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In This Issue

Flour Quality and Leavening Systems in Artisan Breads

FSMA and Artisan Products

Scoring and Evaluation of Artisan Breads

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Advancing grain science worldwide

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Alessandra Marti

Elena de la Peña

When "Old Is New Again" Artisan Baking Grows

Alessandra Marti and Elena de la Peña
Guest Editors

Knitting, home brewing, and hand-crafted goods have gained popularity with people who are seeking experiences and products that evoke nostalgia for earlier times. Simple foods, "like grandma used to make," appeal to these consumers. Perceptions of health and quality surround foods made in small batches using locally sourced ingredients and old-fashioned techniques. Artisan baking, an outgrowth of this trend, is on the rise in local bakeries and grocery stores, particularly in Western industrialized regions.

This issue of *Cereal Foods World* explores the artisan baking trend throughout the value chain, highlighting the challenges and potential solutions for the mass production of artisan breads. Key players from the food industry were invited to contribute their perspectives on artisan baking: from the selection of raw materials to product formulation (e.g., refined versus whole wheat flours), leavening, and finished product evaluation. Their perspectives embrace the "imperfect beauty" of artisan breads, while also exploring technical challenges, such as consistency in dough performance, extending shelf life, and achieving overall quality.

We hope that this issue serves as a conversation starter among bakers and millers. As Jeff Yankellow indicates in his article, "Defining Artisan: What It Is and What It Means," there is no clear-cut definition of artisan. In a world where there are probably as many definitions for artisan bread as there are bakers, he invites us to join the debate about what is and what isn't artisan. "Is it the ingredients, the process, the amount of work done by hand or machine, or the bread itself that matters most?"

If flour is the body of artisan baking, leavening is the soul. In two feature articles, the body and soul of artisan baking are examined from technical perspectives. In his article, "Flour Quality and Artisan Bread," Andrew Ross uses scientific data to dissect the chemical and physical properties of flour and associate these characteristics with the performance of the flour in artisan baking systems. Frank DeVos compares different approaches to integrating once common artisan processes into modern baking environments in "Traditional Versus Modern Leavening Systems."

Although some might argue that a bread isn't artisan if it contains enzymes, Dilek Austin argues that bread shape and formulation are more important. In her feature article, "Enzyme Applications in Artisan Bread," she asserts that enzymes can improve the quality and shelf life of artisan breads and provides technical guidance on how they can be used in artisan baking.

Artisan bread is known for its lack of uniformity from loaf to loaf, which poses challenges in applying the evaluation methods used for mass-produced breads. In his article, "Scoring and Evaluation of Artisan Bread," Martin Philip offers practical tips and technical guidance on the art and science of "scoring" loaves, using the dual meaning of the word: 1) cutting the surface of the loaf prior to baking; and 2) evaluating the final quality of the baked loaf of bread.

Artisan bakeries tend to be small- to medium-sized companies that reach a smaller number of customers than larger bakeries. As a result, not all of these bakeries have yet faced the pressure to institute the hygienic standards employed by larger corporations. Many bakers are unaware of the regulations mandated by the 2010 Food Safety and Modernization Act (FSMA) or have procrastinated in implementing required FSMA standards. The article by Len Heflich, "FSMA Implications for Artisan Products," provides useful information for smaller bakers who need to update processes to comply with the new FSMA regulations.

As the artisan baking trend evolves, bakers and cereal scientists will continue to explore a range of opportunities throughout the value chain to adapt old-fashioned baking techniques to modern technology. Along the way they will also grapple with the philosophical and technical question: Can artisan bread be mass produced?

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Defining Artisan: What It Is and What It Means

Jeff Yankellow[1]
King Arthur Flour Company and Bread Bakers Guild of America

I have been immersed in the world of artisan baking for almost 20 years as a baker, teacher, and consultant. I don't often think about the definitions or qualifiers of artisan bread. I feel qualified to recognize one but am not often asked to define what it is. When I was asked to offer my perspective for this article, I put a lot of thought into the definition long before I wrote the first word. I decided it was important to get a well-rounded perspective and awareness of what is being sold as artisan bread these days. I spend a lot of times in artisan-style bakeries, so I took some time to walk through the bread aisles and bakeries of a few supermarkets as well. I asked myself, "Is it the ingredients, the process, the amount of work done by hand or machine, or the bread itself that matters most?"

The more I thought about the answers, the more I found myself going in circles: telling myself it's the ingredients that matter; it's the process that matters; it's the characteristics of the bread that matter. I finally concluded that it isn't only one thing, and it isn't always everything. One thing that is certain is that bakers will never unanimously agree on a definition, because it is subjective and always will be.

A true artisan baker is a skilled craftsperson whose bread is defined by method and ingredients. For most, they make bread this way because of a deep-rooted passion for how food should be made. The best ingredients, minimal number of ingredients, respect for the process, and bread that is flavorful and nutritious are all things that matter to artisan bakers.

For those who believe they are making artisan bread and aren't, I suspect they don't care what it truly means. This would include small bakeries that may not know better and may not wish to, as well as large industrial bakers who are defining artisan through marketing, data, and profitability instead of letting the bread define itself. Flavor is often an afterthought. They don't have the same passion or drive to create artisan breads that is true of craft bakers. In most cases, the term artisan is nothing more than a marketing gimmick used to attract consumers.

Looking at the most common definitions for "artisan," I found myself agreeing that it is most often used as a noun to describe a skilled craftsperson, who is often doing the work by hand. In the world of bread and baking, artisan is also used as an adjective, not only for the baker but for the bread they make. For example, artisan bakers bake artisan breads or, as some would argue, artisanal breads.

I want to focus on the part of the definition that describes the work as being done by hand because I think it puts the work of an artisan baker in context and establishes a point of reference. If we look back to a time when the only way to make bread was by hand, when there were no machines or only very basic machines, no chemical additives, and no commercial yeast, it was a time when most likely all breads were artisanal. Bread was the result of a process that required long hours, hard physical labor, and a working knowledge of the ingredients and how to coax the best out of them. Baking was done in a stone hearth, wood-fired oven because that is all that was available.

Although bakers at the time had a much less thorough understanding of the process at a chemical and physical level than we do today, they knew how to transform flour into bread, and because they worked within their limitations, knowing no other way, they made flavorful, nutritious, naturally leavened artisan breads. For example, long fermentation with sourdough was a tool used to give strength to weak flour and create leavened dough that resulted in bread with complex flavors and aromas. This process was lost when modern high-speed machinery eliminated long fermentation, replacing it with high-speed mixing and the use of additives.

Only now are we defining what is artisan bread to distinguish it from the excess of commercially mass-produced bread found in the marketplace.

Ingredients

The easiest place to start when defining a loaf of artisan bread is the ingredient list. Starting with the best ingredients available for flavor, performance, and consistency is the easy part. Choosing the right ingredients at the right price is an artisan mind-set. Ingredients are all too readily available to think otherwise. You will find it hard to convince me that a bakery needs to buy ingredients primarily based on price to compete, as they often do. The return on use of better ingredients far outweighs their cost.

Just as it is in any loaf of bread, flour is the major ingredient in a loaf of artisan bread. Except for malted barley and enrichments, and some would argue against inclusion of even those additions, the flour should be free of treatments and additives.

Some bakers would likely argue otherwise, but I believe that no matter the style of the finished loaf, artisan bread should be free of ingredients that replace a function that could be achieved through time and technique or that interfere with the inherent function of the ingredients and process. I'm not speaking of an ingredient such as commercial yeast, which when used properly can be a beneficial tool for artisan methods and just as acceptable as using wild yeast for sourdough. I'm speaking more about ingredients that replace skill and technique. One example would be the use of L-cysteine to improve extensibility—there are artisan techniques that can be used to do this.

It is also important to note that what is left out of the ingredient list is not an automatic qualifier for artisan bread, as some would like to think. The front of the package tells you what the producer wants you to believe. The back of the package tells you something different. Strolling through the supermarket I am amused by labels with "artisan" on bread packaging next to claims of "no high fructose corn syrup, artificial colors, or added

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flavors." Then I look at the ingredients and see that the bread contains the powerful emulsifier DATEM (diacetyl tartaric acid ester of mono- and diglycerides) and the preservative calcium propionate. The idea that leaving an ingredient out makes a loaf artisan is wrong at best and deceptive at worst.

This goes for added ingredients as well—including certain ingredients or methods in the process also does not make a loaf artisan. The use of sourdough is not an automatic qualifier nor is the use of whole grains, non-GMO–certified ingredients, or all-natural ingredients, for example.

There are and will always be points of controversy concerning use of ingredients. The use of ascorbic acid (vitamin C) as an oxidizer is one example of an ingredient that would be acceptable to some but not all artisan bakers. At high levels, it can replace fermentation to build strength, improve the fermentation tolerance of the dough, and increase volume. Take a baguette with ascorbic acid added as an example. At a high enough usage percentage, ascorbic acid will produce unnatural characteristics due to excessive strength, resulting in a loaf with abnormal volume for its weight, a fluffy, cotton-like interior, and a paper-thin, crackly crust. At the right level, it can be used in a long-fermented artisanal style loaf to improve tolerance in the dough-handling process without changing many, if any, of the final characteristics. When used properly, many bakers and most consumers would not even know it is present.

Some would argue that if the process is not compromised and the final characteristics are indistinguishable from a loaf made without ascorbic acid, then why can the loaf made with ascorbic acid not qualify as artisan? Perhaps the stronger argument is that if a true artisan was making the bread, they would not need the ascorbic acid and would give the process the attention required to obtain the same results without the insurance provided by the additive.

Clean labels also do not define artisan. Examples of this would be the use of vinegar or cultured wheat as mold inhibitors or enzymes used to mimic freshness through the degradation of starch over time. It is unfortunate that these ingredients even need to be considered. It is my opinion that because of the way food is distributed and brought to market, shelf life is far too high on the list of priorities. Manufacturers are always looking for ways to extend their reach and increase sales. As a result, food is moved long distances, over multiple days, in and out of warehouses, before it hits store shelves, where it needs to retain its intended characteristics until the consumer has a chance to purchase and eat it. I would argue that this is acceptable for canned goods and snack foods, but not for fresh baked goods, and certainly not for artisan breads. For artisan breads, especially those that are free of any fats or sweeteners, true freshness is most often measured in days, and sometimes even hours, such as in the case of baguettes.

There are some exceptions in which artisan breads have a longer shelf life as a result of process and ingredients used. For example, a loaf of sourdough will become inedible because of dryness long before it molds. This is, in part, a result of the low pH caused by natural fermentation. Sourdough bread also tends to be denser and to stale more slowly because of the acidity. In the past, when nothing went to waste and modern methods and ingredients didn't exist, it was acceptable that bread was not the same on day three as it was on day one. This was considered normal. The bread was eaten until it was gone. It was too valuable to do otherwise. Artisan breads made from long-fermented, enriched doughs also benefit from the inclusion of sugar and fat, which result in tenderness and moisture-retaining properties. Challah bread would be a good example of this type of bread.

Unfortunately, commercial producers have adopted new standards to which consumers have become accustomed. Even worse, even consumers who appreciate the qualities of a well-made artisan loaf, will often attach commercial, additive-supported expectations to it. For example, they recognize the flavor of a well-made artisanal loaf but want it to be the same a week after they buy it as it was on day one.

Hand Work Versus Automation

Some artisan bakers forbid the use of any machines. Others are comfortable with full automation and have equipped bakeries with machines used to complete steps that have traditionally been completed by hand, such as dividing dough, shaping loaves, and scoring the bread before it is loaded into the oven. A combination of hand work and the use of some machines is acceptable to most artisan bakers.

I see machines as acceptable in the process if they don't compromise the artisan characteristics of the final loaf or require a change in process that compromises the final baked bread. Compromised properties might include a tighter crumb structure resulting from machine shaping or diminished flavor resulting from cutting fermentation time to allow for easier machine handling of the dough.

Common reasons bakers offer to justify the use of machines are to ease the workload, reduce injuries, cut costs, and increase efficiency. It is important to respect the bread and process but also the baker. Our bodies are not built to last forever. I fully support the use of modern equipment that can improve the quality of life for a baker, giving them longevity in the craft and for many years beyond their career.

If you can achieve the same result by machine as by hand, then the bread will usually appear to be artisan. This requires a complete understanding of the process. If you understand the process, then you can choose the right machine for the job, so there is minimal, if any, need to adapt the dough to fit the machine. In addition, engineers have learned how to build machines that are suited to the artisan process. I have witnessed machines handling dough more gently than human hands. This technology is impressive and constantly improving. One of the things that machines do well is they do the same thing every day throughout the day. This may imply that machines and automation make the process more "idiotproof." I would argue that it actually requires better bakers. The challenge is to provide the machine with the same dough every day, because machines cannot adapt the way hands can to manage day-to-day differences in how the dough feels. This is not easy considering how many variables there are in the breadmaking process.

Identifying an Artisan Loaf

One of the most degraded artisan breads on the market is ciabatta. It is a great example of how a truly artisan bread can be turned into one that is artisan only by name. It also presents a good case for why the characteristics of the final loaf can determine whether it is artisan or not, even when all other qualifiers are met.

