These outreach and dissemination activities provided information about the project and its findings, raised awareness of Kernza and its value-added uses, and helped build stakeholder networks in support of ongoing market development efforts. This included publication of an article in Cereal Technology/Getreidetechnologie in 2023. (Diemer, Gordon, Leiphon, & Stutelberg, 2023) A copy of this publication can be found in Appendix K. A full list of AURI's outreach and dissemination activities can be found in Appendix L.

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Appendices

Appendix A: Effect of Drying on In-Hull Kernza® Perennial Grain (AURI)

Appendix B: Kernza Storage Trials (AURI)

Appendix C: Kernza® Whiskey Development (Rahr Technical Center)

Appendix D: Kernza Whiskey Evaluation Notes (AURI)

Appendix E: Kernza Malt Information Sheet (AURI)

Appendix F: Kernza Specialty Malts (Rahr Technical Center)

Appendix G: Kernza Flaking Trials (Northern Crops Institute)

Appendix H: Analytical Report - Flaked Kernza (Rahr Technical Center)

Appendix I: Kernza Flour Analysis (Northern Crops Institute)

Appendix J: Kernza Straw Compounding and Molding Trials (c2renew)

Appendix K: Kernza Outreach and Dissemination Report (AURI)

Appendix L: Developing markets and value-added uses for a new cereal crop (Cereal Technology/Getreidetechnologie, 2023, Vol 77, Issue 1) (AURI)

APPENDIX A

Effect of Drying on In-Hull Kernza® Perennial Grain
(AURI)

Effect of Drying on In-Hull Kernza® Perennial Grain

Kernza Supply Chain (LCCMR)

Project: #22051

2024

Alan Doering
Camren Nikoley
Agricultural Utilization Research Institute
P.O. Box 251
Waseca, MN
adoering@auri.org

Goal:

Identify the effect dryer temperature has on Kernza® perennial grain seed quality, specifically focusing on heat-damaged protein (vs. germination).

Procedure and drying trial:

Due to the lack of harvested in-hull Kernza at high enough moisture levels to conduct this trial, water was added to Kernza and allowed to dissipate in a closed container for 18 hours. The starting moisture of the Kernza grain averaged 9.6%. Water was added to the grain to obtain a targeted 16% moisture to mimic a situation when grain was harvested at greater moisture and drying is required.

Testing focused on two dryer temperatures in a Kasson Fluid Bed Dryer. The first test conducted used 150 °F (65.5 °C) air temp. Based on information from the North Dakota Extension, this exceeds the recommended maximum air drying temp for wheat intended for milling that is over 20% moisture. Likewise, the second dryer temperature evaluated was 180 °F (82.2 °C) which is the temperature frequently utilized for drying grains such as corn. This temperature exceeds the maximum recommended temperature for wheat with moisture below 16 percent. The Kasson Fluid Bed Dryer maintains a constant temperature based on blower and exhaust fan speed.

Protocol:

1. Obtain control samples of re-hydrated Kernza grain (in-hull) for moisture analysis.
2. Divide grain into two even quantities for drying trial.
3. Conduct a heat/drying trial with one media sample and a dryer temperature set at 150 °F (65.5 °C). Collect and measure three material samples documenting product temp and time in the dryer until they reach 150 °F (65.5 °C). In this case, **focus on product temperature, not dryer temperature.**
4. Conduct a heat/drying trial with one media sample and a dryer temperature set at 180 degrees F (82.2 °C). Collect and measure three material samples documenting product temp and time in the dryer until they reach 180 °F (82.2 °C). **Focus on product temperature, not dryer temperature.**
7. Collect product samples from each trial to send for Acid Detergent Fiber heat-damaged protein and moisture analysis.
8. Develop a drying curve based on samples and sample times collected for each temperature test.

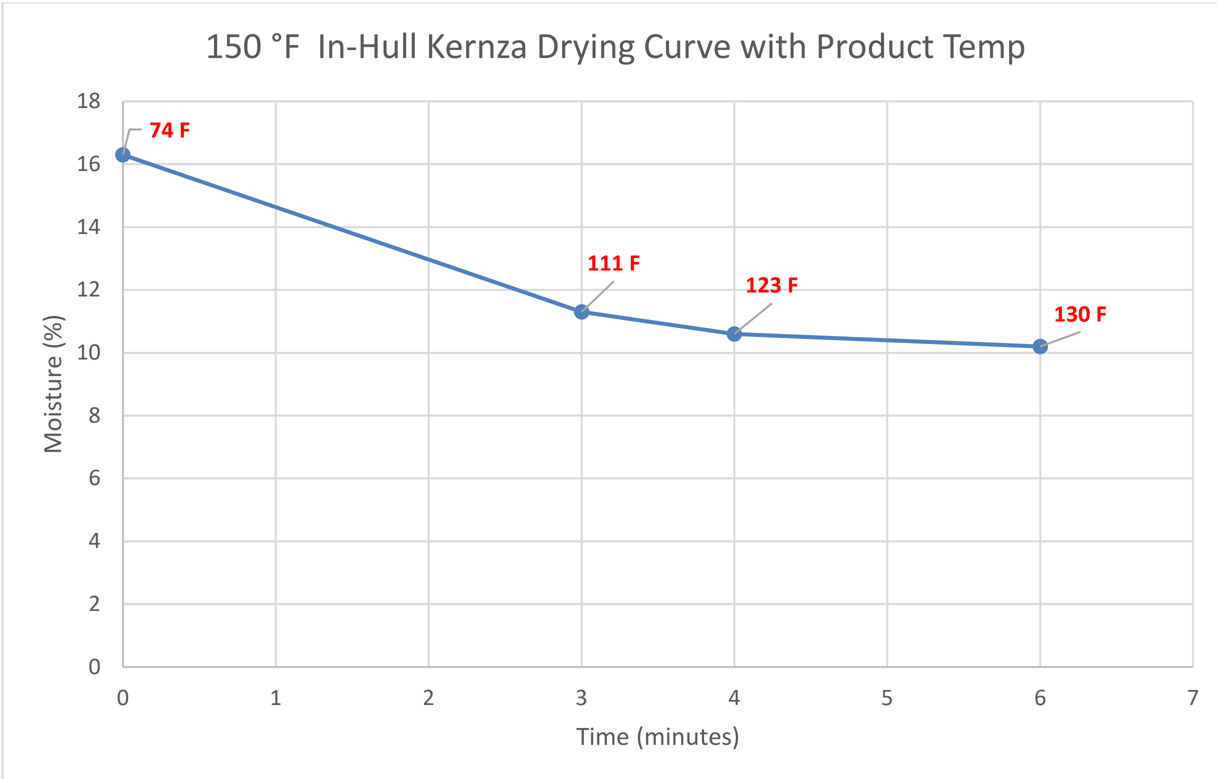
Heating and drying were conducted using a Kason Fluid Bed dryer (Model K30) following the protocol identified.

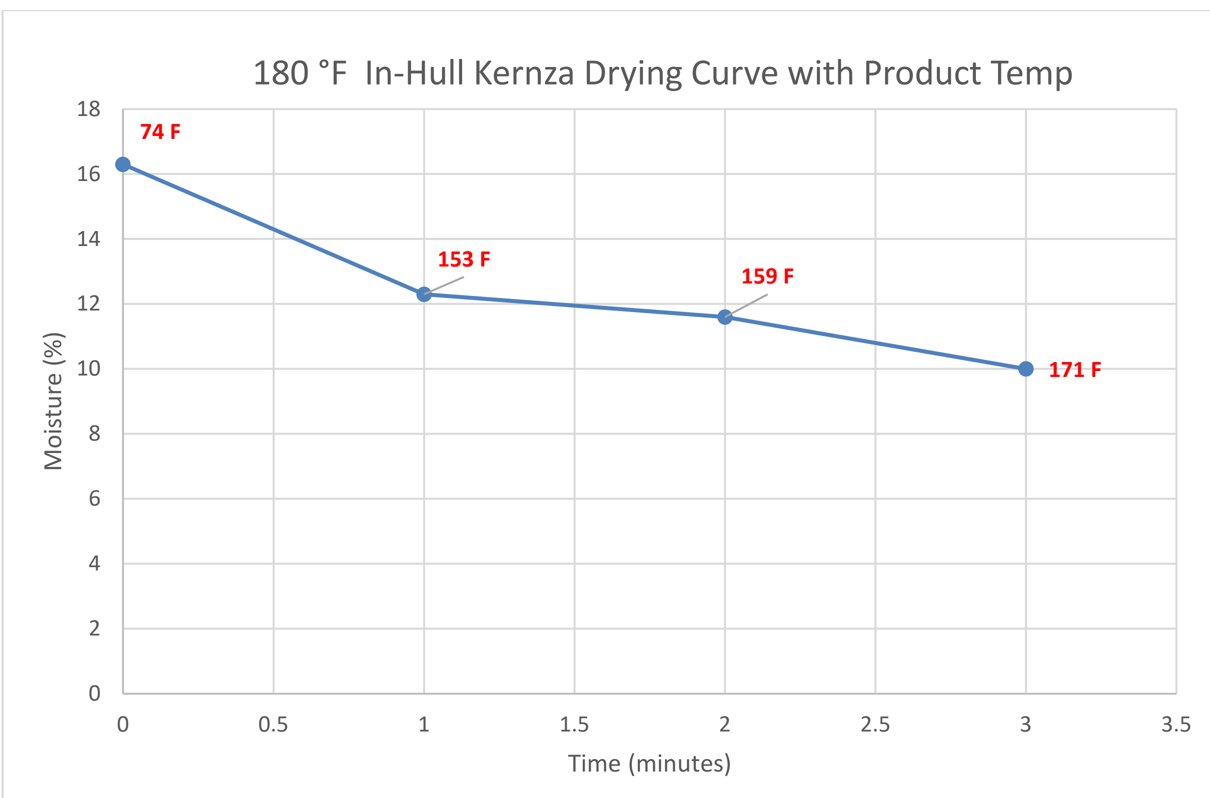
Kason K30 fluid bed dryer

Kason K30 with exhaust line

Control panel

The following charts provide an indication of the drying curve observed when utilizing two different drying temperatures. Increasing the drying temperature from 150 °F to 180 °F reduces the drying time by half to achieve 10% moisture. However, increased drying temperature also results in increased product temperature.


150 °F In-Hull Kernza Drying Curve with Product Temp
Moisture (%)
Time (minutes)
74 F
111 F
123 F
130 F
0
2
4
6
8
10
12
14
16
18
0
1
2
3
4
5
6
7


180 °F In-Hull Kernza Drying Curve with Product Temp
Moisture (%)
Time (minutes)
74 F
153 F
159 F
171 F
0
2
4
6
8
10
12
14
16
18
0
0.5
1
1.5
2
2.5
3
3.5

Product samples were allowed to cool naturally without any external fans or air conditioning to speed up the cooling process. Product samples were sent to Midwest Laboratories in Omaha, Neb. for moisture and acid detergent fiber analysis of indigestible protein (ADF indigestible protein), which may have occurred due to product temperatures obtained during drying. Following are the lab results (Table 1):

Table 1 – Product moisture and ADF indigestible protein percent

Product	Product Temp from Drying (°F)	Moisture (%)	ADF Indigestible Protein (%)
Control	74	16.3	0.82
150-1	111	11.3	0.56
150-2	125	10.6	0.6
150-3	130	10.2	0.62
180-1	153	12.3	0.39
180-2	159	11.6	0.47
180-3	171	10.0	0.42

Observations:

- Dryer set temperatures intentionally exceeded the recommended drying temperature for wheat to identify the potential for heat-damaged protein.
- Higher product temperatures in this test indicated a reduction of indigestible protein in the acid detergent fiber based on the control data. Additional testing should be conducted if exceeding dryer air temperature limits for wheat, which range from 130 °F to 150 °F, based on previous drying research conducted by the North Dakota State University Extension.
- Utilizing a dryer temperature setting of 180 °F compared to 150 °F reduces drying time by approximately 50%.
- ***Utilizing a conventional dryer would not be recommended for drying in-hull Kernza based on the high quantity of free-threshing Kernza grain that was observed when exiting the dryer.***

APPENDIX B

Kernza Storage Trials
(AURI)

Kernza Storage Trials

September 2023 to May 2024

Purpose:

To evaluate the storage stability of Kernza® perennial grain raw (in-hull) vs cleaned grain over time with a moisture content of 9-10%.

Procedure:

Kernza grain was sourced and provided to the Agricultural Utilization Research Institute (AURI) to conduct storage trials. The grain obtained was stored in cardboard drums and consisted of dehulled and cleaned Kernza® grain that was left in-hull as harvested with only minor screening to remove large weed seeds or debris. Samples from each lot were pulled and evaluated for storage stability over an eight-month period (T-0, T-2, T-4, T-6, & T-8 months).

The storage trial focused on five main topics, including: (1) Storage conditions based on temperature and humidity variations throughout the trial; (2) Proximate Analysis, which analyzes for moisture, protein, fat, ash, and carbohydrates analysis at various time points to determine the grain's storage stability; (3) Germination; (4) Mold, yeast, and bacterial levels; and(5) the presence of Deoxynivalenol (DON) or Aflatoxin in the stored grain samples.

Storage Conditions

"The length of time grain can be stored without significant deterioration is determined by temperature and the moisture content at which it is stored."[i] To provide context to the quality metrics collected during the trials, temperature and humidity data was gathered throughout the storage period. Data was compiled using electronic temperature and humidity data loggers placed into storage with each grain lot (cleaned/dehulled and in-hull.)

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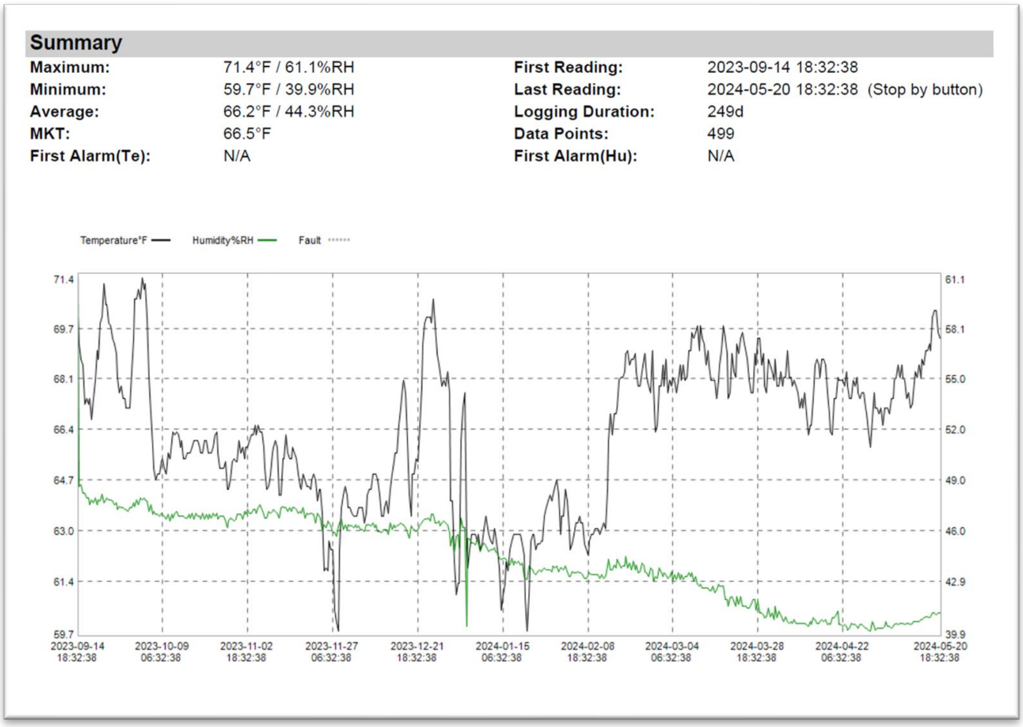
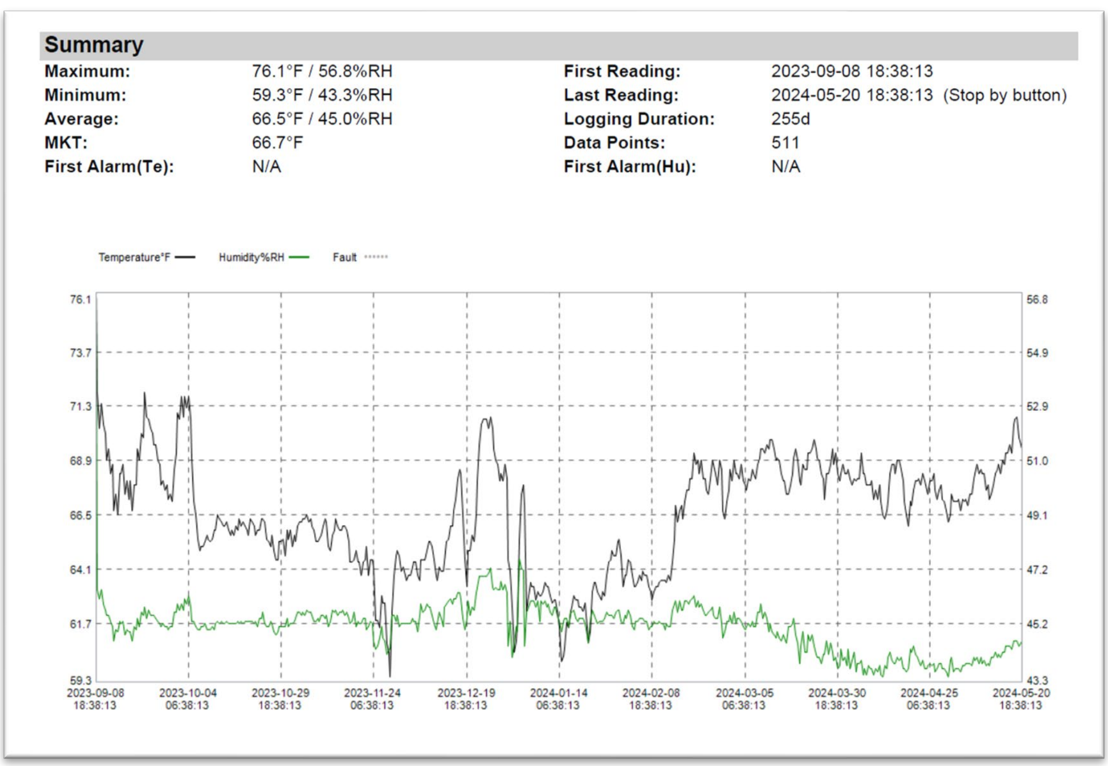
Figure B1: Storage Conditions (Temperature and Relative Humidity), Cleaned and Dehulled Kernza



AURI Bioindustrial Innovation Center

Figure B2: Storage Conditions (Temperature and Relative Humidity), In-Hull Kernza



AURI Bioindustrial Innovation Center

Outcomes:

Storage trials from September 14, 2023, to June 20, 2024, resulted in similar average storage temperatures for both the clean and dehulled Kernza, which averaged 66.2 °F and 44.3% relative humidity, and the in-hull Kernza, which averaged 66.5 °F and a 45.0% relative humidity. Typical on-farm or commercial storage would generally see larger temperature and relative humidity variations compared to the trial results observed.