A traditional ciabatta is a free-form loaf, rectangular in form, but irregular at the same time. The crisp, well-baked, but not too thick, crust yields to a moist, irregular crumb structure of large holes encapsulated by thin membranes of baked dough resulting from the high water content. The complex aromas and flavors imparted by long fermentation are intoxicating. Its popularity is a result of everything people think of in regard to an artisan loaf, including a crisp crust, floured top, and rustic look as a result of minimal or almost no shaping. The top of the loaf has a beautiful, minimal coating of flour, which is the result of using the right amount of flour needed to handle such a wet dough, but not so much that it interferes with the flavor. The beauty of ciabatta lies in its irregularities and imperfections.

The popularity of this bread has likely grown because of its versatility and mass appeal. Unfortunately, the same reasons have led to the commercialization of a loaf that is no longer rustic, no longer crusty, and no longer beautiful because of its imperfections. Instead, it is uniform in height and color and rarely baked to even the least amount of crispiness. It is no longer artisan.

To recognize an authentic loaf of artisan bread it is helpful to understand what happened with ciabatta. How did an authentic artisan bread become so commercialized? It's hard to find a sandwich menu, including fast-food menus, without ciabatta as a choice for bread.

Large industrial bakeries look initially to smaller bakeries for ideas. They then find a way to make them their own and force them to fit within a system that does not support artisan processes. They don't care that traditionally ciabatta is a long-fermented, high-hydration, crusty sandwich roll. What they want is a soft, lightly baked, sandwich roll that has the same exacting dimensions in every unit, costs as little as possible, and can be called "artisan" because it is "ciabatta," thereby meeting price points so the end user can be on trend with their latest-and-greatest hamburger bun or breakfast sandwich. The end product is now artisan only because someone decided to place the word on a label. A beautiful loaf of handmade bread has been commercialized for mass production. Perhaps the ingredient label is clean and free of additives, the dough highly hydrated, and the fermentation long, perhaps even sourdough. The sum of the parts, however, does not add up to what the bread is supposed to be. In turn, this version now defines what ciabatta is for those who have never eaten the real thing. For many, ciabatta is now any loaf in the shape of a flat rectangle or square. This is how an artisan loaf loses its identity.

A Complex Relationship of Ingredients, Process, and Characteristics

When many consumers hear the word artisan, they think of crusty, European-style loaves. Many bakers would agree. The most widely known are classic French baguettes and crusty sourdoughs.

At one end of the spectrum there are the extremist, or purist, bakers. They choose to work with nothing more than flour, water, and salt, relying on wild yeast (sourdough) for fermentation and may add some high-quality inclusions, such as nuts, olives, or dried fruits, to select loaves. At the other end of the spectrum are those bakers who view commercial yeast, machines, and "clean" additives as allowable aids in the production of artisan breads.

As mentioned earlier, the process and ingredients define the bread. The process requires long fermentation. How long, however, is a hard question to answer. Perhaps it is fair to say that 2–3 hr of fermentation postmixing would be the minimum needed to reach advanced levels of flavors and aromas. Some characteristics of an artisan loaf can be achieved with less fermentation, but I would argue that flavor cannot be achieved by cutting time, not for an artisan bread.

Often fermentation will take much longer than a few hours, especially with the use of preferments such as sponge, poolish, or sourdough. These are techniques in which a portion of the total flour is mixed with a portion of the total water and some yeast, wild or commercial, and fermented for extended periods of time. These mixtures are then added to the mixing bowl with the remaining ingredients for the final mix. Long fermentation is the only way to develop complex flavors and aromas that are characteristic of a well-made artisan loaf.

The main goal of preferments is to extract flavor from the grain, but they are also used as processing aids. There is a high production of organic acids as well as enzymatic activity resulting from the long fermentation time. Different levels of hydration and temperatures and the use of commercial or wild yeast result in preferments that are all different. Some will improve the strength of the dough, and others will increase extensibility. The better understanding the baker has of the different types of preferments, combined with hands-on experience, the better able they will be to choose the right match for the specific type of bread and process. Preferments replace the need for additives that could accomplish the same thing: preferments require time and effort, but without the cost of additional expensive ingredients.

There are many who think artisan must always imply a bread with a crisp crust, rich brown color, and irregular crumb structure. This is too strict of a standard for me. If we qualify artisan bread by this definition, we would have to ignore a whole category of soft, sweet, enriched breads, many with a history that dates back to times when the artisan method was the only method, such as the French brioche. White sandwich loaves, hamburger buns, and soft dinner rolls are all examples of this group.

I would argue that any style of bread can be artisan: crisp or soft, fermented with commercial yeast or sourdough starter, made by hand or machine—these all qualify as artisan for me. What is most important is that the bread is true to itself and that no shortcuts have been taken to create the loaf.

A well-made artisan-style baguette contains flour, water, salt, and yeast, and sometimes malted barley to aid in fermentation. It is long and skinny. It has a crisp crust and irregular crumb structure. Its complexity lies in its simplicity. The long shape shows all of the faults that could be related to ingredients or process and is meant to highlight the crust. The high proportion of crust to crumb results in a loaf with a very short shelf life. It is meant to be eaten soon after it is baked.

In contrast, a well-made artisan Italian panettone that is long fermented with wild yeast through a multistage process pushes the upper limits of sugar and fat and has a soft yielding crust and crumb that is so tender the loaves are hung upside down to cool to prevent them from collapsing. When made properly and packaged correctly, panettone can be enjoyed for 30 days, maybe longer, without the use of any preservatives or high-tech methods of packaging. The long sourdough fermentation results in a low pH that acts as a natural mold inhibitor. It is a complex process that is just as exemplary of a skilled artisan as is a crusty loaf of sourdough.

Parbaking

It is important to address parbaking when talking about artisan bread. Parbaked "artisan" bread has taken the market by storm in the last 20 plus years. This style of bread is taken from the oven when 10–15% of the time remains before it is fully baked. It is sold frozen with the intention that the end consumer at home or in a commercial setting will bake it for the remaining 10–15% of the time required to complete baking. This has certainly led to wider availability and awareness of higher quality breads, but it would be hard not to argue that it is a new style of bread in and of itself. It is made with an artisan mind-set and artisan methods, but the mass production of it has almost certainly compromised its end quality. I would also argue that because the artisan is not the person finishing the baking it is rarely baked correctly, resulting in a loaf that lacks the qualities that would have otherwise been present if it had been fully baked in the bakery.

Final Thoughts

I don't know how successful I've been in defining artisan. Two hundred years ago we wouldn't be having this discussion. Bread was sustenance, a basic food, that was not categorized by titles.

What I do know is that if I want a great loaf of artisan bread, I will find it in a neighborhood bakery or made by a neighborhood baker. This could be a small or large shop. I will first recognize the bread by its imperfect beauty and, then, upon further inspection will evaluate it for aroma and flavor. It is a study that requires all of one's senses. The ingredient label will tell me a lot about the bread. I will evaluate it for what it is whether it be a crisp baguette, dark-baked sourdough, or soft and tender, buttery brioche.

The beauty of having so much variety to choose from is that we don't have to judge a bread as bad or good. Consumers are free to choose what they like and what suits them best regardless of the label.

Jeff Yankellow manages bakery flour sales for King Arthur Flour in the western region. He is currently chair of the Board of the Bread Bakers Guild of America. He was part of the Team USA that captured gold in Paris at the Coupe du Monde de la Boulangerie in 2005. He brings a wide array of experience that includes cooking, artisan baking, consulting, and teaching.

Flour Quality and Artisan Bread

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ABSTRACT

A technical definition of artisan breads is proposed based on the concepts of lean formulations, long fermentations, and the use of process as the primary way to adapt to changing flour qualities. The current status of what constitutes refined flour that is suitable for artisan bread production is discussed. A conclusion is drawn that very high protein flours that create very strong doughs are likely not to be optimum for artisan breads. Because the long fermentations used in artisan production create acidified doughs, even when only baker's yeast is used, the effect of long fermentations on acidification and its impact on dough strength are also covered. In addition, the article discusses the state of the art in the rapidly changing world of whole wheat baking at the artisan level, where the use of ancient and heritage wheats with weaker dough properties is growing, along with the use of modern hexaploid wheats with more conventional, "normal," dough performance. Preliminary data suggesting that whole wheat sourdough breads respond to different aspects of flour quality compared with refined flour straight-dough breads are also presented.

Because hearth breads have so few ingredients (basically flour, water, leavening, and salt), and because they have been made for centuries, one is tempted to oversimplify the process.
–James MacGuire (6)

Flour quality for artisan bread—where do we even start? Are we in danger of oversimplifying the process, in part because there are so many kinds of bread that can be considered "artisan"? The philosophy of what constitutes artisan with respect to breadmaking is covered elsewhere in this special issue of *Cereal Foods World* (47), but clearly there is a need to define a target from a technical perspective. To manage the scope of this article, it is focused on lean-formulation, risen breads and not on enriched-dough products, such as panettone or brioche, that are legitimately "artisan" when made using traditional processes. This article does not aim to be the definitive tract on the topic but, rather, to be a conversation starter. The article also has an unavoidable North American bias as a result of the author's domicile there.

To get a better idea of the technical framework surrounding artisan breads a series of interviews was conducted within the artisan baking community, both in the United States and Denmark. All of the interviewed bakers and millers espoused a common theme: for artisan breads and processes, within certain constraints, the process can be adapted to the flour. This conclusion is supported by Leonard (28), who wrote that an artisan baker "adapts each formula and the timing of mixing, rest, scaling, molding and proofing, to variances in [among other factors] the quality of flour." In contrast, the interviewees suggested that in modern high-speed, continuous, industrial processes, because of their comparative inflexibility, in a sense, the flour needs to be adapted to (i.e., chosen specifically for) the process. The interviewees suggested that the adaptability of artisan processes results from the employment of well-trained bakers, use of modular or batch processes, judicious use of retarding, and use of hand-shaping, the latter even in facilities processing upwards of 5,000 kg of dough per day. Because of their relatively lower capacity for adapting to variability, industrial processes require greater levels of consistency in flour and dough performance. They also arguably require stronger dough characteristics than might be considered optimum for most artisan-style breads. Obviously, there is considerable overlap somewhere between the two extremes: no artisan process is infinitely flexible, and no industrial process is infinitely inflexible.

From a technical viewpoint, artisan breads and processes could be defined by the following factors:

1) The use of lean formulations generally consisting only of flour, water, salt, and microbial leavening. Additional ingredients aimed specifically at improving flour functionality are restricted to diastatic malt flour and occasionally ascorbic acid. The use of fats, oils, and sweeteners is restricted to specific bread types.
2) Despite the simple formulation template, there is a large variety of breads, and many types are baked directly on the hearth, unsupported by a pan.
3) The frequent use of high hydrations, creating soft doughs that are not easily machined.
4) A strong focus on long preferments using either commercial yeast or *Lactobacillus* species-based mixed cultures (also known as levains or sourdoughs) perpetuated by traditional type 1 back-slopping procedures (12,19).
5) The use of gentle mixing and dough development techniques. These are used, in part, to maintain the color of the endosperm carotenoid pigments by limiting their oxidation (5,6,33,40).
6) An emphasis on flavor development, both through long fermentations and the use of higher ash flours that have been shown to have a positive influence on fermentation vigor (40) and bread flavor (24), arguably through increased metabolite production (39).
7) Hand-shaping or minimal and gentle machine-shaping.
8) The use of process changes as the primary strategy to address changes in flour characteristics and dough properties and maintain finished-product quality, rather than the use of processing aids such as dough conditioners. For example, in yeasted breads, increasing dough strength or adapting to flours with poor fermentation tolerance by adding greater levels of preferments (40,47).
9) A broader view of the traits that constitute the totality of processing quality and finished-product excellence (26, 36): for example, flavor, aroma, open crumb textures with a creamy appearance, crust crispiness, quality and appearance of cuts on the bread, and adherence to type when traditional breads are produced, among others.

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In addition to technical considerations, in my experience, artisan bakers are trend leaders, guiding the way to a more thorough appreciation of the array of traits that create exceptional bread quality. Artisan bakers are more frequently using older wheat types with weak dough properties (6,26) and, as noted above, refined or semirefined flours with high ash contents. Artisan bakers are also exploring hulled wheats (einkorn, emmer, and spelt) for use as raw materials in regions where their use has diminished, such as North America (15,34). A newer factor is a growing focus on the flavor, aroma, and health potentials of whole grain flours, which are increasingly milled either in-house, primarily using stone mills, or sourced from small- to medium-scale and specialty milling companies. Locally or regionally grown grains are often used and fermented using sourdough for both its ability to enhance flavor and its potential nutritional benefits (11,12,23,37).

Refined Flours

There are few concrete frames of reference for assessing refined flour qualities for artisan breads given the wide variety of bread types produced, each of which has quite different optimum flour characteristics. The one seemingly invariable factor in the craft-baking community, at least in the United States, is the use of unbleached refined flour. This is connected to the desire to retain the endosperm carotenoid pigments for color and flavor (6), although Myhrvold and Migoya (33) have disputed the flavor factor and suggested that retaining pigmentation only impacts the aesthetics of breads. When breeding common wheats specifically for artisan breads, however, selecting genotypes with a high lutein content (endosperm yellowness) that persists into the finished product may also provide, beyond the aesthetic and flavor dimensions, health benefits for consumers, as has been suggested for durum wheats (5).