Proximate Analysis

The proximate analysis measures moisture, protein, fat, ash, and carbohydrates at various time points to determine the grain's storage stability. This test focused on determining the variability of seed quality over time, specifically on protein and carbohydrate content. Data from these tests is included in Table 1.

Table B1: Average Proximate Data for Kernza (Raw and Cleaned) During Storage Trials

	Moisture	Protein	Fat	Ash	Carbohydrates
Test Method	AOCS Ba 2a-38	AOCS Ba 4d-90	AOCS Ba 3-38	AOAC 930.05	Calculated
Units	% As-Is	% DM	% DM	% DM	% DM
Raw (In-Hull)	9.49±0.44	17.42±0.58	2.19±0.14	2.19±0.32	72.29±0.63
Clean (Dehulled)	9.34±0.31	16.73±0.17	2.06±0.28	2.50±0.23	73.08±0.17

AURI Analytical Chemistry Laboratory

Outcomes:

The moisture and protein varied minimally over the storage trial, indicating that eight months of storage at less than 10% moisture did not negatively affect grain quality.

Germination

Evaluating the germination percentage of the Kernza seed was important because it can directly affect seed quality when used for production seed and for value-added applications such as malting in the brewing industry. Table 2 shows the results of tests conducted at the start and end of the storage trial.

Table B2: Germination Rate, Cleaned and Dehulled Kernza

	Sept 2023 (Start)	June 2024 (End)
Warm Germination Rate	47%	58%
Lab Notes	Seedling rot/fungi present	No notes

Minnesota Valley Testing Laboratories- New Ulm, Minn.

Outcomes:

The germination rate of the Kernza seed used for storage was extremely low with a starting germination percentage of 47% and an ending germination rate of 58%. The reason for a greater germination rate at the end of the storage period is unknown and may be due to sample variability. However, the low germination rates are potentially due to the extremely hot and dry growing season during 2023, which may have resulted in seed coat damage and/or seed fracturing.

It should be noted that additional studies conducted by AURI have observed germination rates greater than 80% for Kernza seed.

Mold, Yeast, and Bacteria Presence

Kernza grain samples were evaluated to determine the level of bacterial presence throughout the storage trial, along with the level of coliform bacteria, E. coli (non-pathogenic), mold, and yeast. These tests were used to identify whether storage at the identified moisture and temperature affected grain quality.

Sampling was conducted on three grain samples: (1) Kernza grain that was cleaned and dehulled at the start of the trial; (2) Kernza grain that was stored with the hull intact and analyzed in-hull; and (3) Kernza grain that was stored in-hull with samples cleaned and dehulled (Fresh Clean) prior to analysis. Tables 3 through 5 show the results of the three samples evaluated.

Table B3: Microbial Loads in *Cleaned and Dehulled Kernza Grain at* Various Storage Intervals

Test	Units	T-0	T-2	T-4	T-6	T-8
Aerobic Plate Count (APC)	CFU/g	2,500,000	6,100,000	1,400,000	790,000	350,000
Coliform	CFU/g	5,000	7,000	<10	1,400	<10
E. coli (non-pathogenic)	CFU/g	<10	<10	<10	<10	<10
Mold	CFU/g	37,000	58,000	40,000	8,000	7,000
Yeast	CFU/g	45,000	90,000	14,000	12,000	4,000

Market Fresh Food Testing Laboratories- Minneapolis, Minn.

Table B4: Microbial Loads in *In-Hull Kernza Grain* at Various Storage Intervals						
Test	Units	T-0	T-2	T-4	T-6	T-8
Aerobic Plate Count (APC)	CFU/g	1,700,000	1,700,000	1,700,000	3,100,000	440,000
Coliform	CFU/g	2,000	4,000	200	100	4,000
E. coli (non-pathogenic)	CFU/g	<10	<10	<10	<10	<10
Mold	CFU/g	240,000	190,000	160,000	84,000	47,000
Yeast	CFU/g	140,000	170,000	120,000	58,000	31,000

Market Fresh Food Testing Laboratories- Minneapolis, Minn.

Table B5: Microbial Loads in *Fresh Cleaned and Dehulled Kernza Grain at* Various Storage Intervals					
Test	Units	T-2	T-4	T-6	T-8
Aerobic Plate Count (APC)	CFU/g	5,400,000	5,100,000	2,400,000	230,000
Coliform	CFU/g	12,000	800	12,000	90
E. coli (non-pathogenic)	CFU/g	<10	<10	<10	<10
Mold	CFU/g	50,000	220,000	33,000	10,000
Yeast	CFU/g	70,000	210,000	31,000	3,000

Market Fresh Food Testing Laboratories- Minneapolis, Minn.

Outcomes:

Observations from the testing to identify levels of microbial activity during storage indicated storing cleaned and dehulled grain (Table B3) tended to have the lowest level of microbial contamination over time. However, it should be noted that the storage conditions were controlled and did not represent storage in a grain bin that could have moisture migration and exposure to insects or rodents. Realistically, storing grain for a period in the hull would be the practice generally observed with on-farm or commercial storage. Results from this testing indicate the presence of the grain hull during storage may be the primary source of microbial contamination, thus the need for proper initial storage moisture to prevent bacteria, mold, and yeast growth.

DON/Aflatoxin Evaluation

Deoxynivalenol (DON), commonly called vomitoxin, is a mycotoxin produced in wheat and barley grain infected by Fusarium. Aflatoxin is a toxic compound caused by various forms of mold. AURI evaluated the Kernza grain at the beginning and end of the storage trial for these two compounds to identify their presence in the grain and the effect storage has on these compounds when stored at the previously stated environmental conditions. Results from the DON and Aflatoxin testing can be viewed in Table 6.

Table B6: DON (Deoxynivalenol/Vomitoxin) and Aflatoxin				
	Aflatoxin (parts per billion)		DON (parts per million)	
	Sept 2023 (Start)	May 2024 (End)	Sept 2023 (Start)	May 2024 (End)
Raw (In-Hull)	1.7	0.0	0.039	0.0
Cleaned (Dehulled)	1.0	0.0	0.0	0.0

State Grain Inspection- Savage, Minn.

Outcomes:

Safe levels for Vomitoxin or DON are less than 0.5 parts per million. In all analyses at the start and end of the storage trial, DON levels were below this threshold or not present. Ideal levels for Aflatoxin are less than 5 parts per billion. The raw and clean and dehulled Kernza were well below this level at the start of the storage trial, and no aflatoxin was detected at the end of the trial in either sample.

[i] Hellevang, K. J. (1994). Grain Drying. Fargo, ND: North Dakota State University Extension Service.

APPENDIX C

Kernza Whiskey Development
(Rahr Technical Center)

RAHR

Kernza Whiskey

August 2023

Rahr Technical Center

Agenda

Executive Summary

Project Overview & Objective

Malt Production

Mash Production

Distilling and Aging

RAHR

Executive Summary

Executive Summary

AURI contracted with Rahr Technical Center, to produce a batch of malted Kernza® and a malted Kernza American Whiskey.

Germination testing of Kernza was done to evaluate for malting parameters and a batch of malted Kernza was produced on the pilot system. A high level of broken kernels in the dehulled grain resulted in a low germination rate and highly under-modified malt. It was determined that the use of enzymes in the mash production would assist with conversion of starch to sugars for fermentation. The need for enzymes may be a barrier for most distillers in the adoption of this malt if a high rate of broken kernels continues to be a challenge.

A mash was produced using 51% Kerzna malt and 49% Rahr Distiller's malt. As a bonus a 100% Rahr Distiller's Malt batch was also produced for comparative purposes. Enzymes were applied to both mashes to increase efficiencies. After being separated from the grain, the washes were inoculated with Fermentis SafSpirit™ M-1 and left to ferment. Though the fermentation time was extended to 12.5 days, the alcohol by volume (ABV) at 48 hours was similar to the final ABV. The ability to ferment quickly is a desired characteristic for most distillers as ferment residency time is typically as short as possible.

The wash was then processed through stripping runs and was followed by a final sprit run in which the hearts were collected. Both spirits were proofed and placed into Squarrel® Square Barrels with new American Oak staves. At the time of this report, the products have been aged for 3.5 months. An informal tasting described the Kernza whiskey as having a very sweet flavor with a unique spiciness, higher alcohol aroma and flavor. It was deemed that more aging time was needed. The product will be aged for up to 6 months in the small barrels, approximating 2 years of aging in a full-size barrel and a guided tasting will occur once the final product has been bottled.

RAHR

Project Overview & Objective

Project Overview & Objective

Agricultural Utilization Research Institute of Minnesota (AURI) contracted with Rahr Technical Center (RTC), to produce malted Kernza® and a 51% malted Kernza American Whiskey at 1-2 different accelerated ages up to 6 months.

The final deliverables of this project were bottles of aged whiskey, a final report to address the brewing and distilling experience, challenges and other learnings, a guided tasting/final meeting of resulting product with AURI employees, and a bonus comparison of 100% barley whiskey produced on same still for informal comparison of Kernza flavor impact. A formal sensory analysis of the product by the Rahr Technical Center team fell outside the scope of this project.

The guided tasting will occur once the final product has been bottled, anticipated to occur end of 2023.

RAHR

Test Overview

- Germination testing of stored Kernza was done to evaluate for malting parameters.
- One pilot-scale malting batch of Kernza was produced, resulting in ~150 pounds of finished malt
- Utilizing the resulting Kernza malt, one 3 hL batch size mash was produced (off-grain) using 51% Kerzna Malt and 49% Rahr Distiller's Malt. A second batch was produced using 100% Rahr Distiller's Malt. Enzymes were applied to increase reduced efficiencies.
- Both washes were inoculated with Fermentis SafSpirit™ M-1 and left to ferment for approximately 12.5 days. Fermentation data was collected during this time.
- Both spirits were proofed to ~ 60% ABV and put into Squarrel® Square Barrels with 12 new American Oak staves char number three.
- Aging of resulting white spirit in small batches resulting in accelerated aging for 1-2 different time points, up to six months total time in barrels (approximate accelerated aging of 2 years)

RAHR

Malt Production

Kernza Selection

- Four samples of Kernza were evaluated for peroxide germination prior to malting, with the results shown below. A very high number of broken kernels were observed, and it is assumed that all damage is associated with the dehulling process.

Sample	% Broken	% Germ	Total damaged
1	39	80	59
3	37	86	51
4	46	82	64
5	35	85	50

- AURI then removed more broken kernels using an indent separator at MNL in Foley, removing about 110lb of broken kernels from the 600lb of grain in barrels 3 and 5.
- The resulting lot of grain was then sent to the RTC and evaluated again.
- Approximately 37% broken kernels were recorded. Germination was 83.3% with obvious broken kernels removed. The remaining non-germinated kernels also had embryo damage that became visible when wetted for the germination energy test, so damaged kernels was closer to 55%.
- Of note, the more recent batch (pilot malted in June '23) had 1.3% obvious broken kernels with 86% germination; total damaged kernels around 15%.

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Malt Production

- Malting of Kernza was done according to similar parameters as previous trials at the Rahr Technical Center.
- As with previous pieces for brewing with Kernza malt, the grain became sticky with germination water additions. The water increased the Kernza size & shape, creating compaction of the grain bed and resulting in somewhat poor airflow and therefore some anaerobic conditions.
- Similarly, kilning required special attention to add time and stirring steps due to compaction and channeling.
- The final steep out moisture was 42.5%.

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Malt Production

	Rahr Distillers	Kernza
Color (SRM)	1.85	3.98
Moisture (%)	4.19	7.88
Fine Grind as is (%)	77.8	73.9
Total Protein (%)	12.3	26.3
Soluble Protein (%)	5.43	9.88
Soluble/Total Protein Ratio	44.1	37.6
FAN (ppm)	224	472
β-glucan (ppm)	88	29
pH	5.99	6.04
α-amylase (DU)	61.2	54.1
Diastatic Power (°Lintner)	217	259
Bushel Weight (lbs/bushel)	41.9	42.9

Grading	Rahr Distillers	Kernza
7/64	52.4	.4
6/64	34.6	.4
5/64	11.9	1.4
Thru	1.1	97.8

A high level of broken kernels resulted in low germination rate and highly under modified malt. It was determined that the use of enzymes in the mash production would assist with conversion of starch to sugars for fermentation. This is not a practice that most large-scale distilleries employ and may be a challenge in adoption of this grain. Improvements in grain-handling (especially dehulling) will ameliorate this issue, however.

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Mash Production

Mash Test Design Summary

- Two 300 L batches of mash were produced to evaluate Malted Kernza for distilling potential. The malt bill for each mash were as follows:
    - Distillers – 100% Rahr Distillers Malt
    - Kernza – 51% Malted Kernza + 49% Rahr Distillers Malt

- Enzyme additions were made to each mash to help with saccharification and the breakdown of β-glucan. Sour Wort was also added to each mash to reach a desired mash pH.
    - 15 mL Bioglucanase GB
    - 15 mL Amylo 300
    - 1200 mL Weyermann Sour Wort

- The mashes were designed with the following set parameters:
    - Mash Parameters (1.5°F/min ramp rate)
        - 122°F – 20 minutes
        - 148°F – 180 minutes
        - 171°F – 5 minutes
    - Original Gravity: 15.15° Plato
    - Yeast: Fermentis SafSpirit™ M-1
    - Pitch Rate: 80 g/hL
    - Fermentation Temperature: 80°F

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Brewhouse Performance

	Rahr Distillers Malt	Kernza
Foundation Water pH	7.10	7.09
pH, Ramp to 2nd Rest	5.46	5.35
Starch Check	Negative	Negative
Clarity After Vorlauf (EBC)	12	12
1st Wort °Plato/pH	19.4°P / 5.40 pH	- / 5.27 pH
Last Wort °Plato/pH	4.5°P / 5.40 pH	6.34°P / 5.32 pH
Total LT Volume Pulled (L)	330	-
Lautering Time (min)	103	128
KTF °Plato/pH	16.1°P / 5.39 pH	15.5° P / 5.25 pH
KO °Plato/pH	17.3°P / 5.28 pH	16.0°P / 5.12 pH
Evaporation Rate (%)	5.0	5.0
Final Cooled Volume (L)	300	300
Fermenter Full °Plato/pH	16.09	15.31
Lautering Efficiency (%)	90.5	80.9

Kernza kernel size is much smaller than barley, increasing lautering times and reducing efficiencies.

Deep cuts with the lauter tun rakes were performed multiple times to ensure continued flow during lautering.

Flow meter was not recording correctly during Kernza lauter, so an accurate volume could not be recorded (~330 L based off recorded Kettle volume).

Due to the high viscosity of the Kernza wash, there was a significantly lower lautering efficiency, which corresponded to lower extract. The viscosity of the wash would be reduced with lower inclusion rates of Kernza.

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Cellar Performance Data - Fermenter

	Rahr Distillers	Kernza
Yeast Strain	Fermentis M-1	
Pitch Amount (g)	240 g	
Original Gravity (°Plato)	16.09	15.31
Final Gravity (°Plato)	1.01	2.31
ROH (v/v %)	6.49	7.07
RE (w/w %)	3.91	4.81
Ratio (RE/ABW)	0.60	0.86
RDF (%)	77.5	70.4

In addition to a lower extract, the Kernza was less fermentable than the distiller's malt, resulting in a higher final gravity.

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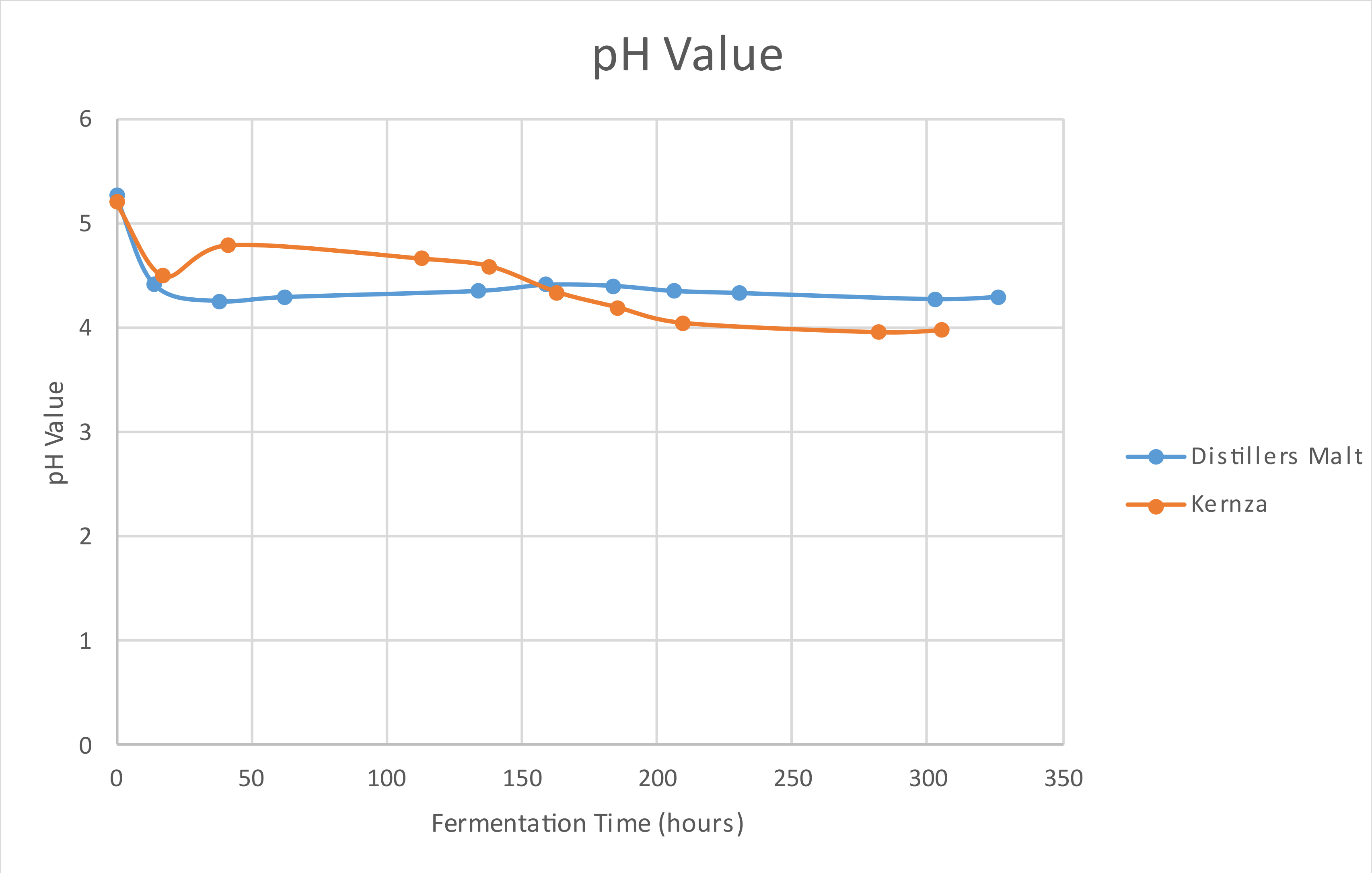
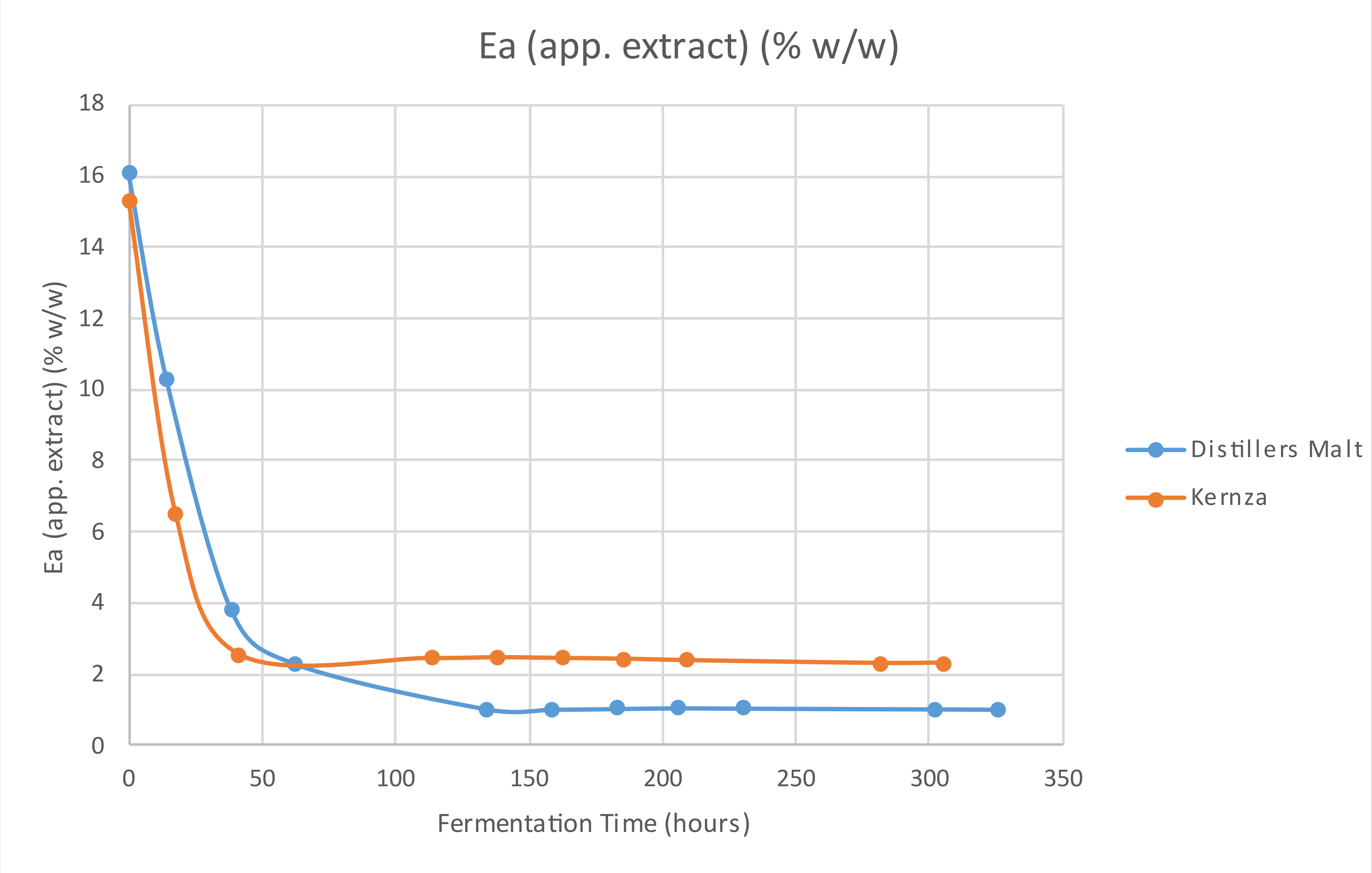
Fermentation Trends - pH



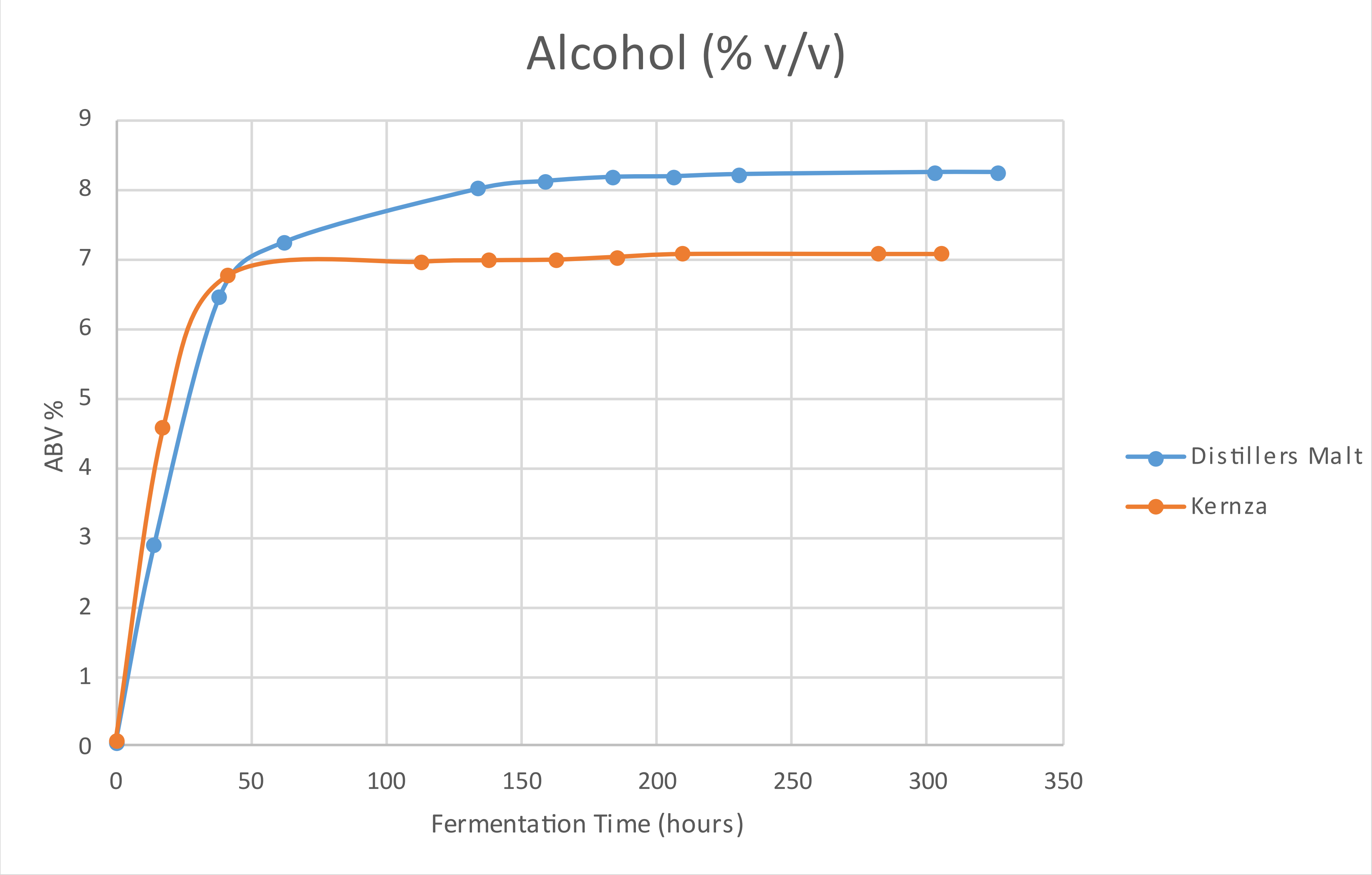
The pH of the Kernza wash was higher than the Distiller's from about 14 hours to about 158 hours, after which it decreased to below that of the Distiller's wash.

Fermentation Trends – Apparent Extract (°Plato)



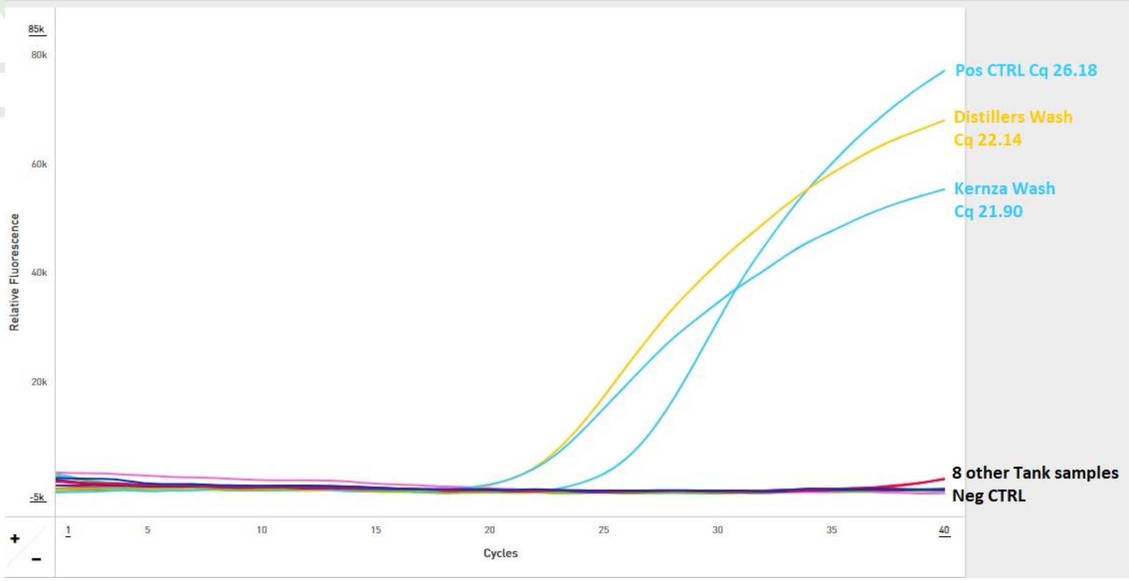
The Kernza was less fermentable than the distiller's malt, resulting in a higher final gravity. This could be overcome with an adjusted ratio of Kernza to Distiller's malt.

Fermentation Trends - %ABV



An extended fermentation time was employed but the ABV% of the Kernza wash did not increase much between 48 and 110 hours. This indicates that a shorter fermentation may be utilized in the future, a positive aspect for most distilleries.

Lactic Acid Bacteria

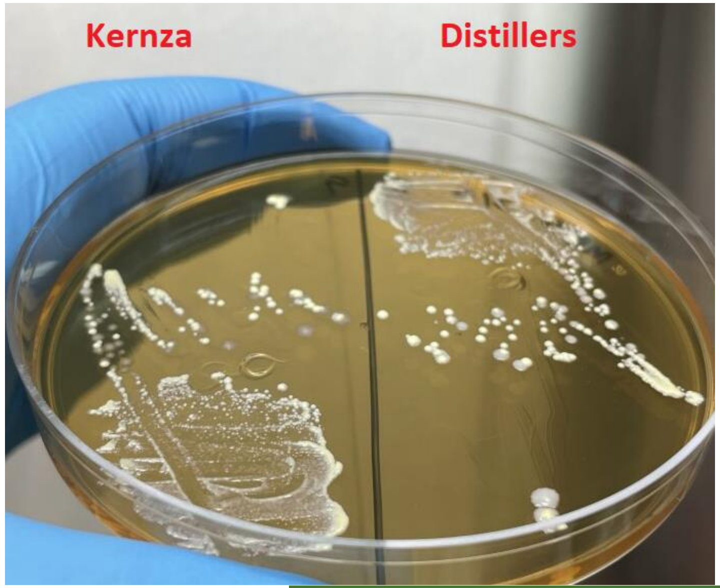


As a curiosity, the presence of lactic acid bacteria (LAB) was tested for.