An online survey of refined flours sold specifically as professional "artisan bread flours" in the United States revealed a divergent set of specifications. Refined flour protein contents ranged from 11.5 to 14.0%, and ash levels ranged from 0.48 to 0.80% (all ash and protein contents were reported on a 14% moisture basis unless otherwise noted). There were very few easily available examples of certificates of analysis or more detailed specifications related to dough mixing or strength properties. Where specifications were available, they indicated the flours created doughs of intermediate mixing time and intermediate tolerance to overmixing. *Breadlines*, the Bread Bakers Guild of America trade magazine, published a desired specification for U.S. flours used for artisan breads of 11 to 12% protein, 0.48 to 0.54% ash, a flour falling number of 250 to 290 sec, farinograph absorption of 60 ± 2%, and stability time of 10.0 ± 2 min (18). These specifications correspond closely to the published specifications of a number of commercial refined flours targeted at artisan bakeries. They also conform somewhat to the protein ranges and strength characteristics suggested for risen breads recommended by Wrigley et al. (46): >11% with medium dough strength to >12% with medium to strong dough. However, for panned sandwich breads Békés et al. (3) suggested strong doughs made from flour with >13% protein. The wheat varieties for these stronger doughs are designed, through selection of desired glutenin compositions, to minimize bubble coalescence in dough foams through high levels of strain-hardening in extension (8). These flours, therefore, are also associated with fine, even crumb structures and are not necessarily compatible with the more rustic, open crumb structures associated with artisan breads—the archetype being the baguette (Fig. 1).

Despite the fact that many of the commercial resources reviewed insisted that flour for hearth breads should have a high gluten content and strong dough characteristics, the popularity of lower protein flours with less absolute strength for use in artisan breads has evidence to support it. For example, Paulley et al. (35) showed that a lower protein (12.0%) Canadian Western Red Spring (CWRS) wheat flour had better overall performance in a Uruguayan French bread process, with fermentation times of up to 75 min, than did a 13.8% protein CWRS wheat flour. Færgestad et al. (10) found that form ratio (height/width) was positively related to dough resistance and the presence of high molecular weight glutenin subunits 5+10 when using a low-speed mixing process relevant to artisan processes. Loaf volume was positively correlated with dough extensibility and protein content. Loaf volume and form ratio at a fixed mix time using low-speed mixing were negatively correlated. This suggests that for flours with strong dough characteristics full volume potential was not realized with gentle mixing, which may have insufficiently developed their glutens, and may suggest these flours are not suitable for use in artisan processes that employ minimal mixing. Tronsmo et al. (43) showed that although higher flour protein contents were associated with increased pan loaf volumes, a higher flour protein content and increased monomeric to polymeric protein ratio were associated with lower form ratios in hearth loaves. They concluded that "higher flour protein content [was] not necessarily advantageous for the properties of hearth loaves." This conclusion fits with the practice by many artisan bakers of using bread flours with 11–12% protein.

The concept that lower protein bread flours with intermediate dough strength may be optimal for use in artisan breads is also supported by observational evidence in the craft-baking community. Forestier (9) wrote that use of flours with protein contents of 14% or higher is often advocated for artisan breads. However, she suggested that despite their ability to be "stretched without tearing," a tendency to buckiness makes them unsuitable for the long fermentations that are necessary for flavor development. She also observed that high-protein flours were associated with tough crust and crumb textures. Huff (18) indicated an optimum flour protein content between 11 and 12%. Suas (40) wrote that flour milled from U.S. hard red winter (HRW) wheat

Fig. 1. Baguettes made with a high-ash refined flour. Breads were made at the San Francisco Baking Institute during a training course. (Photo courtesy of Andrew Ross)

(by inference not as strong or as high in protein as U.S. hard red spring [HRS] wheat flour) is preferred for long fermentations because its fermentation tolerance (defined in that reference as "the ability of the gluten structure to maintain its shape in a dough system during long fermentation times" [40]) is better. There is no consensus definition for "fermentation tolerance," and most of the commercial milling company websites and product brochures indicate that their high-gluten flours have excellent fermentation tolerance, which contradicts the experience and observations of Suas (40); there is no clear answer to this conundrum. Suas (40) also indicated that very strong doughs produced finished-product defects, including shorter loaves with round cross-sections with cuts that did not open correctly.

To look more closely at the differences between winter and spring wheats in the United States, the 2017 U.S. Wheat Associates crop report (44) was consulted. This report showed that U.S. HRW wheat had 5 year average values of 12.6% for grain protein (corresponding to around 11–11.5% flour protein), 0.56% for flour ash, farinograph absorption of 59.5%, and farinograph development and stability times of 5.2 and 9.2 min, respectively. These values correspond remarkably well with the desired specifications for U.S. artisan flours noted earlier (18). For the HRS crop the 5 year average values were 14.0% for grain protein (corresponding to around 12.5–13.0% flour protein), 0.50% for flour ash, farinograph absorption of 63.0%, and farinograph development and stability times of 7.1 and 11.3 min, respectively. The HRS values were generally higher for protein, a little higher for absorption, and stronger for mixing properties than the desired specifications and the HRW values, but not tremendously so. Perhaps more telling regarding the differences between HRW and HRS wheat flours were the extensograph and alveograph data. Extensograph maximum resistance at 135 min (Rmax135: arguably the appropriate metric for long-fermentation doughs) was 476 BU for HRW and 768 BU for HRS. Extensibility at 135 min for HRW flour was slightly better than for the HRS flour (142 versus 137 mm). Calculated Rmax135 to extensibility ratios of 3.4 for HRW flour and 5.6 for HRS flour showed that the HRS-derived doughs had much greater tenacity (approaching double) per unit extension compared with the HRW-derived doughs. These observations lend credence to the remarks of Forestier (9) regarding the apparent buckiness of high-protein flours, which in the United States are commonly milled from HRS wheats. Five year average alveograph work values (W [10^{-4} J]) were 239 for HRW and 362 for HRS. Calvel et al. (6) provided alveograph W specifications for U.S. wheats "appropriate for the production of French breads" of between 250 and 290, assuming a balanced dough tenacity/extensibility (P/L) ratio. To put this into context, the W values reported by Calvel et al. (6) for French breadmaking flours ranged from 150 to 200, suggesting that even though the 5 year average HRW W value was lower than that specified for HRW wheat flours by Calvel et al. (6) it was still arguably more suitable for French breads than the 5 year average W value of 362 for HRS.

Two other factors may play a role in the desirability of flours with 11–12% protein that create doughs of intermediate strength in artisan baking. The first is the fact that flours with the specifications outlined by Huff (18) are, in a rather uncharitable sense, so unremarkable and middle-of-the-road that they have great potential to be adapted to changes in formulation and process to produce different outcomes in the finished breads. In the hands of a skilled artisan these flours are capable of creating the most delectable, open-structured baguettes at one end of the spectrum and fine-structured *pain de mie* sandwich breads at the other end through judicious alterations to the process and, in the case of *pain de mie*, the addition of at least a small amount of shortening. The second factor is related to one of the technical factors suggested earlier as defining artisan processes and breads: the almost universal use of long fermentations. By long fermentation, I mean very often longer than the yeast-based sponges used in sponge-and-dough, industrial-scale sandwich bread production (Cauvain [7] indicates 4–8 hr); in straight-dough, yeast-risen breads, bulk fermentations of at least 3 hr; in yeast-risen breads with preferments, 12–16 hr or more of fermentation before the preferment is added to the production dough; and in sourdough-risen breads, sourdough starters prefermented for between 4 and 24 hr before addition to the production dough (12). In the case of sourdough breads, preferments are often followed by quite long bulk fermentations and proofing times.

The outcome of long fermentation times, for both sourdoughs and yeast-risen doughs is acidification. This seems obvious for sourdoughs, in which the presence of a diverse range of heterofermentative *Lactobacillus* spp. (12,19) produces levels of lactic and acetic acids above the sensory thresholds for detection in the finished breads. What may be less obvious is the potential for acid production in yeast (*Saccharomyces cerevisiae*)-risen doughs. The reported sources of acidification in yeast-risen doughs are, first, the production of lactic acid by lactic microbiota that arrive with the baker's yeast when fermentations exceed 8–12 hr (12) and, second, the production of succinic acid by *S. cerevisiae* (20,21,25). An enduring assertion by artisan bakers is that acidity strengthens the dough (4,14,32,36,39). This assertion contradicted the understanding gleaned from the literature concerning the influence of acid on gluten proteins, especially decreased mixing tolerance (17,45) and activation of wheat proteases at low pH, which hydrolyzes the gluten proteins (2,12,13). However, other reported evidence does point to a dough-strengthening effect of low pH. Harinder and Bains (16) showed marked increases in resistance to extension in doughs with 1.5% NaCl at pH 5.0 and 4.2 after both 5 and 45 min of resting, with an attendant decrease in extensibility at pH 4.2. Maher Galal et al. (30) showed increases in farinograph mixing and stability times with the addition of a mix of organic acids at concentrations relevant to sourdough bread production and in the presence of 1.5% NaCl. Although Tanaka et al. (42) showed decreased dough consistency and a shortened mix time with the addition of acetic acid they also showed an increased resistance to extension and decreased extensibility at pH 4.2 compared with pH 5.8 in the presence of 1% NaCl. Jayaram et al. (21) reported similar results for both uniaxial and biaxial extension after addition of succinic acid to doughs at concentrations consistent with what is produced by *S. cerevisiae* during bread fermentations. They concluded that succinic acid led to swelling and unfolding of the gluten proteins that potentially allowed for greater entanglement within the elastic network. This seems to be the most likely cause of the observed increased strength and decreased extensibility. Similarly, lactic acid solutions are known to swell glutenin proteins more than water alone, and this is the basis of the lactic-acid solvent retention capacity test (27). The strengthening effects in sourdoughs may also then be a result of greater swelling and entanglement of glutenins in lactic acid. Additionally, because acidification is a factor in long fermentations, either with sourdough or baker's yeast, the preference for a flour that, unacidified, creates a medium strong dough can be conceived of as a way to avoid overstrong doughs if starting with, for example, a very strong spring wheat flour.

Whole Wheat and Sifted Flours

If at the start of this article it seemed to be a daunting task to assess refined flour quality for artisan breads, summarizing the modern iteration of whole wheat artisan baking in the United States is even more daunting. It is in this environment that we can observe substantial experimentation involving raw materials, milling, processing, and finished product quality. Modern artisan bakers are reinvigorating the use of einkorn, emmer, and spelt in the United States, partly from a desire to exploit their unique flavor and aroma characteristics. Artisan bakers are compensating for the generally weak dough properties of flours milled from these hulled wheats (15) through alterations in processes or blending with higher strength hexaploid wheat flours. For example, a demonstration at the San Francisco Baking Institute of a high-hydration, whole grain emmer and spelt bread utilized the simple expedient of proofing and baking in pans to accommodate the more fluid nature of the dough (Fig. 2). There is also a fascination in the craft-baking community with older hexaploid wheats that is propelled by a variety of motivations, including the perception that they provide better flavor. I can attest to the distinct and attractive flavor of breads made with the whole wheat Red Fife flours to which I have had access (Fig. 3).

Sources of these flours vary. Large U.S. milling companies may supply both roller-milled and stone-milled whole spring and winter wheat flours. However, whole wheat flours are increasingly being sourced from small- to medium-scale regional flour mills, many of which have only been established in the last five years or so. Some of these mills supply flours milled from a blend of wheat varieties, and increasingly, some mills supply flours from traceable single varieties. Some of these mills sift out the coarse bran, making high-extraction flours that have some of the dough-handling attributes of refined flours. Unfortunately, a mishmash of terminologies, some European (type based on ash content) and some North American (extraction rate conflated as "type") in origin, is being used to market these sifted flours. The confusion is palpable. Leonard (29) has made a plea for the system to be standardized based on ash levels: for example, a type 85 flour would have 0.85% ash (on a 14% basis or on a dry basis is another argument) and would not be, as some millers are marketing it, an 85% extraction flour. The small mills are most commonly stone mills, but some flour manufacturers use straight-through roller or attrition systems.

Fig. 2. Whole grain spelt and emmer bread doughs proofed in pans prior to baking. (Photo courtesy of Andrew Ross)

There is also an increasing number of bakeries that are installing their own stone mills onsite. The motivations for this include enabling a closer connection to the farms where the grain is grown, a perception of better flavor derived from very freshly milled grain, and claims of health benefits for very fresh flour, which may not be supported by evidence. However, there is scientific support for the use of fresh-milled whole wheat flours. Mense and Faubion (31) reviewed the effects of aging on both refined and whole wheat flours. Contrary to the improvement in baking quality of refined flours after a period of aging postmilling, they concluded that whole wheat flours provided their best baking performance immediately after milling, observing that whole wheat bread volume slowly decreased over storage time for whole wheat flour, even when the flour was stored at –20°C! The culprit appears to be oxidation of unsaturated lipids (41). Arguably, there are also nutritional consequences. Lipid hydroperoxides created by auto-oxidation or lipoxygenase action are associated with the oxidative degradation of carotenoid pigments (5). Increased levels of lipid hydroperoxides after extended storage of whole wheat flour, which has not been stabilized by heat-deactivated lipases and lipoxygenases, could further degrade lutein in whole wheat doughs during mixing, and loss of this pigment constitutes a small potential decrease in nutritional value.

The flexibility of artisan baking processes plays a key role in this environment. Unless bakers are sourcing their whole wheat flour from large mills they can expect a high degree of variability in the flour they use. This variability can be attributed to several factors. First, when buying grain directly from farmers for in-house milling or when buying flour from small milling operations that are sourcing locally and regionally grown grains, there is no capacity to blend grains or flours to compensate for changes in grain and flour functionality. Bakers need to be aware that even when buying the same variety of wheat grain or flour, baking performance can be altered from one location (farm or field) to another by the growing environment, including soil N status and relative water stress, among other factors. Another variable is the miller and the mill. In stone mills variations in particle size distributions and starch damage may be more difficult to control than in roller mills. Particle size dis-

Fig. 3. Bread made from flour consisting of 85% stone-milled Red Fife whole wheat flour and 15% "artisan" refined baker's flour using a hybrid sourdough and baker's yeast leavening system. Of the total flour, 15% (all of the baker's flour) was prefermented overnight as a sourdough starter. Dough was bulk fermented for 2 hr, with a 30 min intermediate proof and a 90 min final proof. (Photo courtesy of Andrew Ross)

tribution in stone-milled flours does affect baking quality but not as much as the characteristics of the grain being milled (38).

Having the skills and experience to alter fermentation schedules, amounts and types of perferments, and other process steps is key to adapting to this fast-changing aspect of artisan baking. There appears to be no one prescriptive set of flour specifications for whole wheat flours given the enormous range of wheat species and varieties and, as a result, dough characteristics encountered in artisan bakeries around the world. For hard hexaploid wheat varieties, there is preliminary evidence that panned loaf volume in yeast-raised breads made from refined flours responds to different facets of the flour quality profile than does the loaf volume (panned) and free-standing aspect (or form) ratio of whole wheat sourdough breads. The results of principal component analysis (PCA) of refined flour protein, solvent retention capacity, mixograph and farinograph data, and bread data for 25 hard wheat samples, with protein contents ranging from 11.6 to 15.9%, that were submitted to the Pacific Northwest Wheat Quality Council in 2015 are shown in Figure 4. Refined flour straight-dough breads were made using AACC International Approved Method 10-10.03 (1), without optional dough conditioners and oxidizers. Whole wheat sourdough breads were made with 100% whole wheat flour, optimized water addition averaging 85%, and 2% NaCl. Of the total flour, 15% was prefermented at 100% hydration, using a type 1 sourdough starter as inoculum, for 16 hr at 21°C before being added to the production dough. Doughs were mixed to clean up in a 20 qt Hobart mixer, bulk fermented for 3.5 hr at 23°C with three sets of folds at 30 min intervals. Divided doughs were rested (intermediate proof) for 20 min, shaped, and proofed for 1.5 hr before baking. The results illustrated in Figure 4 show that in this analysis refined flour loaf volume (RF-LVOL) was associated most strongly with factors that were correlated with total protein content. This indicates that RF-LVOL in this sample set was responsive to differences in the total protein in the flour. In contrast, whole wheat sourdough loaf volume (WWSD-LVOL) and aspect ratio (WWSD-ASP) were associated most strongly with different aspects of flour quality—farinograph mix time and stability and mixograph peak time—and not responsive to total protein. Flour and wheat protein contents were effectively orthogonal to farinograph peak time and stability and mixograph peak time, suggesting no relationship between the groups of factors. The results of PCA for the same samples versus the extensograph and alveograph data for the refined flour analyses are shown in Figure 5. Once again it is clear the two bread types responded to different aspects of flour quality. RF-LVOL was still associated with total protein, as well as with facets of quality related to increased dough extensibility: that is, positively related to alveograph L value and extensograph extensibility at 135 min and negatively related to alveograph P/L ratio. Again, in contrast, WWSD-LVOL and WWSD-ASP were associated with facets of quality related to dough strength—extensograph Rmax135 and alveograph W and P values—and again, WWSD-LVOL and WWSD-ASP were not systematically affected by total protein. These preliminary data are not definitive but do indicate a fundamental difference between whole wheat sourdough and refined flour straight-dough breads. They also give credence to a comment made by an artisan baker with vast experience, who when switching his entire operation to whole grain flours said that he needed to completely relearn his craft.

Stephen Kaplan (22) had the last word: "The fact remains that [even] with the best raw materials in the world, an ill-trained or

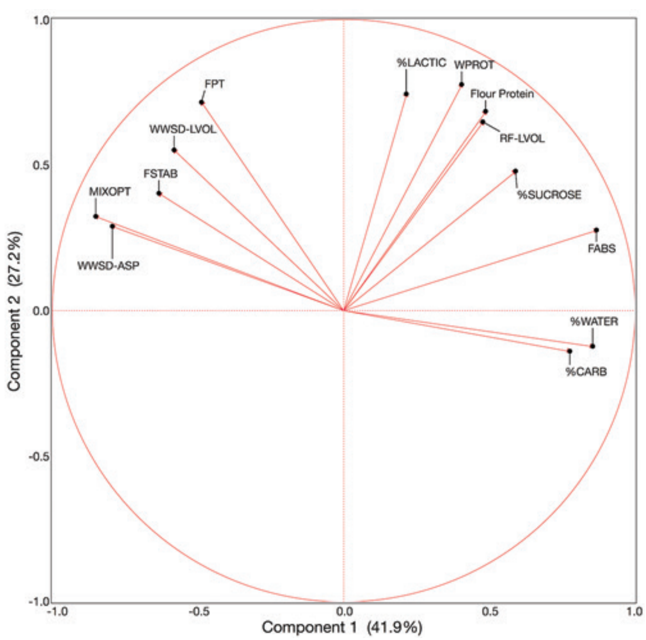

Fig. 4. Principal component analysis of bread, flour, mixograph, farinograph, and solvent retention capacity (SRC) traits for refined flour straight-dough and whole wheat sourdough breads. WPROT = wheat protein; MIXOPT = mixograph peak time; FABS, FPT, and FSTAB = farinograph absorption, peak time, and stability time, respectively; %WATER, CARB, SUCROSE, and LACTIC = water, carbonate, sucrose, and lactic acid solvent retention capacities, respectively; WWSD-LVOL and WWSD-ASP = whole wheat sourdough loaf volume and aspect ratio, respectively; RF-LVOL = refined flour loaf volume.

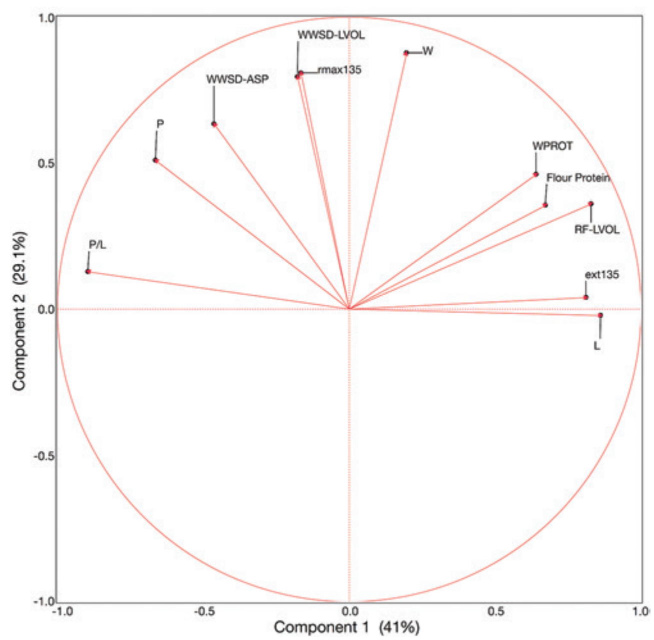

Fig. 5. Principal component analysis of flour, extensograph, alveograph, and bread traits for refined flour straight-dough and whole wheat sourdough breads. WPROT = wheat protein; ext135 = extensibility after 135 min of resting; Rmax135 = maximum resistance after 135 min of resting; P, L, P/L, and W = alveograph overpressure, length, P/L ratio, and work, respectively; WWSD-LVOL and WWSD-ASP = whole wheat sourdough loaf volume and aspect ratio, respectively; RF-LVOL = refined flour loaf volume.

insufficiently motivated baker cannot make good bread. This is why…[we] attached so much weight to the competence of the artisan."

Conclusions

From a technical perspective, artisan breads might best be defined by the use of lean formulations, process changes to adapt to variability in flour and dough performance, and short, gentle mixing and long fermentations. For refined flours there is plenty of precedent established in the scientific and trade literature concerning flour qualities that may best suit artisan bakers—the details of which were laid out in the preceding narrative. However, the emerging focus on whole wheat breads by some bakeries has thrown the door wide open for artisan bakers. We are now seeing the adaptability of artisan processes and thinking applied to an astonishingly wide spectrum of wheat types (species and varieties) in a quest to create exceptional breads, almost regardless of the intrinsic functionality of the flour used. This trend is leading to a wonderful array of breads being produced by artisans worldwide who are exploring new horizons in flavor, aroma, and texture.

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Traditional Versus Modern Leavening Systems

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ABSTRACT

Breadmaking as we know it, with kneading, leavening, and baking, has existed since the ancient Egyptians. With the introduction of commercial yeast some 150 years ago, much faster processes were suddenly possible, fueling the rise of modern industrial baking in the 20th century. Today's consumer trend is shifting back toward authentic artisan-style breads made using traditional processes. One of the key elements is the use of sourdough with only very small amounts of yeast or no yeast at all, along with extended fermentation times. Several methods exist for starting the fermentation process in a sourdough, from spontaneous fermentation to collecting yeast water or refreshing an existing sourdough. The ecosystem obtained can be very specific, resulting in a unique flavor profile through the breakdown of starch, protein, and mineral fractions in the wheat grain. Process parameters such as time, temperature, and consistency further influence dough and bread characteristics. As a result, the possible combinations are endless, creating a number of challenges for the modern baker who is looking to apply traditional techniques in a larger scale bakery. A variety of systems exist to manage sourdough and long-fermentation processes at different stages of breadmaking. As an alternative, ready-to-use sourdoughs are available and can be used in artisan breadmaking applications.

The Future of Bread Lies in Its Past

Hieroglyphs dating back thousands of years indicate that fermented bread has been made since the time of the ancient Egyptians. Commercial yeast as we know it today was introduced into the bakery only about 150 years ago, so how was bread leavened before this time? Welcome to the world of spontaneous fermentation and sourdoughs. What was once observed with astonishment is now understood to be the work of numerous microorganisms, mainly wild yeasts and lactic acid bacteria. Having been largely replaced by modern commercial yeast systems, these traditional leavening systems are back and bigger than ever. Production of artisan-style breads is booming all over the globe in response to consumers who are seeking authenticity, flavor, and stories far removed from bread with an unhealthy image. Traditional leavening systems offer many benefits. The good news is there are a number of processes and solutions available to integrate these once-common artisan processes into a modern bakery environment.

Sourdough and Artisan-Style Breads

If you ask U.S. consumers what a sourdough bread is like, many will describe the pungent and acidic San Francisco-style sourdough bread. In English the use of the word "sour" in sourdough can be misleading, as the truth is most sourdoughs do not have an acidic flavor. The French call it "*levain*" and in Spanish it carries the beautiful name of "*madre*" (the motherdough)—a term that precisely describes what it does. When added to a freshly made bread dough, the diverse microorganisms in sourdough start the leavening process and develop—many hours later—the unique and complex flavors typical of sourdough breads: fermented, fruity, etc., and yes, to some extent, acidic.

Do all "traditional artisan" breads need to be made with some sort of sourdough preferment? Not necessarily. Yeast too can be used in many different ways, and the same basic principle applies: time (a lot of time) is required to make an outstanding artisan-style bread that is different from mainstream modern bread, which is often made on high-speed lines in less than 90 min using high levels of baker's yeast. The additional time used in artisan baking can be applied at different stages of the process: in preferment, bulk proofing, or a retarded final proof or in combination. There is no clear definition of what an artisan or traditional bread is, but other parameters such as higher water content, stress-free dividing and make up, and baking conditions further contribute to its perceived quality.

Leavening Systems—A Little History

Two main categories of naturally leavened preferments are used in traditional breadmaking: baker's yeast-based preferments (e.g., sponge, poolish [French], biga [Italian], etc.) and sourdough preferment, which is a combination of natural yeasts and bacteria (e.g., sourdough, *levain*, *madre*, etc.). The different categories of preferments result in different flavor profiles—the former being more alcoholic and the latter more complex, with fruity and acidic notes.

Baker's yeast (*Saccharomyces cerevisiae*) as we know it today was discovered in 1857 by Louis Pasteur. Soon afterward, industrial production of this yeast spread around the world. We may take it for granted today, but in the 1800s, this yeast revolutionized the entire baking world. Predictable, easy to use, and fast, it helped boost the industrial production of bread and ensured more consistent quality. Consumers grew used to the more alcoholic taste and liked the fluffy texture of the resulting bread. Traditional methods of breadmaking declined quickly, and with this trend, so too did knowledge of how to make bread using traditional methods. Some of the knowledge survived, however, out of necessity or a passion for breadmaking, and so the sourdough survived, refreshed day after day, generation after generation.