The presence of LAB was verified in both the Distillers and Kernza washes by PCR analysis using a Pika *Lactobacillaceae* test kit. Samples were obtained during fermentation from the fermenters.

Two distinct colony morphologies were isolated from both washes

- Samples of each colony type from both washes were sent to Azenta for 16S sequencing and identification
- Both washes had a combination of *Levilactobacillus brevis* and *Lactiplantibacillus plantarum*
- The presence of these may be due to a short boil being insufficient to achieve reduction of LAB load from the grain, or due to contamination, either from the yeast or brewery sources.
- Overall, the presence of these are not of great concern.



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Distillation and Aging

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Initial Distillation

The distillation process was performed on two different stills at the Rahr Technical Center.

The initial stripping runs for each spirit type was performed on a 200L still with a maximum operating capacity of 170L. The stripping runs are done to separate the water, yeast, and any sediment from the wash before primary distillation.

Due to the batch size two stripping runs were done for each spirit. FermCap® S was added as an anti-foam agent to aid in transfer and reduce loss.

The total volume produced from the stripping runs of the 100% Distillers spirit and the 51% Kernza spirit was 37 and 35 liters of ~ 33% ABV spirit, respectively.

	Rahr Distillers	Kernza
Stripping Run Charge	170 L + 7ml FermCap® S	
Stripping Run	37 liters @ 33.22 ABV	35 Liters @ 33.75 ABV

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Primary Distillation

The resulting spirit runs were further distilled to increase the ABV%. These were performed on an 8 gallon still (shown on the left in the photo).

The heads are the initial cuts containing a high percentage of low boiling point volatiles. The tails are the final cuts that contain low alcohol and high levels of fusel alcohols. Both the heads and the tails were discarded.

The heart cuts are the most desirable portion of the spirit. These were collected when the boiler head reached 193°F until the temperature hit 207°F.

	Rahr Distillers	Kernza
Spirit Run Hearts	80.23% ABV	80.69 % ABV

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Barreling and Aging

Both spirits were proofed from ~80%ABV to ~ 60% ABV and put into Squarrel® Square Barrels with 12 new American Oak staves char number three on April 21, 2023.

The spirits will reside in the small barrels for up to six months total time, approximating 2 years of aging in a full-size barrel.

	Rahr Distillers	Kernza Straight
Squarrel Square Barrels	59.95 % ABV	60% ABV

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Initial Tasting Impressions

Initial tasting of the product was done on August 3rd, 3.5 months from the time the product began aging, approximately equal to 14 months non-accelerated aging.

The Kernza whiskey was described as having a very sweet flavor with a unique spiciness, higher alcohol aroma and flavor. More aging time was deemed necessary, and a 100 mL sample was retained for future comparison purposes.

From a sensory standpoint, the 100% Distiller's product had a more woody and traditional whiskey flavor at this timepoint and was preferred by the majority of the sensory panelists.

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Project Summary

Working with Kernza in the malthouse and the brewhouse requires patience and adaptability to manage the small grains appropriately.

When comparing a 51% malted Kernza whiskey to a 100% distiller’s malt whiskey, the residual sugars in the mash was much higher. The lower extract may be mitigated at least in part by decreasing the number of broken kernels prior to malting, allowing for more complete germination and thus a greater conversion into fermentable sugars.

It should be noted that in a distillery where fermenting on-grain is done, the challenges with lautering would not present an issue, increasing the valuable extract for fermentation.

From a sensory perspective, at 3.5 months aging the flavor of the whiskey still had a higher alcohol aroma/flavor to it indicating that further aging was necessary to achieve a desirable product.

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Thank You

TechnicalServices@rahr.com

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Rahr Technical Center

APPENDIX D

Kernza Whiskey Evaluation Notes
(AURI)

Kernza Whiskey Evaluation at Rahr Technical Center

March 27, 2024

AURI Evaluation Panel

- **Alexandra Ostlund**
- **Michael Stutelberg**
- **Lolly Occhino**

Background, Production Notes

- Kernza Whiskey produced during trials is analogous to a scotch, using all malted grain. An American Single Malt Scotch is all malted Barley. Could call this product Malted Kernza Whiskey, it is comprised of 51 % Malted Kernza plus 49 % Distiller's Malt.
- The Kernza grain used had embryo damage from de-hulling. As a result, germination rate was low- 86%. Rahr needed to add enzymes to the mash to make the malt available for fermentation.
- Mash time was long- 205 minutes. Typical is 60 to 90.
- 86% germination rate on Kernza Malt
- A little less was extracted for the Kernza test vs the Control, slightly less alcohol.
- The whiskey was proofed from 80 % down to 60 % and aged in new American Oak "squarrels" for 8 months, then proofed down again to 50%.

Tasting Notes

Kernza Whiskey Sample:

- Slight citrus, toasty and "warm" notes
- Similar flavors to a Stroopwafel
- Sweet characteristics, spice, cinnamon/caramel
- Some fruit
- Very pleasant, aged well, more complex spice versus Control

Control Whiskey Sample:

- Note that this sample hasn't been proofed down to 50 % yet, it is at 60 % but it is barrel aged
- Aroma is like banana cream

Collated notes from Alexandra O., Lolly O.

APPENDIX E

Kernza Malt Information Sheet
(AURI)

Kernza® Perennial Grain

Malt Info Sheet

Agricultural Utilization Research Institute

Grain Type

- Kernza® Perennial Grain (intermediate wheatgrass- *Thinopyrum intermedium*)

Grain Source

- Minnesota (Perennial Promise Grower's Cooperative)

Grain Cultivar

- MN-Clearwater (World's first commercial food-grade intermediate wheatgrass grain cultivar. Developed by the University of Minnesota and released for production in 2019.)

Malting Location

- Rahr Technical Center- Shakopee, Minn.
- May 2023

Malt Data Analysis (Rahr)

Bushel Weight (lbs)	42.3
Alpha Amylase (DU)	51.9
Beta Glucan (ppm)	50
Color (SRM)	9.72
NTU	11
Diastatic Power (DP Units)	217
DON	0.1
Extract % (Dry Basis)	75.4

FAN (ppm)	492
Moisture (%)	4.7
pH	6.08
S/T Ratio (%)	57.5
Soluble Protein % (dry basis)	12.3
Total Protein % (dry basis)	21.39
Viscosity (cP)	1.84

For More Information Contact:

- Alexandra Diemer
- Business Development Director of Novel Supply Chains, AURI
  - adiemer@auri.org
  - 218-281-7600, ext. 149

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

APPENDIX F

Kernza Specialty Malts
(Rahr Technical Center)

1847

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Kernza Specialty Malt

August 2024

Rahr Technical Center

Agenda

- Executive Summary
- Grain Quality
- Malting Process
- Malt Quality
- Sensory

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Executive Summary

The scope of this project was to explore the deeper flavor and aroma potential of malted Kernza. Based on the learnings from previous Kernza maltings, the goal was to push the malting process to develop a high-color specialty malt that would boast a bolder flavor. This goal stemmed from two premises. First, the malted Kernza already showed some unique flavor and aroma characteristics that were displayed in the malted Kernza hazy IPA as well as in the malted Kernza whiskey. Second, a malt with a bolder flavor could be used at a lower inclusion rate in a grist bill, thereby potentially providing a better value to prospective users.

Preliminary grain testing was done to evaluate the germination and kernel integrity of dehulled Kernza. Next, the Kernza was pilot malted using steep and germination conditions optimized and extrapolated from previous RTC pilot maltings of Kernza with a goal of reaching the kiln with high moisture and modification to facilitate extensive color formation. Kilning varied from typical base-malt type regime by inclusion of a "stew" step conducive to proteolysis and Maillard reactions, and then high-temperature curing added the finishing touches for color formation. Unfortunately (but also ultimately beneficially), the first attempt failed in the kiln as a technical malfunction caused the kilning to be carried out without the air recirculation for the stew step. A second attempt was successful, and the result was two malts from the same lot of grain produced with very similar modification but different kiln regimes. This allows for very useful comparisons of what might be considered Vienna- and Munich-type Kernza malts.

Malt quality analysis and descriptive sensory analysis were applied to evaluate the final products. Some exceptional, unique flavor and aroma attributes were described in the sensory panel, and overall, the panelists gave extremely positive reviews.

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Preliminary Grain Quality

- Broken kernels
  - 2% measured
  - minimum estimate due to difficulty in distinction
    - Embryo damage is not always apparent in raw grain
      - more visible once hydrated
- Germinative Energy
  - 69% average
    - Very low, even compared to past Kernza (85-93 in the past)
    - Not much visible embryo damage—other causes of poor germination
  - This result aligns with other reports of this lot (per Matthew Leiphon commentary)

GE	Day 1	Day 2	Day 3	Total
Dish A	29	27	10	66
Dish B	33	28	11	72

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Malting Process

Piece 1 (Vienna)

- Steep
  - 300 pounds raw Kernza
  - Double immersion
    - 6 hrs immersion, 6 hrs air rest, 4 hrs immersion, 2 hrs couch
  - Steep-out moisture 42.2%
- Germination
  - 4 days at 68, 70, 72, and 74°F, respectively
  - 1.0 gal water additions at 20,30, 40, 50, 60, 70, 80, and 90 hrs
  - Germ-out (on-kiln) moisture = 48.0%
- Kiln
  1. 160°F, 20 hrs, no recirculation
  2. 195°F, 5 hrs, no recirculation

L to R: raw, Vienna, Munich

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Malting Process

Piece 2 (Light Munich)

- Steep
  - 350 pounds raw Kernza
  - Single immersion + spray steep
    - 6 hrs immersion
    - 12 hrs spray steep
      - 5-min short bursts, hourly
      - 2x 45-min long bursts
  - Steep-out moisture 41.0%
- Germination
  - 4 days at 68, 70, 72, and 74°F, respectively
  - 1.0 gal water additions at 20,30, 40, 50, 60, 70, 80, and 90 hrs
  - Germ-out (on-kiln) moisture = 46.6%

- Kiln
  1. 160°F, 6 hrs, 100% recirculation
  2. 145°F, 2 hrs no recirculation
  3. 150°F 4rs no recirculation
  4. 155°F 8hrs no recirculation
  5. 195°F, 5 hrs 50% recirculation

L to R: raw, Vienna, Munich

Malting Process Observations and Learnings

- Stickiness in the grain bed was not an issue this time around
    - Much less broken material than in previous Kernza pilot maltings
    - Higher steep-out moisture reduced need for hydration compensation during germination
    - Delayed initial watering run in germination also employed to minimize surface moisture
    - Reduced water amount per run (1.0 vs 1.75 gal)
- While longer steep time (higher steep-out moisture) improves germination conditions, bridging occurs in steep vessel with increased residency.
    - Unloading steep vessel becomes difficult.

- Reduced airflow in early kilning improved the fissuring/channeling experienced in previous batches
    - Highly reduced airflow (2/3 of normal) during early free dry was noticeably better
        - Some room for improvement still for further reduction (maybe 50%)
    - Fissuring/channeling requires pausing kilning to rake the grain bed

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Malt Quality

Identity	Off-kiln date	α-amylase	diastatic power (DP)	color (SRM)	turbidity (NTU)	pH	extract (% db)	FAN (ppm)	soluble protein (%db)	total protein (%db)	S/T ratio	β-glucan	viscosity (cP)	Moisture %
Piece 1 (Vienna)	10-May-2024	41.9	106	4.62	39	6.2	74.9	219	11.74	21.77	53.9	93	1.75	8.44
Piece 2 (Munich)	19-Jul-2024	44.8	60	9.82	19.4	6.02	73.5	251	9.79	20.8	47.1	97	1.69	6.11

- Color was expected to reach higher levels as previous pieces achieved substantial color without pushing the process
  - Nevertheless, the color near 10 SRM is a new level reached
  - color reached by higher temperature kilning may have different hue expression and flavor outcomes
  - Low germination rate may have hampered modification, thereby limiting color precursor formation
- Relatively good enzyme retention for the Munich malt.
  - Production of higher color will reduce enzymes
- Lower extract and viscosity from higher color malt while having slower S/T is unexpected
  - Maybe due to some variance between the grain lots (slight TP difference also noted)

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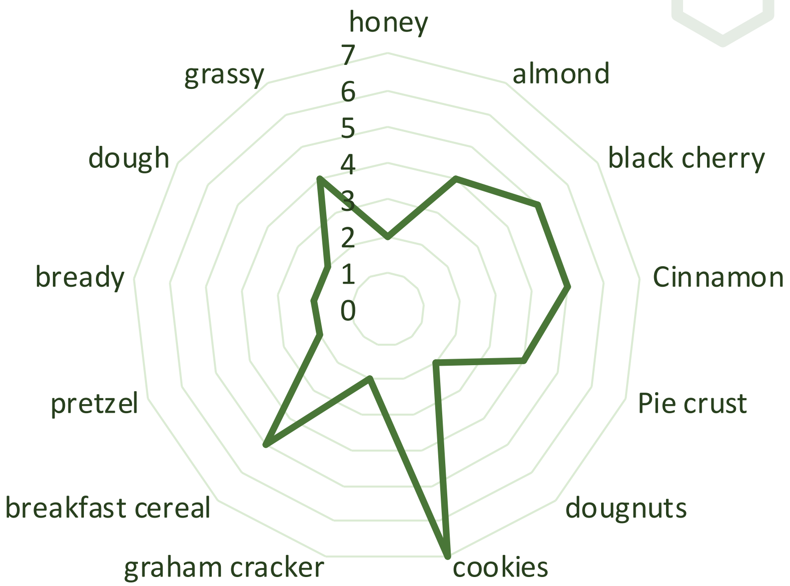
Sensory

- Congress wort was produced at an inclusion rate of 50%, cut with 2-row pale malt for practicality
- Only the second piece (Munich) was formally analyzed by the trained sensory panel
- Sensory panelists were impressed with the wort
  - Flavor and aroma attributes stand apart from any other worts ever tasted by this panel
  - Many sweet, spiced desserts were used as comparative descriptors
  - Fruity, nutty, and bready descriptors were also prominent

Kernza Munich Malt: Top Sensory Descriptors



Sensory and Appearance Comparison

- Hot-steeps were made to compare wort colors and were also informally tasted for comp
- The paler malt (Vienna) seemed to have some of the unique, prominent attributes as the Munich but at a lower intensity
  - Key color/flavor formation probably occurred specifically at the high heat step (195°F)
    - Reasonable to expect further potential with higher modification, more stewing, and/or higher maximum temperature application
      - Also, new attributes might appear, others might fade

Vienna wort (L), Munich wort (R)

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Conclusion

Overall, the results of the high-color malting with Kernza are very encouraging. Very unique and prominent attributes increase the appeal and justification for malted Kernza as a specialty ingredient in brewing. These results should encourage others to pursue high color Kernza malts for their unique flavor potential, and there must certainly be more flavor and aroma to be unlocked with even higher color malts.

While a new level of color was reached in this trial, it was done with a cautious approach. Stewing highly modified grains can cause liquefaction inside the kernel, and while this can be risky enough with barley, grains lacking hulls are even more vulnerable to collapsing into a gooey mess. Future endeavors in making highly colored malts can use the production regime in this experiment as a baseline framework for incremental increase toward higher color.

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Thank You

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APPENDIX G

Kernza Flaking Trials
(Northern Crops Institute)

AURI- Kernza Flaking

Project # 2455

Kernza dehulled seed

Start 1/9/24

Date/ Time	What	Warmed to temp. (F)/ time in min,	Moisture (%)	Comments
1.9.24				
	Check Kernza seed , excellent very clean and dehulled, 50 lbs			
3-	check moisture, using tester in the pasta lab		10.37	
4p	check seed thickness 0.038-0.065", average of 10 seeds 0.0513"			
1.10.24				
10-	Sample #1			
	Temper no, seeds to moisture/ as is/ 1 lbs		10.4	good but lots of flour, dust
	Warm seeds before flaking, No- Room temp			
12p	Flake with Creason 2M roller (Flat/smooth) set to 0.006"			
1p-	Sample #2			
	Temper no, seeds to moisture/ as is/ 1 lbs		10.4	better but some fines and flour
	Warm seeds before flaking	160/12min		
	Flake with Creason 2M roller (Flat/smooth) set to 0.006"			
	Sample #3			
	Temper to Moisture, 1 lbs=0.007 lbs water		11	good flakes, fines
	Warm seeds before flaking	160/12min		
	Flake with Creason 2M roller (Flat/smooth) set to 0.006"			
	Sample #4			
	Temper to Moisture, 1 lbs=0.0182 lbs water		12	good flakes, little fines
	Warm seeds before flaking	160/12min		
	Flake with Creason 2M roller (Flat/smooth) set to 0.006"			
	Sample #5			
	Temper to Moisture, 1 lbs=0.0299 lbs water		13	good flakes, little fine
	Warm seeds before flaking	160/12min		
	Flake with Creason 2M roller (Flat/smooth) set to 0.006"			
	Sample #6			
	Temper to Moisture, 1 lbs moisture tested		16.7	Very nice flakes, low flour
	Warm seeds before flaking	160/12min		
	Flake with Creason 2M roller (Flat/smooth) set to 0.006"			
	Moisture after flaking		12.4	
	flakes measure 0.012" average thickness			
	width 0.150" average			
	length 0.275" average			
430p				

APPENDIX H

Analytical Report - Flaked Kernza
(Rahr Technical Center)

The following report summarises the findings of the Rahr Technical Center team regarding the six (6) flaked Kernza samples received on February 5, 2024.