A unique collection of these heritage sourdoughs is stored in the Puratos Sourdough Library in Belgium. Thanks to this library, the research work at different institutions, and the information available in the literature, we now know much more about traditional leavening systems used prior to the industrial yeast era. The main systems are

1) **Spontaneous Fermentation:** A mixture of water and flour is let for a minimum of 2 days, followed by at least 1 week of daily refreshments with flour and water. Gradually, bubbles appear when the microorganisms start to multiply and feed on the sugars in the flour. Probably the oldest

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Puratos Sourdough Library

Nothing demonstrates commitment to traditional fermentation in breadmaking more than the Puratos Sourdough Library. Located within the Center for Bread Flavour, the Sourdough Library has been created to safeguard the sourdough biodiversity of the world and preserve the sourdough heritage and baking knowledge. This is the first of its kind repository in the world.

The idea is simple but important. When a sourdough becomes part of this project, often because of its uniqueness, age, composition, or location, it will be fully characterized, including its microflora. Safe within the library, the sample can then be kept alive and maintained for years to come.

Today this library is home to a unique collection of sourdoughs from bakers across the globe and has contributed to the identification of more than 900 types of yeasts and lactic acid bacteria.

If you would like to learn more about the sourdough library, you can visit it at www.puratossourdoughlibrary.com.

system, this method of leavening depends heavily on the flour used.

2) **Harvested Wild Yeast and Bacteria:** In nature, plants, fruits, and leaves carry microorganisms, wild yeasts in particular. The art of utilizing wild yeast and bacteria involves knowing which ones to harvest and then maintaining them with water and honey or other sugar source until an active "yeast water" is obtained that is capable of fermenting a dough.
3) **Sourdough:** Rather than starting from scratch, as with harvesting, many bakers prefer to refresh their sourdough on a regular basis with flour, water, and other ingredients. Over the years and even generations, many of these sourdoughs and their microorganisms have evolved to contain specific compositions that result in signature bread flavors.
4) **Yeast Obtained from Barm:** Before baker's yeast was widely available, bakers also used yeast obtained from the foam that appears on top of beer brewing tanks, called barm. This foam is heavily loaded with yeast and is an effective source for dough leavening. Historic documents describe how bakers in London were taught to make bread with less barm as it became more scarce, when brewers switched from a top to a bottom fermentation process. The shortage of barm occasionally led to fights among bakers, and eventually, a ban on its use was imposed.

In addition to different types of leavening starters, bakers can also experiment with extra-long fermentation times to enhance the artisan-style characteristics of the bread: utilizing a prefermented sourdough or sponge (usually 3–24 hr), an extended bulk proof (1–2 hr or longer), or a slow, retarded process during the final proofing stage (8–24 hr). Often a combination of all three is used.

	French baguette made with *levain* (wheat or rye flour and sourdough starter; liquid; 15–24 hr at 25–30°C)
	Croissant made with poolish (wheat flour, water, and yeast; soft dough; 4–16 hr at 15–22°C)
	Rye bread made with *sauerteig* (rye flour, water, and starter; dough or liquid; 15–20 hr at 25–30°C; 1 to 3 steps)
	San Francisco sourdough bread (wheat flour, water and starter, containing among other bacteria *Lactobacillus sanfranciensis*; stiff dough; 15–20 hr at 22–25°C)
	Panettone (wheat flour, water, sugar, [egg], and starter; stiff dough; 3 step refresh, each 10–18 hr at 22–25°C)
	Hamburger buns made with sponge (wheat flour, water, and yeast; stiff dough [or liquid]; 3–4 hr at 25°C)

Fig. 1. Examples of breads made using traditional leavening systems.

Traditional leavening systems are still in use today, either in distinct regions, as with German rye breads made with sourdough, or by individual bakers, either craft or industrial, who are convinced of the benefits that sourdough and other traditional fermentation systems can provide. Examples of breads made using traditional leavening systems are illustrated in Figure 1.

Benefits of Using Traditional Leavening Systems Versus a Mainstream Direct Process

The goal of both mainstream and more traditional leavening systems is to raise the dough, resulting in bread with a typical aerated and light crumb. Use of regular commercial yeast at high dosages, in the range of 3 to 5%, fermented at temperatures between 30 and 40°C ensures the dough will rise very quickly, within 1 hr. This is not the case with traditional systems, which require up to 48 hr either with a preferment, as bulk, or a final proof or in combination. This adds complexity to the manufacturing process and requires skilled labor, so why then are an increasing number of bakers using sourdough and other traditional leavening systems?

- **Flavor:** First and foremost, sourdoughs add a distinctive and pleasant flavor to bread. Many people particularly like fermented foods such as wine, beer, or cheese, and bread is no different. Flavors can vary from alcoholic, to mild, creamy, and buttery, to fruity and acidic. In numerous studies (Puratos Sensobus [mobile sensory analysis lab] data), consumers identify flavor as the number one purchase criteria for bread.
- **Texture:** Similar to flavor, but still very complementary, is the waxy, cohesive, slightly chewy, and more moist texture that is obtained when using long fermentation times and high hydration as opposed to the more foamy texture resulting from faster direct processes. This texture allows for longer chewing without development of gumminess, which in turn develops more saliva and flavors in the mouth.
- **Rheological Properties:** Some bakery applications, such as pizza crusts, baguettes, and croissants, require the dough to be stretched further during make up. The use of preferments (e.g., sponges, poolishes, or sourdoughs) or long resting times creates a final dough that is more relaxed, allowing extension without snapback. This is particularly beneficial on high-volume industrial lines.
- **Acidification:** Obtaining a lower pH is particularly important in the production of rye breads. This enables a gas-retaining dough matrix to be built in the absence of gluten—a matrix based on starch and pentosans. Moreover, low pH inhibits spoilage microorganisms and natural amylases that otherwise would disintegrate the bread structure during baking.
- **Healthy Image:** Although no definite health claims can be made, several studies have confirmed the beneficial effects of long fermentations on the nutrition and health-promoting properties of bread, mainly due to the effect of microorganisms in the dough. Better digestibility is obtained by predigestion of the proteins and starches and lowering of the glycemic index. People who are sensitive to gluten may benefit from this as well. Additionally, minerals such as iron are better absorbed in the gut due to the breakdown of naturally occurring phytic acid.
- **Storytelling:** Breads made with a sourdough often have a strong character. If the sourdough has a story, then so do the breads made with it. Often the story relates to the age of the sourdough or its origin. For example, San Francisco sourdough traces its roots back to French settlers who moved west during the California Gold Rush. Sourdough, and even more so the story behind it, is what many consumers appreciate.

Sourdough—An Ecosystem of Bacteria and Yeasts at Work

In yeast-leavened preferments, such as sponges, poolishes, or bigas, alcoholic yeast fermentation is the dominant biochemical process. There is also some activity from endogenous bacteria present in the flour.

Very different and more complex is the ecosystem within sourdough and its biochemical reactions. Typically, colonies in sourdough consist primarily of a mixture of lactic acid bacteria (around 10^9) and yeasts (around 10^7). Approximately 80% of the bacteria are *Lactobacillus* spp.; the remaining bacteria are *Leuconostoc*, *Pediococcus*, and *Lactoccoccus* spp., as well as others. The scenario for yeasts is similar. In addition to the dominant baker's yeast, *S. cerevisiae*, the yeast colonies also include *Candida*, *Kazachstania*, and *Torulaspora* spp., among others. The proportion of yeasts and bacteria and their composition depends largely on the origin of the sourdough; however, the baker's hands, flour used, storage conditions, etc. also play roles in shaping the colony that will create the signature flavor of a baker's sourdough bread.

Several fermentation pathways occur when flour, water, and a starter colony are blended. Interestingly, bacteria and yeasts work very closely together.

Carbohydrate Fermentation. Carbohydrates such as starch and free sugars are very quickly partially fermented by yeasts and converted into ethanol, CO_2, and aromatic compounds. Almost simultaneously, but at a slower speed, lactic acid bacteria metabolize carbohydrates into lactic and acetic acids and CO_2 gas. In stable sourdoughs, there is no direct competition between yeasts and bacteria because each metabolizes different sugars. The resulting gas raises the dough, while at the same time the pH drops and acidity increases. Depending on the fermentation temperature and cultures used, a pH value of around 3.5 can be reached after a minimum of 15 hr, after which further slow acidification occurs until full stabilization of the bacteria and yeast in the dough.

Protein Degradation. During the long hours of fermentation, bacteria break down some of the proteins, mainly gluten, into smaller amino acids. This allows the number of bacteria to multiply. The yeasts present in sourdoughs further digest these amino acids, while producing superior alcohols and aldehyde components that are responsible for the complex fruity and flowery notes in sourdough breads.

Because sourdoughs are complex living systems, the results obtained depend largely on a number of formulation and process variables. The substrate (flour) is key. With rye flour, more fruity notes are obtained compared with wheat flour. A higher ash content creates sourdoughs with higher acidity due to the buffering capacity of the bran. Damaged starch, proteins, and germ further influence fermentation and its by-products. In addition, the level of water influences the acid profile: stiffer doughs tend to result in a more vinegar-like flavor. Furthermore, the temperature is critically important: lower temperatures (20–25°C) are more favorable for yeast growth, while temperatures around 30–35°C are more favorable for lactic acid bacteria growth.

Traditional Leavening Systems in Modern Bakeries—Hurdles and Practical Solutions

Traditional leavening systems require time—lots of it. This means that to use traditional systems a bakery needs to create a large, temperature-controlled space for storage and handling. For bulk proofing, after mixing the dough can be placed in bowls and set aside or it can be placed in a container that can be stored through the use of automated systems. The same is true for the final proofing. The crumb texture benefits from a slow, extended proof (a minimum of 6 hr), ideally overnight at around 10°C, especially if no bulk proof is performed. Large retarding proof boxes can be used—first in, first out, on racks or in a continuous system. The cost, however, can be significant.

Sourdough production is a different story. Making sourdough at home is not all that complicated; social media is full of home bakers proudly sharing their breads and stories of their sourdough. An interesting source is the website thequestforsourdough.com, which features more than 1,100 sourdoughs from all over the world.

The sourdough process becomes much more complex when it is used to make quality sourdough bread consistently in a large-scale production environment. The challenges, in addition to space and capacity, include finding the skilled labor needed to manage food safety concerns and to ensure enough product with a constant quality is produced day after day. Several options exist: bakeries can either make the sourdough in-house or buy it from a third party, customized and ready to use. The most common method of making sourdough involves use of a high-shear mixing device and a fermentation tank, followed by cooling and storage. A second smaller tank may be required to prepare the starter, using previous sourdough or pure starter cultures. Typical fermentation times range from 15 to 24 hr. Full control of the incoming raw materials, time, temperature, and cleaning, as well as a stable and dependable starter, are prerequisites for successful and consistent sourdough production.

As an alternative, some companies (e.g., Puratos) offer ready-to-use live sourdoughs and can even customize these on demand. Such sourdoughs are extremely convenient to use and solve most of the challenges associated with space, labor, food safety, and consistency. Combinations of these two options exist as well, allowing bakeries to complement the flavor profile of their in-house sourdough with ready-to-use sourdoughs made with different microorganisms and flours.

Traditional Leavening: Old-Style Processes for Modern Bakery Trends

There is no doubt that we are experiencing a renaissance of artisan-style breads around the world. Just open any life-style magazine and chances are you will come across an article featuring traditional sourdough or hipster bakeries in London and New York. Beautiful books explain the art and science of breadmaking. Restaurants have diversified the breads they offer, just as they did for wine and beer many years ago. Following the molecular cooking trend and the scaremongering concerning breads loaded with bad carbs, gluten, GMOs, and additives, consumers are rediscovering traditional breadmaking as it has existed for many centuries: flour, water, salt, and…passion. They are looking for artisan-style breads, seeking their authentic looks and pleasant flavors and textures. Sales of such breads are soaring, whether they are sold fresh in artisan shops, prepared as a sandwich, or packaged and sold in the deli aisle of the grocery store.

Bakers have a multitude of ways they can respond to this trend. The form of the perfect artisan-style bread is not defined, so the combinations that can be used to make it are endless. Solutions exist both for smaller and industrial-scale manufacturers—it is simply a matter of choosing the right one and grasping the opportunity.

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Enzyme Applications in Artisan Breads

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Basic enzymatic processes have been used in brewing, alcohol production, and baking since prehistoric times. Enzymes are active proteins found in all living things, including plants, animals, and microbes, that catalyze the biochemical reactions necessary for life. They work by temporarily binding to one or more specific elements of the reaction that they affect. In doing so, they lower the amount of activation energy needed to trigger the reaction and accelerate it. Unlike many chemical alternatives, enzymes are efficient, specific, and biodegradable (10). The use of enzymes can contribute greatly to sustainability and a reduced carbon footprint by reducing waste, energy, and off-specification products.

With the exception of some of the earliest studied enzymes, such as pepsin, rennin, and trypsin, most enzyme names end in "-ase." The International Union of Biochemistry and Molecular Biology (IUBMB) initiated standards of enzyme nomenclature that recommend that enzyme names indicate both the substrate acted upon and the type of reaction catalyzed. The Enzyme Commission number (EC number) is a numerical classification scheme used for enzymes based on the chemical reactions they catalyze:

- **EC 1. Oxidoreductase:** Oxidoreductases catalyze oxidation reduction reactions. At least one substrate is oxidized and at least one substrate is reduced.
- **EC 2. Transferases:** Transferases catalyze group transfer reactions—the transfer of a functional group from one molecule to another.
- **EC 3. Hydrolases:** In hydrolysis reactions, C-O, C-N, and C-S bonds are cleaved by addition of H_2O in the form of OH– and H+ to the atoms forming the bond.
- **EC 4. Lyases:** Lyases cleave C-C, C-O, C-N, and C-S bonds by means other than hydrolysis or oxidation.
- **EC 5. Isomerases:** Isomerases rearrange the existing atoms of a molecule, i.e., create isomers of the starting material.
- **EC 6. Ligases:** Ligases synthesize C-C, C-S, C-O, and C-N bonds in reactions coupled to the cleavage of high-energy phosphate bonds in ATP or other nucleotides.

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Enzyme activity depends on pH, temperature, water activity, ionic strength, and the presence of different molecules in the medium. Differences in enzyme activity also occur depending on the origin of the enzyme preparation. For example, fungal, cereal, and bacterial amylases exhibit different pH and thermal stabilities. Fungal α-amylase is inactivated after 2–3 min at 65–75°C. Cereal α-amylases are slightly more thermostable and remain active during the early stages of starch gelatinization. Bacterial amylases have even higher thermal stability and may survive baking temperatures (1).

Enzyme Classes Used in Baking

Enzymes are commonly used in flour and dough to improve the quality of finished baked goods by altering the way flour behaves in mixing and the way dough behaves in forming, proofing, and baking. Hydrolyzing enzymes such as amylases, proteases, lipases, and cellulases, which require water to act on polymers (starch, protein, lipids, and fiber), are commonly used in the baking industry, with amylases and endo-xylanases by far the most widely used today (9). Typical effects that can be achieved with baking enzymes include improved dough fermentation, handling, and machinability properties; enhanced mixing tolerance and proofing stability; more intense crust color; increased loaf volume; improved crumb characteristics; and extended shelf life.

- Amylases modify damaged and gelatinized starch in flour, providing more substrate for the yeast, which results in better bread volume and crumb structure. Malto- and tetraogenic amylases create starch structures that slow staling due to starch retrogradation, thereby extending bread freshness (shelf life).
- Proteases hydrolyze the hydrogen bonds between peptides, reducing dough mixing time and improving pan flow.
- Lipases act on flour lipids (polar and nonpolar), improving the emulsifying effects of these lipids and providing increased dough strength and larger loaf volume.
- Arabinoxylanases (pentosanases) act on 5-C sugar-containing arabinoxylans, reducing their water absorption during dough mixing, which improves gluten development and results in better bread quality.
- Cellulases can help to increase water-soluble dietary fiber in whole grain flours and decrease the water-holding capacity of cellulosic material in bran. This provides more water for gluten development during dough mixing, resulting in improved loaf quality.
- Glucose and hexose oxidases are classified as oxidoreductases and are nonhydrolyzing enzymes. In the presence of

glucose (or hexose) and oxygen these enzymes generate hydrogen peroxide, which can play several different roles in dough formation, including

1) Oxidizing the sulfhydryl groups in peptides, forming disulfide bonds and providing increased dough strength (11).
2) Oxidizing glutathione from yeast, preventing or reducing its dough-weakening effect (13).
3) Oxidizing the ferulic acid residues on the arabinose side chain (termed oxidative gelation) and improving the stability of dough during baking (5).
4) Forming tyrosine cross-links and strengthening dough (14).

- Transglutaminases (transferases) are used in gluten-free dough to create a better protein network to maintain the structure of the baked bread (12). The enzymes combine with a glutamine residue, releasing ammonia. The combination reacts with the amine group of a lysine residue of another protein, releasing the enzyme to react again, until it either has no more glutamine residues to cross-link with or is inactivated during baking.

Challenges Associated with Artisan Bread Baking

Consumers perceive "artisan-made foods" to be foods made in small batches and prepared with familiar ingredients found in their kitchens. They also perceive "artisan bread" to be bread made by a skilled baker using a lengthy process in which unique aromas, textures, and crumb structures are developed.

Artisan bread has an open cell structure, thick crust, intense flavor, and chewy texture, and no two loaves look exactly alike. Industrial bread producers are looking for formulation options that enable them to make artisan-style breads with the same attributes, but more consistently and faster to reduce labor and waste. Maintaining quality while increasing production is the main challenge to making artisan-style breads on an industrial scale. Enzymes, which are active proteins, can aid in the processing, dough stability, and end quality of artisan breads, whether they are produced in the local bake shop, supermarkets, or higher volume bakeries.

Despite a faster rate of consumption than is experienced with packaged bread, bread staling remains a challenge for artisan bread. Bread staling is caused by the gradual transition of amorphous starch to a partially crystalline, retrograded state. The chemical and physical changes of staling in the bread crumb begin as soon as the loaf is removed from the oven. Increased firmness, dryness, and loss of product freshness are prevalent features of stale bread crumb, and all of these changes negatively affect consumer preference. The rate of bread staling depends on flour, formulation, processing, and storage conditions (6). Enzymes can be used in formulations to decrease the rate of staling and improve dough stability and baked bread appearance.

Use of Enzymes to Overcome Artisan Bread Production Challenges

There are several challenges encountered with artisan bread production. Enzymes can be used by bread makers to overcome numerous challenges:

- Small deviations in the quality of raw materials result in inconsistencies in dough and bread quality. Enzymatic flour correction can assist with overcoming these issues.
- Artisan doughs typically have a high hydration ratio and sticky nature, which can cause production issues. Enzymes can be used to improve dough rheology.
- The long fermentations used in artisan dough production result in dough that is more vulnerable to degassing and cell structure damage in automated systems. Enzymes can be used to increase dough strength and improve volume and crumb structure.
- Staling occurs within hours of baking. Enzymes can be used to slow the rate of starch retrogradation, resulting in a softer and more resilient bread at the time of consumption.

Flour Correction. In artisanal bakeries, small deviations in the quality of raw materials can be compensated for by making minor adjustments to process conditions based on the baker's experience. This is termed flour correction and may involve the addition of fungal α-amylase. Addition of fungal α-amylase is useful when variations in flour quality moderately impact dough handling or machinability properties (3).

There are expectations for flour quality as far as processing (i.e., flour economy or water absorption, tolerance to mixing, and tolerance to fermentation) and performance (i.e., bread

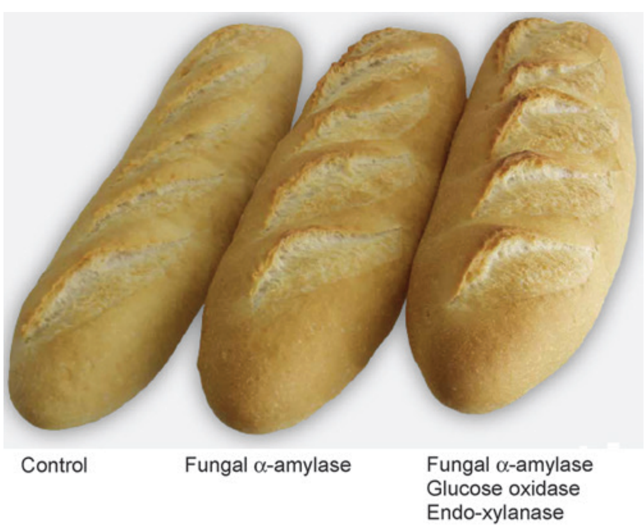

Fig. 1. Effects of fungal α-amylase, endo-xylanase, and glucose oxidase on baguette appearance (50 ppm ascorbic acid used in each loaf). (Photo: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

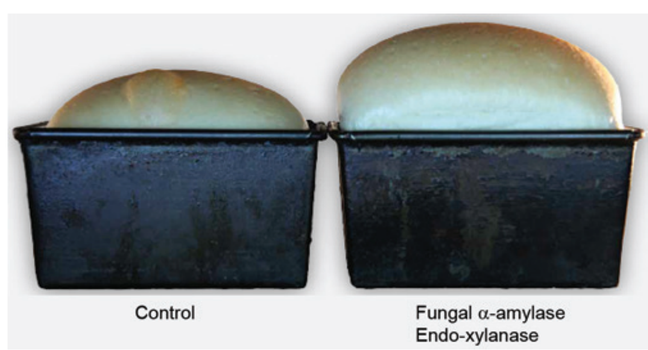

Fig. 2. Effect of fungal α-amylase and endo-xylanase on oven spring of pan bread after 12 min of baking. (Photo: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

volume, crumb color, and crumb structure) are concerned. Because these expectations are the same for every bag of flour, it is important to maintain consistent flour quality (Novozymes, “Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking,” unpublished).

The dynamics of individual milling and baking markets are influenced by many factors, not the least of which is the objective to increase yield, which can be achieved by adding fungal α-amylases, endo-xylanases, and glucose oxidases to flour. As illustrated in Figure 1, enzymatic solutions can further help increase loaf yield, if bread is sold per piece. The example shown in Figure 1 demonstrates how enzymatic flour correction can improve baking performance, helping millers satisfy evolving customer needs and achieve cost optimization.

Differences in climates, baking procedures, and dough temperatures can be compensated for by improving fermentation tolerance and oven spring. As shown in Figure 2, flour can be supplemented with fungal α-amylase and endo-xylanase to produce a loaf with better volume as a result of enhanced oven spring.

Dough Rheology Improvement. ***Uninhibited Xylanase in Baguettes.*** Bread producers desire a dry, stable dough with high tolerance to process variations (2). Uninhibited bacterial xylanase can be used for flour standardization or specialization of bread-improver products, providing improved volume performance, desired texture and appearance, and a dry, balanced dough with the use of one xylanase.

Wheat has naturally occurring xylanase-inhibitor proteins, which also inhibit exogenous xylanases, causing an increase in enzyme dosage used. An uninhibited xylanase works very well under conditions where dough temperature may be higher than 34°C. A tolerance to high temperatures has been seen with this xylanase, which is beneficial under production conditions with fluctuating temperatures (Novozymes, “Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking,” unpublished).

This uninhibited xylanase provides improved baguette volume and desired bloom and crust crispiness, even in low dosages with a French flour type (Fig. 3). The dough shown in Figure 3 was processed using traditional methods, with a long proofing time. The dough properties were dry and balanced. A high proofing tolerance was seen as well, even after 2.5 hr of fermentation, which assisted in securing predictable and stable baguette production.

Cellulase in Whole Wheat Bread. In addition to arabinoxylans, whole wheat or whole grain flours contain other non-starch polysaccharides, such as cellulose, soluble β-glucans, and glucomannans, that may interfere with gluten development. A multicomponent cellulase can be used to modify these different compounds without compromising product quality (Fig. 4) (7).

Improving Dough Strength and Eliminating Undesirable Ingredients. ***Glucose Oxidase in Baguettes.*** In breadmaking, a strong gluten network is needed to resist mechanical stress during dough processing and provide gas retention during proofing. This enables the development of oven spring during baking and results in bread with good volume. A strengthening effect is vitally important when flour with weak gluten-forming proteins is used (6).

Enzymatic solutions such as glucose oxidase and fungal α-amylase can help unlock the full strengthening potential of natural gluten in flour. These enzymes improve dough stability and handling characteristics, leading to greater bread volume and improved appearance of baked products. For companies interested in creating azodicarbonamide (ADA)-free formulas, glucose oxidase is a natural processing aid that can be used as an alternative (Novozymes, “Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking,” unpublished).

As illustrated in Figures 5 and 6, both volume and fermentation stability are increased with use of glucose oxidase compared with 1% vital wheat gluten. For French baguettes fermented for

Fig. 3. Effect of uninhibited xylanase on baguette quality. (Photo: Novozymes, “Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking,” unpublished)

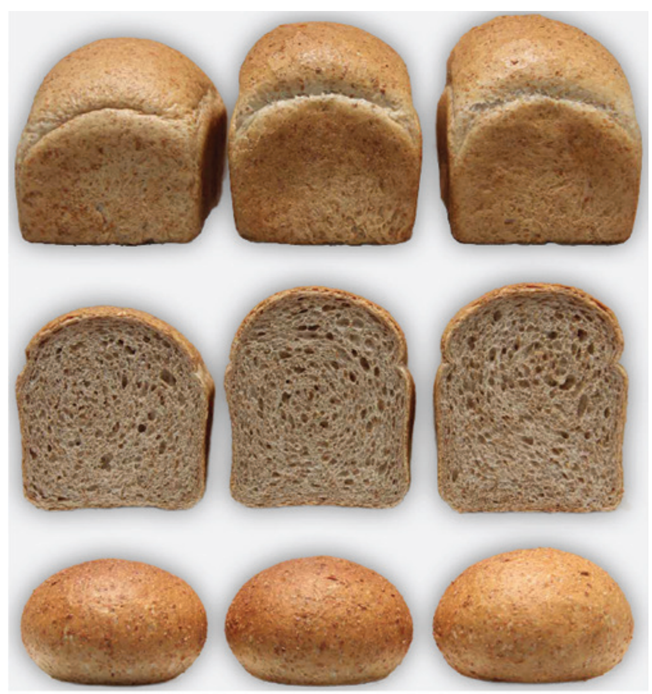

Fig. 4. Effect of a multicomponent cellulase on whole wheat bread quality (60 ppm ascorbic acid and fungal α-amylase used in each loaf). (Photo: Novozymes, “Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking,” unpublished)

2 and 2.5 hr, the addition of glucose oxidase resulted in 7 and 17% volume increases, respectively, compared with the addition of 1% vital wheat gluten (Fig. 6).