Flake Appearance Notes:

Generally, #1 moving toward #6, the samples have a gradient wherein the overall grain integrity is decreasing (broken bits and dust decreasing). Also, the flakes of #5 and #6 appear to have slightly darker color. These observations are somewhat visible in the photos (below) although looking directly at the grain (not though plastic) offered a better assessment. In discussion with our brewers, they have a preference for #6 based on these visible grain integrity attributes. The rationale is that generally dust and broken bits can conribute toward mashing/lautering complications.

Wort Notes:

Based on visual assessment, the worts are nearly indistinguishable. There appeared to be some slight differences in turubidity, but they were minute. Similarly, the taste of the worts did not vary by much. The brewers did not find any differences that would make them choose one over another. Others who tasted noted slight differences in the character of the sweetness and aromatic aspects, but chiefly, there was no sensory aspect of any of the worts that was concerning or outstanding.

Analytical Notes:

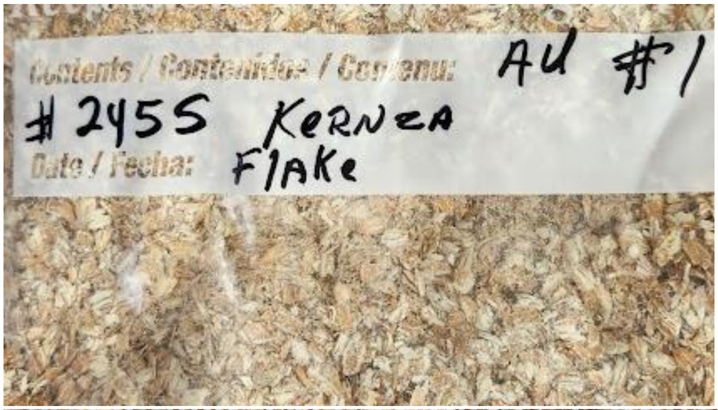
Overall, the heated and tempered flakes look substantially different from the plain flake. Overall, #6 looks the best having the highest extract and lowest viscosity; #1 has equally low viscosity, but this comes at the cost of much lower extract, so it is not a valid advantage.

Conclusion:

Based on the above notes #6 stands out as the clear choice for preferable flake.

Results of the Congress Wort Analysis - prepared 50% flaked Kernza and 50% standard 2-row malt.

Id numeric	Id text	Extract	Moisture	Viscosity
300138	AU#1KERNZAFLAKE-2201	66.9	8.28	1.63
300139	AU#2KERNZAHEAT-FLAKE	69.8	9.19	1.66
300140	AU#3KERNZATEMPERED11	69.4	8.89	1.68
300141	AU#4KERNZATEMPERED12	69.1	9.29	1.66
300142	AU#5KERNZATEMPERED13	69.6	10.11	1.66
300143	AU#6KERNZATEMPERED16	69.9	11.85	1.63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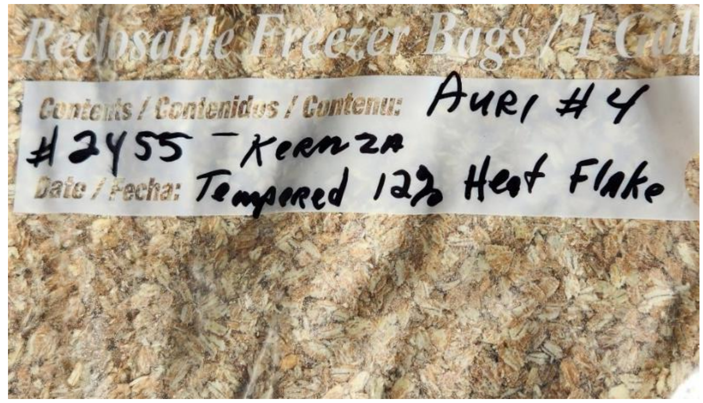
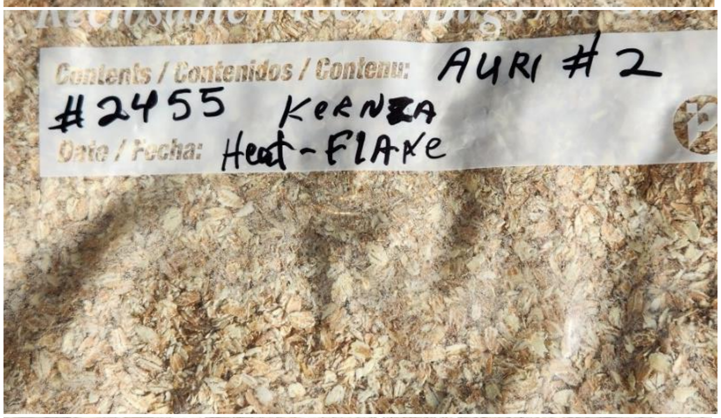
#2455 Kernza
Date / Fecha: Flake


Reclosable Freezer Bags
Contents / Contenidos / Contenu: Auri #4
#2455 - Kernza
Date / Fecha: Tempered 12% Heat Flake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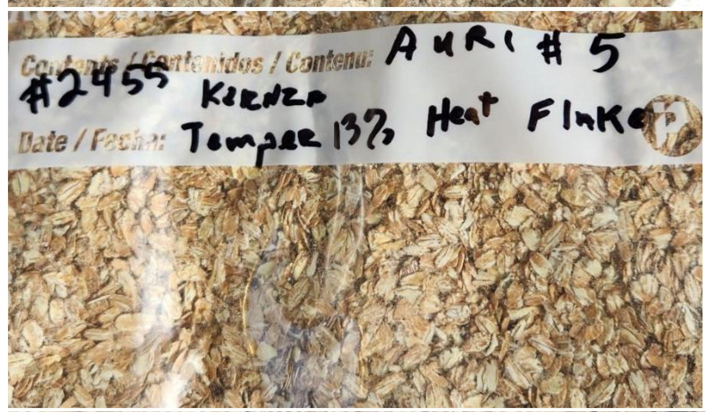
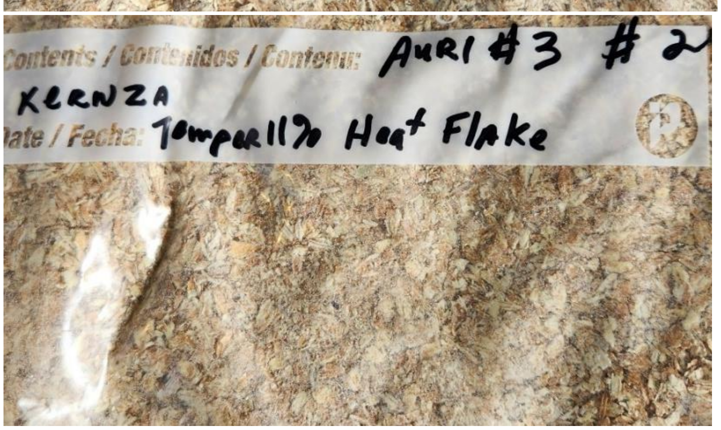
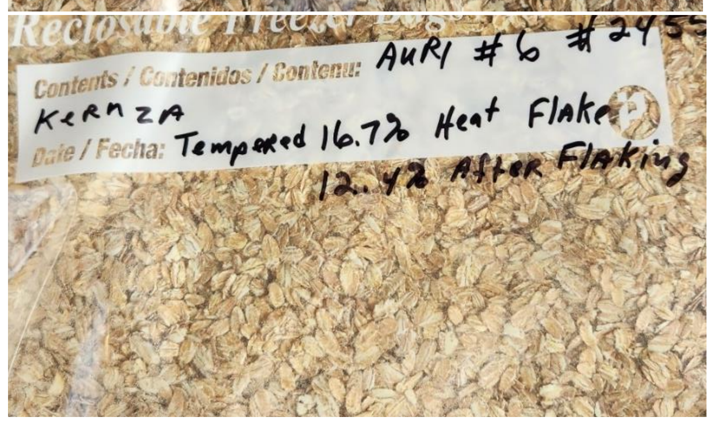
#2455 Kernza
Date / Fecha: Heat-Flake


Contents / Contenidos / Contenu: Auri #5
#2455 Kernza
Date / Fecha: Temper 13% Heat Flake


Contents / Contenidos / Contenu: Auri #3
Kernza
Date / Fecha: Temper 11% Heat Flake


Contents / Contenidos / Contenu: Auri #6
Kernza
Date / Fecha: Tempered 16.7% Heat Flake
12.4% After Flaking

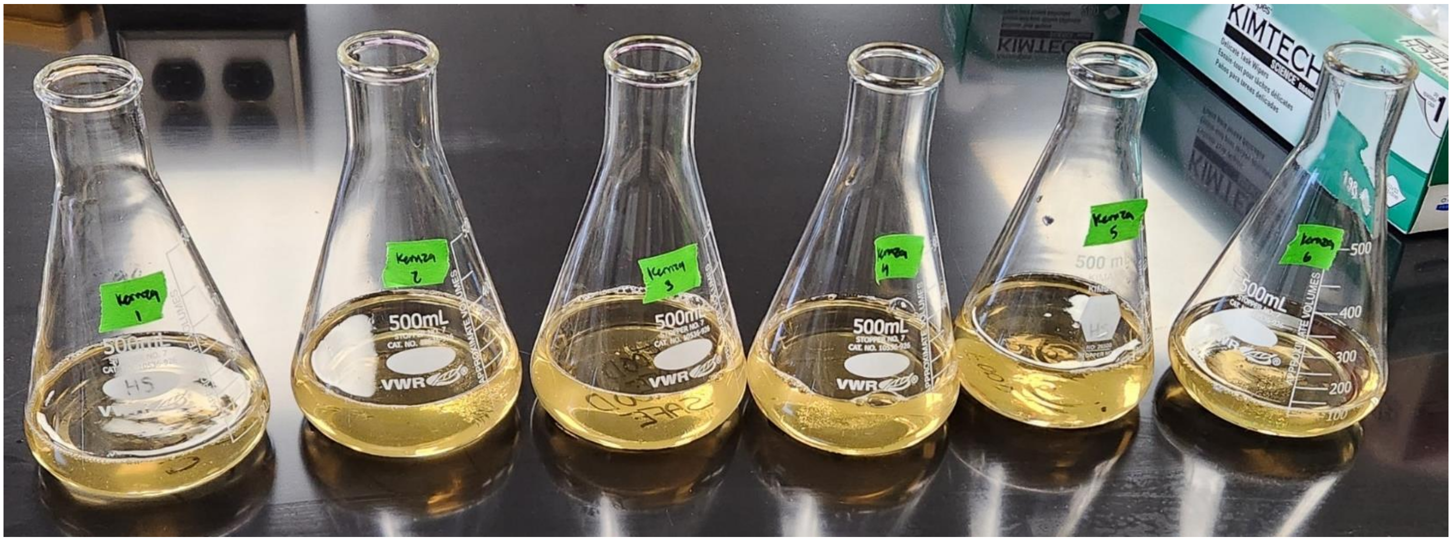


Image of the congress wort samples from left to right. AURI#1, AURI#2, AURI#3, AURI#4, AURI#4, AURI#5, AURI#6.

APPENDIX I

Kernza Flour Analysis
(Northern Crops Institute)

NORTHERN CROPS INSTITUTE
PROJECT REPORT

NCI INVESTIGATION NUMBER: #2490

PROCESSING DATE: 3/20-4/2/2024

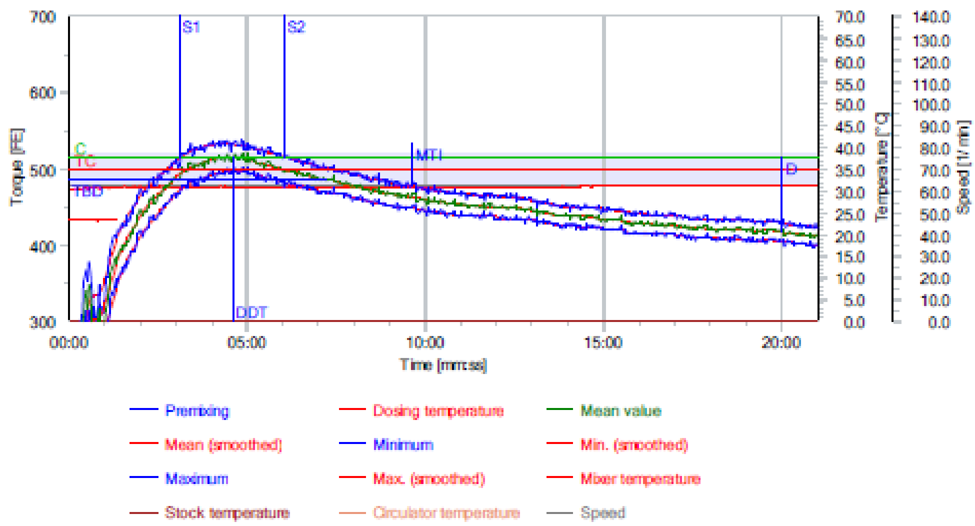
Sample ID:		**Kernza**
	Units	**Result**
Moisture	%	7.87
Wet Gluten	(14% mb) %	6.12
Gluten Index		83
Falling Number	(14% mb) Seconds	247
Farinograph (50g Bowl)	See Attached	
Extensograph	See Attached	
Alveograph	See Attached	
Mixograph	See Attached	

Methods:	
Moisture	AACC 44-15
Falling Number	AACC 56-81
Gluten	AACC 38-12
Farinograph	AACC 54-21.02
Mixograph	AACC 54-40
Extensograph	AACC 54-10.01
Alveograph	AACC 54-30.02

Farinogram:

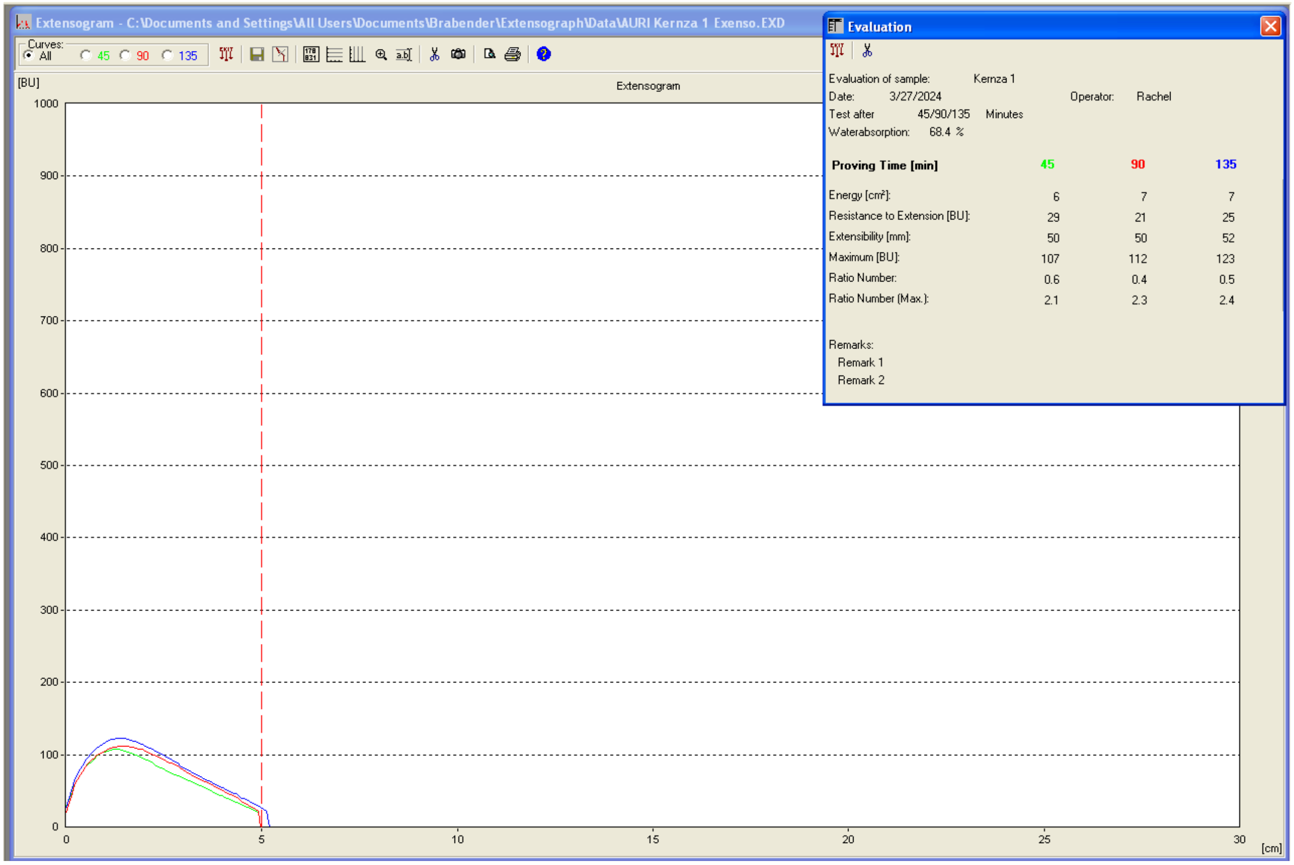
Order:			Date:	3/26/2024 9:36:52 AM	
Code number:			User:	Rachel	
Sample:	Kernza 1				
Method:	AACC 50		Speed:	63.0	1/min
Evaluation:	AACC		Measuring time:	21:00	mm:ss
Mixer:	50 g			12/2/2016 10:06:05 AM	
Sample weight:	46.7	g	Default moisture content:	14.0	%
Moisture content:	7.9	%	Default consistency:	500	FE
WA (given):	70.0	%	Min. consistency range:	480	FE
Additional liquid:	0.0	%	Max. consistency range:	520	FE
			Damping:	1.00	

Remarks:



Evaluation:			
Point	Unit	Value	Description
T	mm:ss	20:59	Measuring time
DT	°C	23.2	Dosing temperature
DDT	mm:ss	04:37	Development time
C	FE	518	Consistency
WZ	%	70.0	Water added
WAC	%	70.4	Water absorption corr. for default consistency
WAM	%	63.8	Water absorption corr. for default moisture content
S	mm:ss	02:56	Stability
MTI	FE	56	Tolerance index (MTI)
FQN	mm	72	Farinograph quality number
D	FE	97	Drop-off
TBD	mm:ss	07:12	Time to breakdown

Extensogram:



Alveogram:

CHOPIN TECHNOLOGIES

Alveolab graph

Northern Crop Institute
1240 Bolley Dr
58105, Fargo, United States of America
(701) 231-7736

CHOPIN Technologies
20 avenue Marcellin Berthelot
92390, Villeneuve-la-Garenne, FRANCE
+33 1 41 47 50 33

Protocol : Alveograph CH
File name : 2403280101[118]
Test name : Kernza 2
Comments :

Test date and hour : : 3/28/2024 11:17:04 AM
Partner name : CHOPIN Technologies
Product : Laboratory wheat flour
S/N : 340
A. : 1.3.11

Temperature

Water : 19.9 °C
Mixer : 24 °C
Resting chamber : 25 °C
Alveo chamber : 20.7 °C

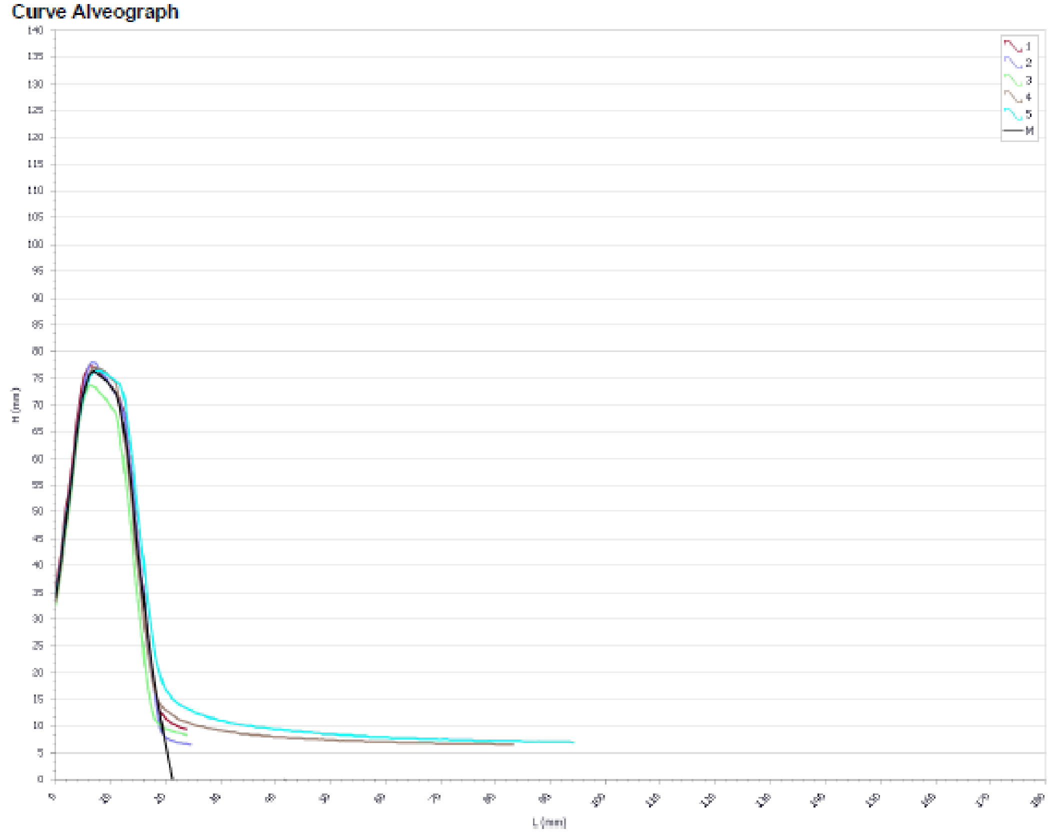
Settings

humidity : 31 %
Moisture content : 7.53 %
Hydration : 50 %
Hydration basis : B15% H20
Water quantity : 157.96 mL
Flour weight : 250 g

Results standard

P : 84 mmH2O
L : 41 mm
G : 14.2
W : 3 10-4J
P/L : 2.05
Ie : 0 %

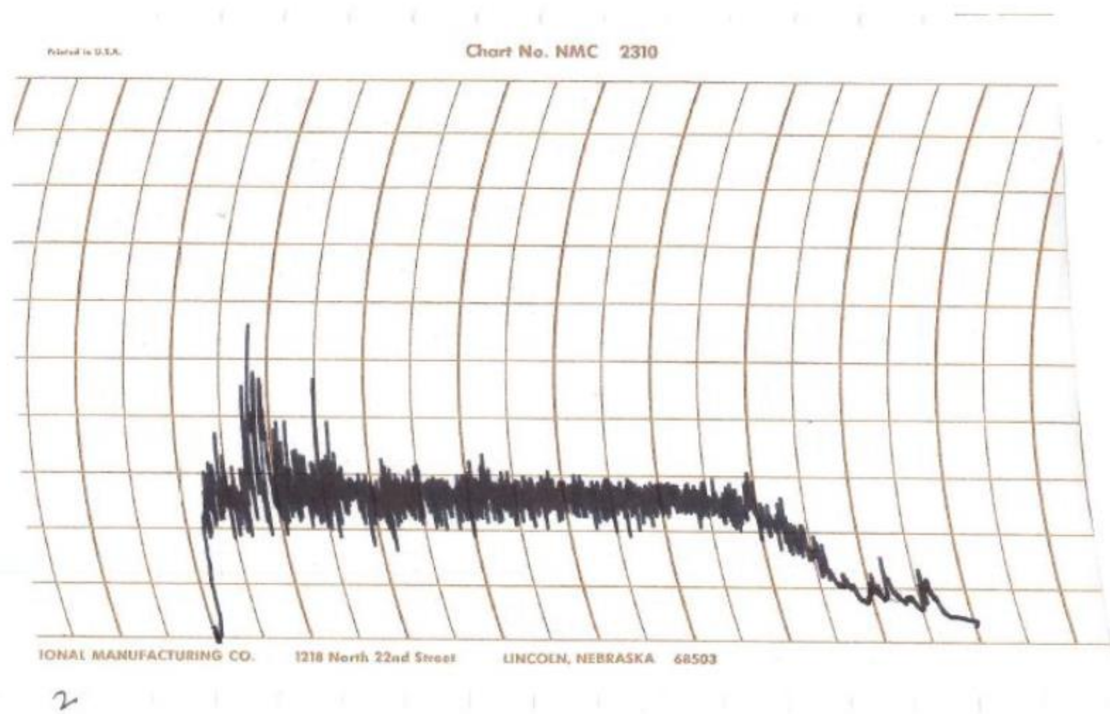
Curve Alveograph



v : 1.1.0.10

1 / 1

Mixograph:



Printed in U.S.A.
Chart No. NMC 2310
IONAL MANUFACTURING CO.
1218 North 22nd Street
LINCOLN, NEBRASKA 68503
2

Observations:

The wet gluten content in the Kernza flour is significantly lower compared to Hard Red Spring Wheat (HRSW) flour, which typically exhibits wet gluten values of 30% or higher. This indicates that Kernza flour has minimal gluten-forming proteins. The falling number value of Kernza flour is close to the minimum desirable level, with values below 250 seconds indicating enzymatic activity that can cause quality issues during baking. In contrast, a sound HRSW flour with minimal enzymatic activity typically has a falling number of 300 seconds or more.

Farinograph data reveals that Kernza flour is very weak, with stability of less than 3 minutes, indicating the flour breaks down and becomes sticky with minimal mixing. This stability is comparable to that found in soft wheats. The Extensogram data further shows that Kernza flour is weak and has low extensibility. For a strong and extensible flour like HRSW, we would expect a graph with a much higher and longer curve. The Alveograph and Mixograph data corroborate the findings from the Farinograph and Extensogram, confirming that Kernza flour is relatively weak and not very extensible.

Although the analyzed Kernza flour produced a weaker and less extensible dough compared to Hard Red Spring Wheat (HRSW) flour, it presents numerous applications and opportunities. Kernza flour can be effectively utilized in products such as batters, cookies, muffins, pancakes, cake donuts, waffles, and crepes.

APPENDIX J

Kernza Straw Compounding and Molding Trials
(c2renew)

Kernza Straw Compounding Trial

Proposed Work

c2renew was approached by AURI to develop a bio composite incorporating kernza straw as a natural filler in a bio derived resin. A formulation containing 15 wt% kernza straw was targeted for use with a blend of PLA base resins. The composite was compounded to assess how the kernza straw would perform during extrusion, produce pellets for injection molding, and to develop a technical data sheet.

Compounding Trial

The kernza straw provided by the Agricultural Utilization Research Institute (AURI) was compounded at 15 wt% with 42.5 wt% NatureWorks Ingeo 3001D polylactic acid (PLA) and 42.5 wt% NatureWorks Ingeo 5200 PLA. Prior to compounding, the kernza was dried in pans with a depth of 3 cm for 48 hours in a 110°C convection oven to remove any excess moisture. The PLA base resins were also dried in a desiccant polymer dryer for 8 hours at 60°C to prepare them for compounding.

Melt compounding was completed on a Nanjing Giant 43mm co-rotating twin screw extrusion system. Small, 5 kg batches of the formulation were hand blended and hand loaded into the primary feeder of the extruder to maintain material consistency in the feed hopper and limit separation of the ingredients during loading due to density differences and static electricity. There were no issues with bridging or rat holing in the feeder, and an agitating screw kept the materials from separating in the hopper. The twin screw extruder system used for compounding the biocomposite is shown in Figure 1 below.

Figure 1. 43mm Nanjing Giant Twin Screw Extruder

Screw speed was maintained at a low, constant RPM throughout the run to minimize degradation due to shear heat at higher speeds. Back pressure at the die ranged from 850-1050 kPa. A low temperature profile for PLA composites was maintained using electric heating bands and cooling water channels along the extruder. The melt temperature of the composite at the die was approximately 190°C.

From the die, strands were then pulled through a cooling water bath prior to strand pelletizing. Some mild off-gassing occurred at the die, and the melt strength of the strands was inconsistent, occasionally leading to broken strands that needed to be hand fed into the strand pelletizer once broken. Shorter straw particles, a lower loading of kernza, and/or a melt strength additive could assist in fine tuning the melt strength consistency for future compounding. Pellets were targeted to be approximately 2.5mm in length and width for consistent molding and melt flow index measurements. From the pelletizer, the pellets were then run through a modified spin dryer to remove excess moisture before being fed through a classifier to remove short and long pellets from the final product shown below in Figure 2.

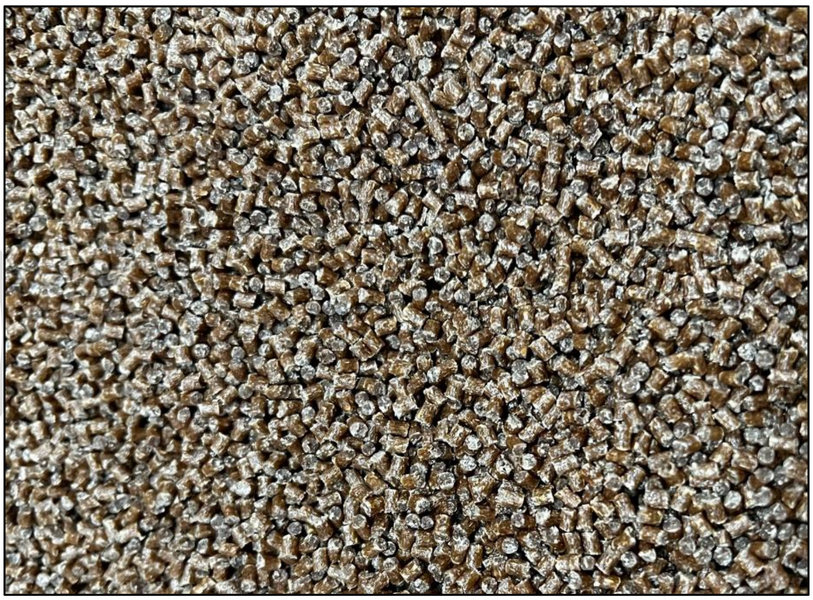


Figure 2. PLA/Kernza Biocomposite Pellets for Injection Molding

The final material was dried post-compounding in a Conair desiccant dryer for 8 hours at 55°C to stabilize it for storage and for future processing and testing. Overall, the kernza straw processed well in the extruder and it appears to be a viable option as a bio-based filler for other PLA based formulations.

Continued Development

Approximately 25 kg of the final biocomposites that were produced for the mold trialing of future products. c2renew identified a couple injection molders to manufacture cups, plates and bowl samples and golf tees utilizing the PLA/kernza biocomposite pellets produced in this trial. The pellets were alsoa used to mold tensile and flexural bars for testing to develop a technical data sheet to serve as a specification sheet for injection molders interested in trialing the composite. Sample plaques with three different surface finishes will also be produced to provide molders with a visual of the molded composite and a target aesthetic to dial in their processing conditions.

c2renew

c2 PLA-OO20G20-15

Material Status:	Experimental
Availability:	North America
Filler/Reinforcement:	Kernza Straw, 15 wt %
Processing Method:	Injection Molding

Physical	Nominal Value (English)	Nominal Value (SI)	Test Method
Specific Gravity	1.28	1.28	ASTM D792
Melt Mass-Flow Rate (MFR)	21.0	21.0	ASTM D1238
Cross-Flow Shrinkage (24 hr)	0.45 %	1.47 %	ASTM D955
In-Flow Shrinkage (24 hr)	0.23 %	0.01 %	ASTM D955

Mechanical	Nominal Value (English)	Nominal Value (SI)	Test Method
Tensile Modulus	668,000 psi	4.61 GPa	ASTM D638
Tensile Strength	7,110 psi	49.0 MPa	ASTM D638
Tensile Elongation (Break)	1.00 %	1.00 %	ASTM D638
Flexural Modulus	949,000 psi	6.54 GPa	ASTM D790
Flexural Strength	11,500 psi	79.0 MPa	ASTM D790

Impact	Nominal Value (English)	Nominal Value (SI)	Test Method
Notched Izod (72°F/22°C)	1.11 ft·lb /in	59.2 J/m	ASTM D256
	2.39 ft·lb/in^2	5.03 kJ/m^2	ASTM D256

The information contained in this datasheet are typical properties to be used by designers and processors of modified thermoplastics, it is not to be construed as specifications. Data obtained from specimens molded under carefully controlled conditions from representative samples of the compound. Properties may be affected by molding techniques applied, and by the size and shape of the item molded. No assurance can be implied that all molded articles will have the same properties as those listed. This datasheet and the material nomenclature used are confidential and proprietary to c2renew.