Polar Lipase in Turkish-Style bread. Recent generations of baking lipases show specificity toward both polar and nonpolar lipids in formulations. This specificity toward polar flour lipids creates more polar substances, increasing their stabilizing capacity (4). By increasing the emulsifying and stabilizing capacity of flour lipids with the appropriate lipase, the level of added stabilizing emulsifiers, such as diacetyl tartaric acid ester of mono- and diglycerides (DATEM) and sodium stearoyl-2-lactylate (SSL), can be greatly reduced, if not entirely eliminated (Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished).

The key benefits of using a polar lipase are improved crumb structure and whiteness (Fig. 7). When used in combination with fungal α-amylase and/or endo-xylanase, polar lipases improve loaf volume without additional dough stickiness, thereby improving the overall quality of the bread.

Due to their activity toward polar lipids during dough processing, lipases with dual specificity contribute to strengthening the dough. This allows for significant savings in ingredient costs and eliminates or reduces the acidic aroma associated with emulsifiers such as DATEM. Polar lipases can be used in a broad range of baking processes with different grades of flour, and they are particularly well suited for Turkish- and French-style breads (Fig. 8).

In these processes, small dosages of polar lipase resulted in optimum performance, which was fully comparable to the performance of DATEM. In contrast to bread without emulsifiers or lipase, the bread with polar lipase had good volume and a nicely open bloom. In general, polar lipases also show good tolerance to variations in flour quality (Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished).

Slowing the Rate of Staling. Maintaining bread freshness (soft crumb with crispy crust) is an important quality parameter in artisan breads. Loss of freshness, or "staling," has a significant negative financial impact on bakers because stale returns may account for 10–15% of their production. A major effect of staling is an increase in crumb firmness and loss of fresh crumb springiness or elasticity over time. The mechanism of bread staling is not known with great certainty. However, numerous publications report that these changes in texture are due to modifications in the configuration of highly branched amylopectin molecules—either due to their reversion from a swollen, amorphous, gelatinized state to their native rigid, crystalline state or to an increase in the number of complexes formed

Fig. 5. Effect of glucose oxidase versus 1% vital wheat gluten in French baguettes. (Photo: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

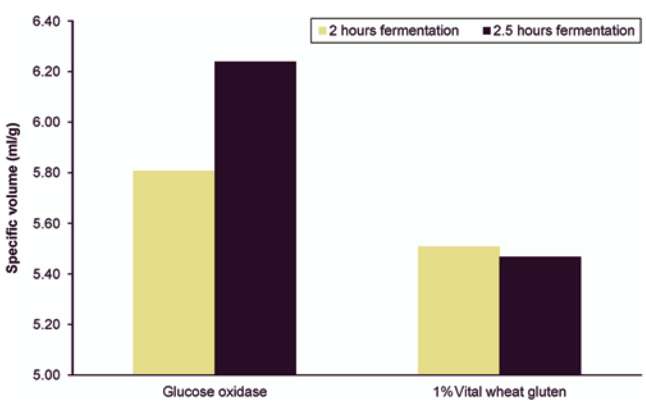

Fig. 6. Specific volume of French baguettes made with glucose oxidase versus 1% vital wheat gluten. (Graph: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

Fig. 7. Effect of polar lipase versus emulsifiers (diacetyl tartaric acid ester of mono- and diglycerides [DATEM] and sodium stearoyl-2-lactylate [SSL]) on quality of Turkish-style bread fermented overnight (16.5 hr of fermentation at 24°C; fungal α-amylase and endo-xylanase used in each loaf). (Photo: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

Fig. 8. Effect of polar lipase versus diacetyl tartaric acid ester of mono- and diglycerides (DATEM) on quality of Turkish-style bread (75 min of fermentation at 30°C; fungal α-amylase and endo-xylanase used in each loaf). (Photo: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

with the gluten protein in flour. The starch can be modified with an amylase to alter the way it reconfigures itself (Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished).

A significant reduction in stale returns and associated costs can be obtained by incorporating enzymes that assist in maintaining bread freshness. At temperatures ≥60°C, when most of the starch is available for modification, fungal α-amylase is largely inactivated (8). Maltogenic and malto-tetraogenic α-amylases, in contrast, are active after the starch gelatinization temperature is reached but are functionally inactivated by the time the bread exits the oven. What makes these enzymes particularly unique is the way they modify the starch molecule. Instead of shattering the amylopectin, like thermostable bacterial amylases do, they leave its primary structure intact, generating small dextrins from the ends of the starch molecules. This results in slowing of starch retrogradation, leading to a softer and more resilient bread for an extended time. A comparison of the activity pattern of traditional bacterial α-amylase with that of maltogenic α-amylase on amylopectin is shown in Figure 9.

Maltogenic α-amylase can be used in yeast-raised baking formulations with different flour qualities where crumb freshness is required. Notably, the enzyme does not influence dough properties, bread volume, or crumb structure (Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished). The main benefits of maltogenic α-amylase include

- Maintaining crumb softness due to retardation of starch retrogradation.
- Maintaining crumb elasticity, resulting in improved mouth-feel of stored bread.
- Improvement of crumb softness and elasticity during long periods of bread storage compared with emulsifiers such as monoglycerides.
- Can be used as an enzymatic tool for quality differentiation and brand building for bakeries.
- Reduced costs per unit as a result of rationalized product and distribution efficiencies.

Specialty Applications

Artisan breads can also be produced using ancient grain and rye flours, depending on regional preferences. Enzymes can help improve these bread formulations as well.

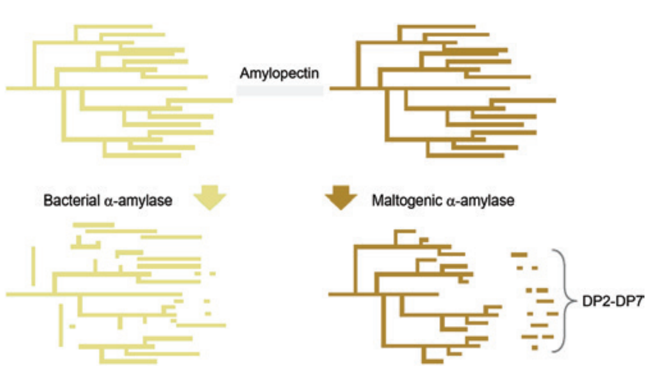

Fig. 9. Comparison of the activity patterns of different α-amylases on amylopectin. (Graph: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

Rye Bread. Maintaining consistent quality and producing a soft, elastic bread has been an ongoing challenge in rye bread production. In 50:50 rye/wheat bread flour formulations, dough-conditioning enzymes can be used to improve dough stability, bread shape, and crumb structure. As illustrated in Figure 10, adding enzymes can improve volume and crumb structure. In addition to improved stability, the resulting bread has a less dense, fluffier crumb structure that gives the bread more pleasant eating properties. Enzymes can also be used to extend freshness and provide a softer, more elastic bread throughout storage (Fig. 11).

Ancient Wheat Breads. Ancient grains, including emmer, spelt, and kamut (Khorasan) wheats, are a part of the global trend toward healthier bread consumption. These ancient wheat varieties provide very different baking performance than modern wheat. They typically produce breads with lower volume and higher density, which is challenging for bakers who want to produce breads with the soft, elastic, and moist texture and aerated crumb structure that many consumers prefer (Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished). In addition, use of ancient wheat flours produces unstable dough and a final bread that stales faster. Fortunately, enzymes can be used to compensate for many of these challenges and make it possible to produce delicious ancient wheat breads with improved dough stability, volume, and crumb structure.

A variety of enzymes can be used to strengthen both gluten and bread dough, resulting in better dough stability and increased dough volume, as well as improved crust crispiness and bloom and a finer crumb structure (Fig. 12). Additionally, maltogenic α-amylase produces a softer (Fig. 13) and more elastic bread (Fig. 14) that stales more slowly. The result is an excellent an-

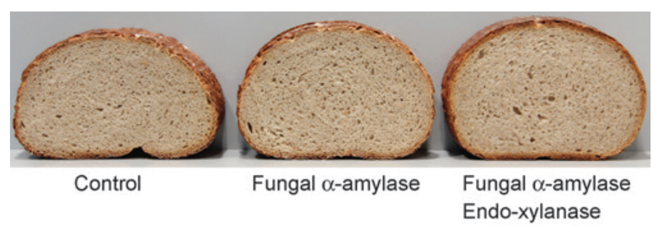

Fig. 10. Effect of fungal α-amylase and endo-xylanase in bread made with 50:50 rye/wheat flour. (Photo: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

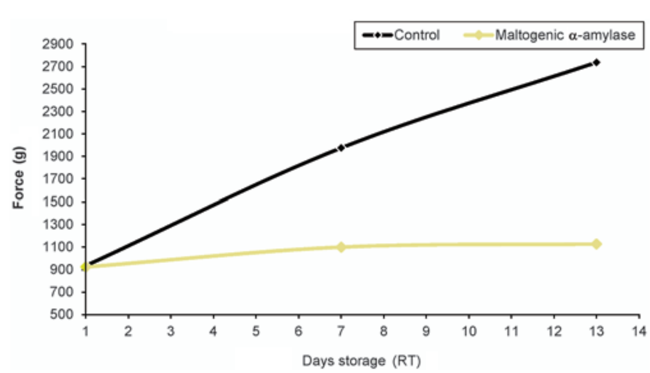

Fig. 11. Crumb softness profile for bread made with maltogenic α-amylase (50:50 rye/wheat flour, including sourdough; pH 4.8 in final bread) stored at room temperature (RT). (Graph: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

Fig. 12. Effects of enzymes (fungal α-amylase, endo-xylanase, lipase, and glucose oxidase) on spelt wheat bread properties. (Photo: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

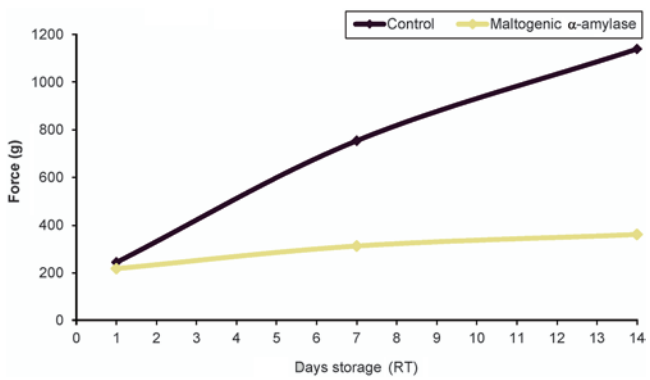

Fig. 13. Effect of maltogenic α-amylase on crumb softness of spelt bread during storage at room temperature (RT). (Graph: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)

cient wheat bread with improved softness, moistness, and eating properties throughout storage.

Conclusions

Enzymes have the potential to be key ingredients that can enable the forthcoming industrial artisan-style bread movement by improving the processing, dough stability, and end quality of breads, whether they are produced in the local bake shop, supermarkets, or higher volume bakeries.

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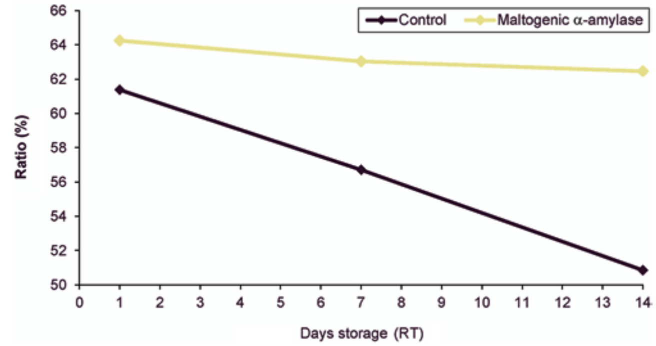
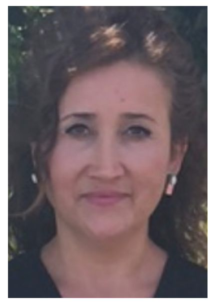


Fig. 14. Effect of maltogenic α-amylase on crumb resilience (elasticity) of spelt bread during storage at room temperature (RT). (Graph: Novozymes, "Unlock the Full Potential of Flour—A Comprehensive Handbook on Enzymatic Solutions for the Milling Industry Baking," unpublished)



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Scoring and Evaluation of Artisan Bread

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The perfect baguette—hearth-baked and crisp, a golden crust with toasty aroma—when sliced, crumbs cascade, foretelling the cracker crunch and moist interior that your teeth will soon encounter. In a single bite, you enjoy the delicious finale of the breadmaking process, which at bakeries such as the King Arthur Flour bakery in Norwich, VT, begins long before customers reach for the bread basket and butter.

Breadmaking, from grain in the field to milling, mixing, fermentation, shaping, scoring, and baking, is a long series of separate but interdependent activities. Each is necessary to create great bread and happy eaters.

The Role of Scoring

Scoring bread doesn't involve points, goals, hat tricks, or three pointers, as in sports. Rather, it is the act of making light razor cuts on the surface of proofed loaves just before baking. Scoring has a long history of use with hearth-baked breads. According to legend, in the days when loaves from many households were baked in communal ovens, scoring was used for identification: an edible name tag of sorts. However, the cuts and resultant marks, while beautiful, actually have a vital functional role beyond assigning ownership.