APPENDIX K

Kernza Outreach and Dissemination Report
(AURI)

Outreach and Dissemination Activities:

Long-Term Nitrate Mitigation by Maintaining Profitable Kernza® Production

Events

AURI's outreach and engagement efforts in support of Kernza® supply chain development during the project included a variety of events and activities.

- Kernza® Con 2022
  - April 21-23- Salina, Kansas
  - A member of AURI's commercialization team attended The Land Institute's annual Kernza convention to build connections and make a presentation about ongoing market development activities in Minnesota.
- AURI Connects: Field of Innovation Event
  - August 23, 2022- St. Joseph, Minn.
  - Information on Kernza was featured as part of AURI's "From Setback to Success" Fields of Innovation event.
- Kernza® Con 2023
  - June 21-23, 2023
  - Hosted by the University of Minnesota in Minneapolis, Minn.
  - AURI Commercialization staff attended and shared information about the project and ongoing Kernza utilization research with participants from the U.S., Canada, and Europe.
- Kernza Field Day at A-Frame Farm
  - July 13, 2023
  - Madison, Minn.
  - AURI staff attended to network and share information on post-harvest handling with attendees.
- Rosholt Research Farm Field Day
  - August 17, 2023
  - Westport, MN
  - AURI's commercialization staff presented an update on Kernza and its uses at a field day presented by the Pope and Stearns Soil and Water Conservation Districts.

- Central Lakes College Field Day
    - August 25, 2023
    - Staples, Minn.
    - Members of AURI's commercialization and technical teams hosted a booth and shared information about Kernza with attendees at Central Lakes College Ag and Energy Center's annual field day.
- Minnesota State Fair Kernza Presentations
    - August 28, 2023
    - AURI partnered with Renewing the Countryside and chef and author Beth Dooley to host demonstrations featuring Kernza-based foods at the Minnesota State Fair.
- Carbon Markets, Kernza®, and Water Quality Field Day
    - October 11, 2023
    - Kellogg, Minn.
    - AURI commercialization staff participated in a Kernza-focused field day at White Barn Acres Farm, featuring presentations on the crop by project partners from the University of Minnesota.

Information Sharing, Promotion, and Collaboration

In addition to supporting and organizing outreach with project collaborators, AURI pursued several other activities to share information with potential growers, processors, end-users, and other interested parties.

- Journal Article: "Developing markets and value-added uses for a new cereal crop"
    - Cereal Technology/Getreidetechnologie, 2023, Vol 77, Issue 1
    - AURI staff published an article about Kernza, market development in Minnesota, and value-added uses for the crop in the journal Cereal Technology. LCCMR/ENRTF support of this work was highlighted in the article.
- Continuous Living Cover Value Chain Coordinators Convening
    - May 9-10, 2023
    - Madison, Wis.
    - AURI took part in a gathering of stakeholders working with continuous living cover crops to discuss market development opportunities for Kernza and share information about ongoing LCCMR-funded value chain development efforts in Minnesota.
- Master Brewers Podcast, Episode 304 "Kernza"
    - March 25, 2024
    - Alexandra Ostlund, AURI's Business Development Director of Novel Supply Chains, was a panelist on a Kernza-focused podcast hosted by the Master Brewers Association of America

Post-Project Dissemination

- 2024 World Brewers Conference
    - August 18, 2024
    - Minneapolis, Minn.
    - In coordination with research partners including the University of Minnesota and The Land Institute, AURI will present at a panel session titled “Production of Grain Ingredients for Brewing: Winter Barley and Kernza.”
- AURI Fields of Innovation- Beverage Industry Kernza Showcase
    - October 9, 2024- Minneapolis, Minn.
    - AURI is partnering with Kernza industry stakeholders to host an event for the brewing and distilling industry.   share information about Kernza wit, and its potential uses as an ingredient in fermented beverage products. The event will include presentations by grain suppl

APPENDIX L

Developing Markets for Value-Added Uses for a New Cereal Crop
(Cereal Technology/Getreidetechnologie, 2023, Vol 77, Issue 1)
(AURI)

Developing markets and value-added uses for a new cereal crop

Alexandra Diemer, Riley Gordon, Matthew Leiphon, Michael Stutelberg

Kernza Perennial Grain Overview

Kernza perennial grain is one of the first commercially available, perennial grain in the United States. Producers harvest Kernza from intermediate wheatgrass (Thinopyrum intermedium). The cultivar is a distant relative of annual wheat and yields various products and potential co-products as well as ecosystem services. Intermediate wheatgrass is being domesticated by Kansas-based The Land Institute and other research partners as a multi-use grain for livestock forage and human food. The Land Institute states that Kernza grain is a perennial alternative for and compliment to annual wheat in foods like baked goods, pasta, and beer or can be used as a whole grain.

As a perennial crop with a root system that can extend 10 feet or more beneath the soil surface, Kernza contributes positively to ecosystem services, including drawing carbon from the air to build organic matter in the soil, providing soil structure and stability to prevent erosion, capturing nutrient runoff and protecting water quality, and improving water holding capacity. In addition, it can create improvements off-farm by positively impacting water and soil conservation and increasing biodiversity. At the same time, it can provide an important food source and habitat for beneficial insects and pollinator species, as well as a food and shelter resource for wildlife.

Fig. 1: Root System Comparison of Kernza Perennial Grain (L) to Annual Wheat (R) at The Land Institute in Salina, KS.

Kernza: Value Chain Development

The Agricultural Utilization Research Institute (AURI), based in Minnesota, helps develop new value-added uses for agricultural products through science and technology, partnering with producers, businesses and entrepreneurs to bring innovative ideas to reality. The overall goal of AURI's work with Kernza is to support development of a resilient value chain—resulting in new opportunities for Minnesota farmers and businesses to produce and utilize a new cash crop that also offers environmental benefits and protects water quality in Minnesota's wellhead protection areas.

This pilot work has been pursued in partnership with the Stearns County Soil and Water Conservation District, the University of Minnesota, and other key stakeholders with funds from the Minnesota Environment and Natural Resources Trust Fund (ENTRF). The ENTRF is a permanent fund constitutionally established by the citizens of Minnesota to assist in protection, conservation, preservation, and enhancement

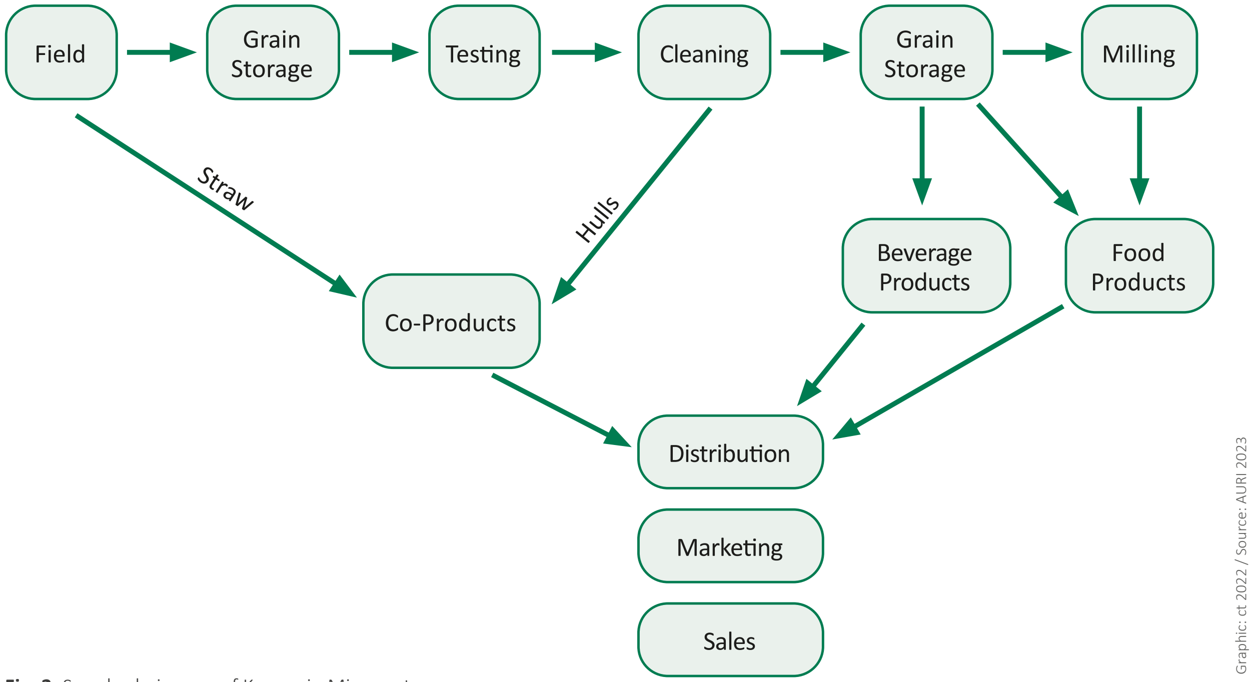


Fig. 2: Supply chain map of Kernza in Minnesotav

of the state's air, water, land, fish, wildlife, and other natural resources.

AURI's work has included the following activitiesv:

1. Development of value chains using Kernza in food applications
   a. Mapping and developing value chains utilizing Kernza in Minnesota.
   b. Evaluating Kernza for inclusion in food applications.
   c. Providing technical information on the processing (cleaning and dehulling), handling, storage and use of Kernza grain and ingredients, as well as formulation of food application concepts for Minnesota-based companies.
2. Coordination with project partners to provide information and content at educational events, forums and field days on market opportunities for Kernza.
3. Development of value chains using Kernza in non-food uses, including feed, fiber, fuel and other bio-industrial applications.

Value chain analysis is an important exercise for emerging crops. In agriculture, the value chain incorporates the progression of a crop from farm to table. At each step of a value chain, additional "value is added" to the product. A well-developed value chain creates one or more pathways for agricultural products to gain value. This was the driving force behind AURI's work: to create a strong demand "flow" for Kernza harvested from Minnesota farms. In addition to identification of key current and potential stakeholders in Minnesota, this process resulted in the identification of potential gaps in the region's supply chain where infrastructure was lacking or underdeveloped.

To obtain a copy of AURI's Kernza Perennial Grain Value Chain Development in Central Minnesota report, which was the basis for this article, visit https://auri.org/guides/kernza/.

Kernza Agronomy and Production

There are several challenges to growing Kernza:

1. While the perennial nature of the crop provides multiple harvests, yields of current cultivars decrease by the third year, even though the crop rotation goal is to replant after four to five years.
2. The large heads show low shatter resistance, resulting in grain loss prior to and during harvest.

3. Small seed size, as small as 25% the size of traditional hard red (annual) wheat.
4. Kernza's large hulls may account for up to 30% of the weight of harvested grain and create challenges in cleaning and processing the crop for end users.

Kernza grain sizes, shatter resistance, and yield potential over time are increasing with each cycle of selection in four core breeding programs, which include farmers and research partners from 15 states and 10 countries .iii If progress is sustained, Kernza seed size will be 50% as large as annual wheat kernel sizes in the next 10 years. In addition to these advances, breeders are working on developing shorter plants that are easier to grow, along with improved flavor and functionality, including free-threshing varieties. While current grain yields for Kernza are relatively low compared to annual wheat production, farmers can still benefit from the ecological impact of producing Kernza perennial grain.

As development of the crop has progressed, farmers have begun to work collaboratively to advance and support expanded Kernza production and value chain development. The Perennial Promise Growers Cooperative (PPGC), a farmer-led, collective marketing and technical support organization, now holds a 30% market share of the 3,957 active acres planted in North America in 20xx with producer members in Minnesota, Wisconsin, Iowa, and South Dakota.

Fig. 3: Kernza In-hull vs. De-Hulled (cleaned and ready for further product development)

Kernza Demand

Kernza's greatest competition in the marketplace comes from organic annual wheat, the emerging market for Regenerative Organic Certified (ROC) annual wheat, and ancient and small grains. Mad Agriculture (Mad Ag), a company working with farmers who are transitioning to regenerative practices, has performed a market feasibility report for Kernza. Based on an estimated average inclusion rate of 30% and subtracting a combined 67% gross margin for supply chain intermediaries, its analysis anticipates Kernza's total-addressable-market to be $238 million.iv Mad Ag also serves as the grain agent for PPGC, and reports that most buyers are interested in Kernza for its environmental attributes. Despite the promise Kernza provides for producers looking to improve soil health and water quality and for food brands looking to decrease their carbon intensity, ultimately, Kernza will need to be economically competitive with other crops in order to establish a viable, resilient place in the market. This will require a continued concerted effort on building supply chains, grower interest, genetic improvements and end markets for the crop.

Market Valuation and Commercialization Potential

Market prices for Kernza perennial grain remain quite high compared to other small grains, likely due to low supply and limited channels for marketing as the crop is still in the early stages of supply chain development and market formation. Mad Ag's market assessment provided context for current prices and impacts to market adoption, noting that "given the pandemic and inflation, price is going to be more sensitive," and may create near-term challenges for the crop as "a high-priced ingredient will be harder to sell."

In early 2022, Minnesota Kernza stakeholders reported prices for Kernza grain ranged from approximately $4.75 per cleaned pound for conventionally raised grain to $6.50 per cleaned pound for ROC-raised grain. iv Growers also reported that buyers appeared willing to pay a premium over the organic price to purchase grain with a regenerative organic certification.

Because of Kernza's ability to enhance its surrounding ecosystem, farmers may be able to stack environmental benefits and diversify economic opportunities. The emergence of market programs to reward farmers and ranchers who are implementing climate-adaptive, regenerative agricultural practices may offer additional sources of income for Kernza producers. These ecosystem services marketplaces exchange value for insetting or offsetting carbon and aim to:

1. Incentivize farmers to transition to alternative growing practices or systems, namely those that enhance water quality, improve soil health, sequester carbon, increase diversity and/or incorporate cover crops with more traditional rotations like soy and corn.
2. Create high-value credits for farmers to either receive payment for carbon insetting or from companies who purchase a carbon offset.

While farmers cannot stack incentives for both insetting and offsetting carbon, they are eligible to receive two payments for each Kernza harvest: one for the market price and one for the ecosystem service market contract they may elect to participate in. The Minnesota Farmer's Union compiled a resource for farmers and stakeholders with detailed information and comparisons on the various carbon market contracts in Minnesota. One key aspect that will be important to emphasize as the Kernza value chain continues to develop is expanding the processing capacity for cleaning, de-hulling, and milling Kernza grain post-harvest, which Mad Ag states is currently the "single-greatest limiting factor, stalling the commercial success of Kernza."

Kernza Processing, Characterization and Product Development

Generally speaking, understanding value chains is a critical component of AURI's work. The organization's work includes business development, commercialization and technical assistance at multiple stages along the value chain, including primary processing and storage, secondary processing, distribution, packaging and handling, as well as wholesale and retail markets.

Tab.1: Kernza Price Targets. ROC = Regenerative Organic Certification.

Management Type	Price
Roc	$ 6,50
Organic	$ 5,50
Transitional	$ 5,00
Non-Organic	$ 4,75

Source: AURI 2023

As part of its commercialization activities AURI explored several supply chains, mostly focused on food products. Of note, the team examined cleaning and processing, milling, beverage manufacturing (brewing and distilling), pasta, and bakery and bread products. The team also investigated the potential uses for Kernza coproducts as feed and as a feedstock for biopolymers. More details on these product and value chain development activities can be found in AURI's full report, available online at AURI.org.

Cleaning, Dehulling, and Milling

Kernza requires cleaning and dehulling to prepare the whole grain for use. This is one of the larger challenges when it comes to processing Kernza, as the grain is smaller than wheat and other small grains and can require specialized knowledge and machinery to process.

With Kernza currently being a novel crop for many growers, processors and end-users, AURI identified a clear knowledge gap when it came to transporting harvested grain from the field and transforming it into marketable grain, flour or seed ready for end-users. Over the past several years, AURI has researched and tested various cleaning, dehulling, separation and milling techniques for Kernza to better understand optimal processing to share with industry. AURI leveraged connections with growers, grain cleaning equipment manufacturers and industry experts to test a wide range of grain cleaners, dehullers, color sorters and more. This work resulted in a deeper understanding of the large variation in the grain sizing and cleanout rates based on the current varietal characteristics and harvesting practices associated with the crop.

Tab.2: Kernza flour compared to white flour nutritional characteristics.

Grain Types	Units	Kernza Refined Flour[a]	All Purpose Whie Flour[b]
Moisture	%	8.1	11.9
Ash	%	0.6	0.5
Calories	-	368	364
Protein	g	17.5	10.3
Carbohydrates	g	73.2	76.3
Dietary Fiber	g	4.3	2.7
Sluble Fiber	g	1	0.9
Sugar	g	N/A	0.3
Total Fat	g	1.2	1
Saturated Fat	g	0.3	0.2
Monounsaturated Fat	g	0.1	0.1
Polyunsaturated Fat	g	0.7	0.4
Trans Fat	g	0	0
Cholesterol	mg	0	0
Calcium	mg	50	15
Iron	mg	3.7	1.17
Potassium	mg	140	107
Sodium	mg	0	2

[a]Results are directional only, data represents analysis of one sample of Clearwater Variety, MVTL, New Ulm, MN
[b]Esha Database composition Data

Source: AURI 2023

AURI has summarized the 'best practices' for selecting equipment and machine parameters (screen sizes, air flow, process flow, etc.) in an industry informational sheet which is currently available to interested industry stakeholders.

AURI also worked with Minnesota-based flour mills, performed internal research, and partnered with external research partners to assess and develop optimal milling techniques to produce whole grain Kernza flour. This work identified a process of hammermilling through a fine 1/64" - 2/64" screen or a stone mill set with a very tight gap. Research was also conducted on refining Kernza flour through a traditional breaker roller mill and sifting method used in the wheat flour industry. However, given the small size of the grain, the yields of a finished refined flour were around half of what is achieved with most common wheat varieties (43% for Kernza vs. 77% for wheat). Therefore, whole grain Kernza flour will be more ideal from a milling output viewpoint.

AURI has also set up small scale Kernza cleaning, dehulling and milling equipment in a food grade lab at its Waseca, Minnesota laboratory to produce small amounts of clean grain and flour for R&D pilot projects as well as to provide education to third parties that are interested in developing Kernza processing capacity.

Baking and flour characteristics

Kernza has a variety of potential uses in food products, from its simplest form as whole grain, to flour, flatbread, crackers, bread, pasta, mixes and more. As with its close relative wheat, this wide array of potential uses for Kernza provides an abundance of opportunities for the food industry. Kernza contains higher levels of protein, dietary fiber, and bioactive compounds such as carotenoids when compared to common wheat but lacks some gluten components (high molecular weight gluten) that limit its functionality in some applications.

To overcome the gluten component deficiency, there are several additives or dough conditioners that can be utilized to help improve functional properties. Kernza can also be blended in different ratios with wheat flour to achieve a desired end-product quality.

Food Product Development

To assess Kernza's utilization in food products and its viability as a commercial food industry ingredient, AURI partnered with the Northern Crops Institute (NCI) at North Dakota State University in Fargo, North Dakota. As part of its mission to support regional agriculture and value-added processing, NCI operates laboratories focused on milling, pasta production, food processing, and baking process development,

Tab.3: Cooking quality and texture results for macaroni samples.

Analysis	Units	100% Semolina Macaroni	34% Kernza Macaroni	66% Kernza Macaroni	100% Kernza Macaroni
Cooking Time	Minutes	6.75	6.75	6.25	5.25
Dry Pasta Weight	G	25.20	25.02	25.05	25.05
Cooked Pasta Weight	G	59.30	58.05	56.56	53.70
Weight Increase	%	135.32	132.01	125.79	114.37
Cookes Loss	%	4.16	5.00	5.08	5.44
Color (Macaroni)	L*	85.41	69.49	66.81	64.72
Color (Macaroni)	A*	-3.33	2.79	3.62	3.90
Color (Macaroni)	B*	31.47	17.79	18.83	18.86
Color (Flour Blends)	L*	81.13	82.04	82.48	82.78
Color (Flour Blends)	A*	-0.49	-1.15	-0.90	-0.80
Color (Flour Blends)	B*	19.72	19.55	17.14	15.81
Texture-Firmness	G	550.16	474.54	447.75	389.75
Texture-Work Of Shear	G.CM	121.97	128.96	142.54	114.80

Source: AURI 2023

offering a unique portfolio of facilities and expertise with the ability to assess multiple potential uses of Kernza.

As part of AURI's collaboration, NCI examined various food applications using whole grain and refined Kernza flour and provided insight on using Kernza as a refined flour versus whole grain flour based on both food application results and milling considerations. As part of this work, NCI coordinated with AURI food scientists to develop research protocols and test the use of Kernza in multiple food applications, including pasta, crackers, tortillas, donuts, and sourdough breads.

In baking applications, there are a number of differences from wheat to consider when using Kernza. It has a higher dietary fiber and protein content than wheat, indicating a nutritional profile advantage. However, Kernza also has a higher fat content, which increases its rancidity potential, and a lower level of glutenin and starch, which limit Kernza's ability to form viscoelastic networks. As such, Kernza flour is best suited for higher percentage use in baking applications where volume is a less important attribute, such as in flatbreads, tortillas, or sweet baked goods like cookies. For applications such as loaf bread, Kernza flour, may be substituted for conventional wheat flour. However, as the ratio of Kernza in the flour blend increases, bread attributes such as volume, texture, taste and color will be severely impacted. Sourdough processing indicates some advantage in increased Kernza usage rates, but this needs to be studied in more detail before a definitive recommendation can be made. Recommended usage of Kernza flour in standard loaf bread applications should be significantly lower than 50% to achieve traditionally acceptable products.

Based on the evaluations conducted by AURI and NCI, the use of Kernza as a food ingredient will face two challenges:

- Kernza is not a direct substitute for conventional wheat in most applications. As such, the recommendation is to use it as an adjunct to conventional wheat flour, typically in lower levels as part of a blend. As the percentage of Kernza in a blend increases, products will typically develop undesirable flavor, texture, and product performance characteristics. In some cases, significant testing is necessary to design an acceptable product.

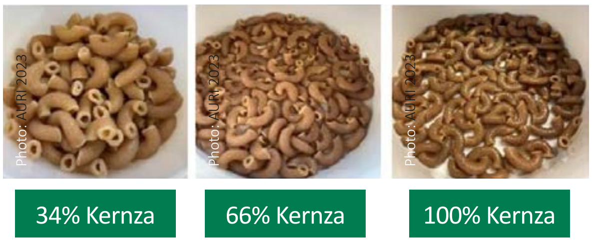


Fig. 4: Kernza inclusion rates in pasta formulations.

- Establishment of a stable and reliable Kernza supply chain, detailed elsewhere in this report, is ongoing. As a result, the per pound price of Kernza is significantly higher than conventional wheat. This will limit Kernza inclusion rates in many product applications, independent of product attributes, unless consumers are willing to pay a premium.

Other evaluated applications of Kernza included pasta and crackers. Research showed significantly higher levels of Kernza to be acceptable in these applications, based on the sensory attributes of aroma, flavor, and color for these products. In the case of pasta, Kernza whole grain flour was found to be useable at up to 66% of the total flour blend, though the recommended usage level is 34% to avoid an impact on cooked weight and texture. In the cracker application, higher levels of whole grain Kernza flour were acceptable at up to 75% of the total flour blend. Four blends of macaroni pasta were produced at NCI on a Demaco Pasta Press:

- 100% durum semolina
- 34% whole grain Kernza, 66% durum semolina
- 66% whole grain Kernza, 34% durum semolina
- 100% whole grain Kernza.

Researchers analyzed the pasta using the AACC method 66-50.01 – pasta and noodle cooking quality – firmness.

Changes were noticeable in cooking quality and results with the inclusion of whole grain Kernza. Specifically, the cooking time and cooked pasta weight decreased while cooking loss increased. Since there was little difference in dry pasta weight, this indicates that Kernza was lost during cooking. Typical cooking loss is related to increased starch in the cooking water. A 34% inclusion rate appears to be relatively close to the 100% semolina check sample. For color, increased inclusion rates had a noticeable darkening effect on the pasta as was exhibited with lower L* scores. This was pronounced in the final macaroni samples, but there were no observable trends found in the flour blends.

Pasta firmness after cooking decreased when rates of Kernza whole grain flour increased, yet no trend was noticed with the work of shear, wherein the 66% inclusion rate was the highest and the 100% Kernza was the lowest, even lower than the semolina check.

Beverage Products

Kernza is a viable option to utilize in brewing beer and holds notable potential as a brewing ingredient. AURI pilot brewing partners report that the addition of Kernza yielded appealing attributes. The assumed color and flavor additions when including Kernza in beer turned out to be more muted than initially thought. While still noticeable at the lower levels (10-20% of the final grain bill), the Kernza did not have as large of an impact as hypothesized by team members and brewers. When added to a brewer's grain bill, Kernza grain did not appear to create any issues with the lautering (separation of wort and spent grain) of the beer. Originally experts thought that the β-glucan levels observed in Kernza could lead to issues with stuck sparges, but no such issues were observed during the two pilot batches conducted as part of AURI's product development activities.

The size of the Kernza berries was the biggest concern voiced by breweries. Due to the berries being roughly one-fifth the size of traditional wheat berries, brewers expressed concerns that the berries could be too small for milling on current equipment, as well as moving through a breweries grain auger prior to addition to the mash. A larger berry size would ease the integration of Kernza into breweries at a larger scale.

Kernza-based distilled products are also a market with notable potential. Kernza-based spirits are under development by several distilling companies in Minnesota and may provide an outlet for grain with specific quality issues that make it less suitable for use in food products and brewing.

Malting

Kernza beer market development will drive opportunities for malting Kernza. Demand for malt Kernza will likely depend on the qualities brewers seek. Kernza is useable as both a malted product and an unmalted adjunct grain in brewing recipes, similar to how wheat is used in beer.

During its assessment of Kernza's use in brewing applications, AURI coordinated with the Rahr Technical Center (RTC) to perform malting and brewing trials at its research facilities in Shakopee, Minnesota. As one of the leading malting companies in the United States, Rahr has extensive experience in the development of ingredients for use in fermented beverages. The RTC includes a pilot malt lab that performs malting experiments, and a pilot brewery that allows staff to "perform real-world trials on malt, hops, yeasts, and other ingredients."

As part of evaluating Kernza's utility for brewing, AURI explored whether it would be best suited for malting in its in-hull or dehulled form. While there are benefits to both malting and brewing with grain that retains its hull, there are also benefits when using naked grains. However, uniformity in the grain is a very important quality. During a 2019 micromalting experience, the Kernza came with hulls on, but it was manually dehulled. It was observed to easily shed hulls with handling, and the malting quality was not harmed. Based on these considerations, the project focused on dehulled Kernza. AURI proceeded to obtain a dehulling service for a quantity of Kernza. Due to concerns of potential damage through the dehulling process, AURI sent small samples of in-hull and dehulled Kernza to RTC for testing. Both samples were tested for germination by the ASBC 4 mL Germinative Energy method, resulting in 93% germinative energy for both in-hull and dehulled samples. Moreover, the kernels that failed to germinate did not appear to have any physical damage or removal of the embryo that might be attributable to the dehulling process. The typical minimum germination rate for malting quality grains is set at 95%, but for this novel grain, 93% was deemed acceptable to proceed with malting.

Since germination was equal for both in-hull and dehulled Kernza, both advanced to micromalting for further comparison. The two samples were malted concurrently under the same conditions, yet yielded markedly different results. The steep out moistures were 40.2 % for the dehulled Kernza and 52.5% for the in-hull Kernza. Final malt quality differences likely arose from this primary disparity. The significantly higher moisture uptake by the in-hull Kernza was presumably due to a combination of high absorbency of the hull material itself and to empty space within the hull that retains excess water by capillary action beyond the immersion of the steep.

Apart from the differences in imbibition, another important difference due to the presence/absence of hull was the grain test weight. Once dehulled, the Kernza achieved nearly double its bushel weight. Thus, an equivalent volume of in-hull has about half the mass of dehulled Kernza. In a full-scale malt production scenario, the throughput in terms of fermentable material would be severely limited for in-hull Kernza compared to de-hulled Kernza, let alone compared to conventional malting grains. Lastly, the in-hull Kernza has a strong tendency to release its hull; by the time micromalting was completed, a large majority of kernels had shed hulls, so the final product was a mix of naked kernels and free hulls. In a production setting, the excess free hulls would be separated and considered lost yield.

Micromalting Analytical Results

Differences in the Kernza malt samples were based on the presence or absence of the hull. The overall modification of the in-hull Kernza is higher (S/T higher, beta-glucan and viscosity lower), and aligns with higher steep-out and germination moisture levels. The extract was much lower in the in-hull versus dehulled Kernza, due to the inert, substantial hull. Due to the slender kernel size, even the dehulled Kernza

Tab.4: Malt analysis of micromalted Kernza vs red wheat malt.

Micromalt Analysis	Alpha Amylase	Beta Glucan	Bushel Weight	Color	NTU	DP	DON	Fine Grind	FAN	Fri-Ability	Moi-sture	pH	S/T	SP	TP	Visc
Dehulled	39.7	110	42.2	2.16	9.7	161	0.67	68.4	125	55.3	3.26	6.23	29.5	6.5	22.02	1.76
In-Hull	40.4	87	26.7	3.77	11.3	144	1.12	60.2	156		3.38	6.12	40.4	6.78	16.77	1.54
Red Wheat	55.7	45	46.3	2.86	7.7	159	0.07	82.3	167		4.83	6.12	41.6	5.42	12.4	1.51

Source: AURI 2023

material in 1kg micro-malting cans during day 2 of germination was much lower in extract than wheat malt. Kernza malts do resemble wheat malts (vs oats, rye, or barley malts), in both visual appearance and in some analytics: enzyme levels, low beta-glucan, and high viscosity. The high viscosity could be due to a high level of pentosans. The level of deoxynivalenol (also known as DON or vomitoxin) was substantially higher in the in-hull sample. The increased DON presence could be a regulatory concern as well as directly affect beer quality.

In conjunction with malting trials, Rahr technical staff brewed a hazy IPA with an inclusion rate of 20.8% Kernza by total extract contribution. Since the roller mill consistency was deemed to be insufficient for proper mashing, the Kernza malt was further milled with the laboratory burr mill on a fine grind setting. This yielded a fine Kernza flour. From the malt analysis, the viscosity of the Kernza was about 2 cP; while high compared to barley base malts (~1.5 cP), it was in line with red wheat malts and significantly lower than other grain malts, like rye that can exceed 4 cP. Rice hulls were employed in the mash to mitigate the high viscosity and fine milling applied to the Kernza. Mashing and lautering proceeded without issues. The brewhouse and lautering efficiency were low for the brew (82.2 & 80.2%, respectively), but this efficiency reduction is consistent with the inclusion of rice hulls. The fermentation began with a wort of 13.6° Plato original gravity and finished with an apparent extract of 4.1° Plato with 5.3% alcohol by volume. The resultant 58.7% RDF (real degree of fermentation) is a little low compared to a comparable brew that resulted in a 60.0% RDF and 5.45% ABV. A reduction in RDF can stem from various causes but excluding the yeast and fermentation conditions (no problems observed), the fermentability of the grain would be the limiting factor. Specific to this Kernza malt, there might have been a curbed fermentability of carbohydrates due to the somewhat under-modified malt. An interesting facet to consider is the large amount of protein comprising the soluble portion of the malt. The protein that remains in the beer beyond fermentation would affect the density measurement used to calculate the RDF. Typically, the soluble protein levels of different malts don't vary enough to noticeably influence the RDF but given that the soluble protein was 50% higher than typical red wheat malts, it could have played a more significant role. The result can be seen with the naked eye, as one of the main sources of beer haze is protein-polyphenol complexes (polyphenols from hops). The Kernza beer was intended to be hazy, and in that facet it performed well. Even 3 months from packaging, the beer retained strong haze. Lastly, a sensory panel found unique flavor attributes in the Kernza beer of elusive spicy and fruity notes, so unique flavor attributes could help drive brewer and consumer interest.

All in all, despite some challenges, the pilot malting and brewing experience with Kernza was a positive and successful one. The positive beer sensory results indicate that Kernza has a strong potential for malting and brewing applications. The main obstacle of small grain size will likely remain a headwind for widescale use, but it has proven be a manageable challenge. Given its promising properties for sustainability in agriculture, excitement for Kernza continues to grow among prospective brewers and consumers. Floor malting might offer the kind of adaptability and special attention to get Kernza into commercial level malting. The future looks especially bright for malting and brewing with the continued breeding efforts toward greater yields and larger, free-threshing kernels that will improve the grain's general appeal and utility.

Conclusion

AURI continues to support the development of the Kernza industry. The partnership developed with the Stearns County Soil and Water Conservation District, the University of Minnesota, and other regional stakeholders has yielded vital information. Significant strides have been and are being made in tying together active and potential value chain players across Minnesota and beyond, including processors to clean and dehull the grain, millers to create flour, and several end users including bakers and brewers.

Authors:
Alexandra Diemer
Riley Gordon
Matthew Leiphon
Dr. Michael Stutelberg PhD
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