The functional role of scoring, as it relates to hearth-baked doughs, is key to optimal "oven spring." Oven spring is the rise that occurs during the early minutes of baking. Hearth-baked doughs are higher in total hydration (relative to pan loaves, bagels, and other categories of leavened doughs) and are baked directly on hot masonry at high temperatures. Without scoring, loaves will not spring predictably or rise to their full potential. Scoring enables and guides loaves to their maximum expansion (Fig. 1). Failure to rise and expand in the oven diminishes the visual appeal of finished loaves. A poorly risen loaf with a constricted interior structure (what bakers call "alveolar structure") will also be dense and have a poor crust texture (Fig. 2). In this case, the desired, open-structured baguette, which is light for its size and crisp, becomes a dense dough tube in the absence of cuts—still edible, but not what bakers strive for.

Scoring skill takes time to develop and years to master. The light touch (and cuts) required for some loaves must be traded for deeper cuts in other types of loaves. After countless loaves and many years at the oven, bakers continue to learn the nuances of their trade.

Scoring Tips

Proofing. In contrast to pan loaves, which may be proofed very fully before baking, for hearth-baked loaves it is best to load them for baking while they retain some strength. The proofing loaves should be loaded before they are so delicate that they will collapse when scored. If cuts don't open as anticipated consider a reduced final proof.

Steam. Steam plays a critical role in oven spring. Baking in a moist environment allows the loaf to expand and stretch to its full potential. A dry oven is a straight jacket of sorts, binding the loaf by drying the crust prematurely and restricting expansion. A properly steamed oven, in combination with good scoring, enables bread to spring to its fullest potential and most open interior.

Evaluation of Hearth-Baked Breads

To the eyes of a customer, what comes out of the oven is simply bread. Good bakers are more than eaters, however; they are also good scientists. They examine inputs (mixing, fermentation, shaping, and baking) as well as results, looking for ways

Fig. 1. Open interior structure, good volume, and beauty of a scored baguette.

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Fig. 2. Tight interior structure, poor overall volume, and poor visual appearance of an unscored baguette.

to improve or for confirmation of quality methods and systems. They know that each baguette, miche, or panettone is more than just a loaf; it is a daily scorecard that rates the baker and the entire bakery. Evaluation is a constant and rigorous process.

As with hand skills, mixing, and even formula work, bread evaluation is a learned skill. It begins with visuals and proceeds to touch, flavor, and texture.

Key Evaluation Points

The King Arthur Flour bakery evaluation model for bread and flour contains many categories, ranging from extensibility to handling, cuts, flavor, and crumb structure. Key points for evaluation of hearth-baked bread include the following.

Aspect. Is the loaf light for its overall size, or does it feel heavy for its length and circumference? Did the loaf expand well in the oven, with cuts (see earlier discussion of scoring) that opened well? Is the crust deeply colored and appropriate to the class of product? A baguette that is baked until it is a darkly burnished color or a ciabatta that is baked to a golden color are not necessarily examples of success. The baguette should be golden, and the ciabatta should be darkly burnished.

Crumb Structure. Is the interior of the baguette filled with marble-sized holes, or is the structure more closed and dense? The bakery standard values a variably open crumb with translucent cell walls that bind a thin, crisp crust. Crumb structure varies by class of product. For example, sandwich loaves should have a closed structure that holds in condiments, whereas rye loaves also should be more tightly structured. These standards vary from bakery to bakery, according to the preferences of bakers, customers, and class of product.

Flavor. Flavor is more than what we taste. In fact, it is the sum of all parts. Bread evaluation begins with its visual aspect and continues on to the structure of a slice and then to flavor and texture, which all combine to form the eating experience.

Balance. A well-made bread is a balance of competing aspects. Sour flavors, the by-products of bacterial fermentation (in the case of naturally leavened products), contrast with malty notes. Dark crust flavors resulting from Maillard reactions are balanced by gentler flavors in the interior of the loaf, and additions such as olives and herbs or dried fruits and toasted seeds are all used and guided to proper proportions by the baker. This balance is evident to the eye and on the palate.

Texture. Texture is the contrasting experience of crisp crust and moist interior. Texture may be smooth, as in the case of brioche, or entirely crisp, as with puff pastry and cheese crackers.

FSMA Implications for Artisan Products

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The Food Safety Modernization Act (FSMA) is the most comprehensive update to food safety requirements in the United States since the Food, Drug, and Cosmetic (FD&C) Act was enacted in 1938. The changes stipulated by FSMA have broad implications for all food manufacturers and distributors. Since the bill was signed by President Obama on January 4, 2011, the U.S. Food and Drug Administration (FDA) has published numerous proposed and final regulations, along with guidance documents totaling over 7,000 pages. Reading through all of these materials is a task in itself, which is why it is important to appreciate the spirit of FSMA as opposed to all of the details—it is easy to overcomplicate FSMA and create a compliance burden. Because the FDA cannot define a food safety plan for every plant, the food industry, which knows the process and products better than anyone else, must develop the plan. For all its verbiage, FSMA is actually a fairly simple and straightforward set of concepts that defines the next steps in the evolution of food safety. Food safety needs FSMA, and the food industry needs to understand FSMA in order to implement its regulations in a practical manner that adds value and improves food safety for consumers without creating an unreasonable burden on the industry. The purpose of this article is to describe how this can be accomplished, with an emphasis on artisan bread producers.

FSMA applies equally to large and small food manufacturers. The challenge for small and very small producers is to find adequate expertise and resources to develop and implement the programs necessary to comply with the new regulations. To successfully attain compliance without over burdening the process requires that programs be kept as simple as possible. The food industry is already doing much of what is required by FSMA; all that remains to become fully compliant is to integrate programs and practices into a comprehensive food safety plan. FSMA introduces five basic concepts: risk assessment, preventive controls, food safety plan, assessment versus audit, and validation and verification.

As a food manufacturer the first step is to identify relevant compliance dates for your business. The FDA identifies three categories for FSMA compliance dates based on business size: very small businesses with less than $1 million in annual sales; small businesses with less than 500 full-time equivalent employees; and other businesses with more than 500 full-time employees. Identifying relevant dates is complicated because different dates have been set for each FSMA rule, and there are exceptions for each of them. There is substantial confusion about compliance dates, even among FDA inspectors. In fact, many inspectors are proceeding as if FSMA is already in effect, so it would be wise to establish a fully compliant program as soon as possible. A comprehensive table of compliance dates has been posted online by the FDA at FDA.gov (www.fda.gov/food/guidanceregulation/fsma/ucm540944.htm).

Risk Assessment

The foundation of FSMA is risk assessment. HACCP (hazard analysis and critical control points) provided the food industry with an introduction to the concept of risk assessment, but the new HARPC (hazard analysis and risk-based preventive controls) model is more comprehensive. Some are calling it HACCP on steroids. To get started, a comprehensive risk assessment of the process, plant, vendors, personnel, and products needs to be performed by a small multifunctional team of knowledgeable personnel in each production facility. A risk assessment must be performed in each facility—do not cut-and-paste assessments from other facilities, no matter how similar they are. Performing an assessment is a great learning process for a team. As they consider equipment, personnel practices, ingredients, products, recent failures, consumer complaints, etc., the team needs to go through the process step by step and ask, "What can go wrong?" This generally can be done effectively in a few hours.

After making a list of the risks, each risk should be rated for severity and probability. This helps separate risks based on how often a failure could occur and the magnitude of the potential loss if a failure were to happen. Focus your improvement efforts on reducing the risks with the highest likelihood of occurrence and highest potential loss, while also doing what is feasible to reduce or eliminate all risks. Necessary projects should be identified, including ones that require investment or outside involvement. Building awareness of the risks among other people throughout the organization, especially upper management, is essential. It is impossible to effectively reduce a risk until there is sufficient awareness of it. The goal is to identify what can be done to reduce risks in a reasonable and responsible manner. Resources are always finite, so it is not possible to do everything, but what can be done must be done. Not being aware of a risk that exists is ignorance and is unacceptable. Being aware of a risk but choosing not to act is negligence and is a civil crime. Being actively aware of a risk and doing what is reasonable is diligence. This is the appropriate behavior regarding risks.

When considering how to reduce a risk, think about both short term and long term scenarios. In the short term, what can be done in the next few months to reduce the risk? In the long term, if there were a five year horizon, could the risk be eliminated? Risk assessment is a process, not a one-and-done activity. Plan to review and update your assessment at least twice a year: review what has been done to reduce the risk, the effectiveness of implemented changes, the impact on the risk, and the next steps needed to further reduce the risk. More information on how to perform a practical risk assessment can be found in the chapter on "Risk Management" in *Juran's Quality Handbook*, 7th edition, by Joseph DeFeo (American Society for Quality, 2016).

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Artisan bread producers perform many manual operations and, therefore, may experience a higher risk of product contamination from misplaced dough scrapers, gloves, rags, pens, etc. These potential contaminants should be included in the risk assessment, with ways the risk can be minimized or eliminated identified. The risk of a dough scraper ending up in a mixer and becoming a foreign material, for example, can be minimized by making operators aware of the risk and giving them a place to put the scraper when it is not in use. Once established, there are only two acceptable places for the scraper to be: in the operator's hand or in the designated place. A scraper sitting on a bench or on top of a mixer is not allowed. If this is consistently practiced, the risk of a misplaced scraper can be greatly reduced or eliminated. To eliminate the risk of a pen or pencil becoming a foreign material in a product, documentation can be performed electronically, and pens and pencils can be banned in the facility. Rags are another foreign material risk that can be reduced by creating awareness and designating a place to keep them when not in use—sticking a rag in a pocket is not acceptable. The other advantage of having a designated place to put these items, is that every time someone walks past a designated place, it is possible to quickly look to see if an item is where it is supposed to be. If it is not in use or in its designated place, where is it? Consistently reinforcing this practice may also enable detection of a misplaced item before it can become a foreign material in finished product.

The following is a short list of specific situations, commonly encountered in artisan baking facilities, for consideration as potential risks that need to be minimized and controlled in the operation:

- Plastic tubs and buckets used for dough or ingredients can crack or fray, releasing fragments into the product. What steps can be taken to minimize or eliminate the risk?
- Upholstered couches can become dirty, moldy, or frayed. What are the practices for inspecting, cleaning, and replacing furniture as needed?
- Wooden peel boards and bagel boards crack and splinter, creating a foreign material risk. What steps can be taken to reduce or eliminate the risk?
- Proofing baskets can become dirty, moldy, or fall apart. What steps can be taken to reduce or eliminate the risk?
- Glass and hard plastics can crack or break. What steps can be taken to reduce or eliminate the risk? Is glass in any form allowed in the facility? Are all light bulbs covered with shatter shields? Can hard plastics be replaced with soft, unbreakable materials?
- Direct hand contact with product after baking poses a contamination risk. Are operators who handle product after baking required to wear sanitary plastic gloves? Is there a program to manage glove use and disposal in the facility?
- Loading and unloading racks poses a risk that foreign materials will drop onto product from the rack. There is a method for loading and unloading racks that can minimize this risk. Are operators aware of this practice and are they consistently performing it properly?
- Condensation on refrigeration coils and inside chilled boxes can support the growth of mold. Are coils cleaned frequently on a regular schedule? Is condensate piped away?
- Hand washing in utility sinks creates a contamination risk. Are there separate hand wash and utility sinks with adequate supplies of detergent and sanitizer and an appropriate method for hand drying?
- Pathogens may be present in the plant environment—introduced on people's shoes and hands, from ingredients and pallets, etc. FSMA requires that the environment in food manufacturing facilities be actively tested for the presence of pathogenic microorganisms, especially in areas where product is exposed. A program should be implemented to test drains, floors, and the non–food-contact sides of equipment for *Listeria* and *Salmonella* spp. If pathogens are found, the area should be cleaned and sanitized and retested, with these steps repeated until the contamination has been eliminated. Cleaning and sanitizing practices should be modified to assure that the procedures are adequate to prevent a reoccurrence. Without an effective program in place, it is likely that the FDA will perform testing during inspections. A small artisan operator may not have the expertise to collect surface samples, necessitating the use of an expert third-party lab.
- There is a risk of product contamination when food and food-contact surfaces are not isolated from non–food-contact surfaces and materials. What practices can be implemented to assure adequate separation? It is not advisable to test food-contact surfaces or the food itself. A positive pathogen test result must be reported to the FDA. In such an event, the minimum appropriate response would be to destroy the product on the line, and a recall might be triggered if there is a chance that product in the market could be contaminated. Testing alone cannot assure food safety because the sensitivity of the test is not sufficient to prove the absence of pathogens.
- Pests such as insects and rodents are a risk. Is there an effective program in place to monitor for the presence of these pests and to exclude them from the facility? It may be helpful to hire an expert third-party to set up and document a pest control program for the facility.
- Chemicals such as lubricants, solvents, pesticides, sanitizers, detergents, etc. in the facility are a risk. Is there a program in place to segregate these items from production areas and restrict access to only trained, authorized personnel?
- Intentional contamination is a risk. FSMA requires implementation of a program to assess and take steps to minimize the risk of intentional contamination. The program should be kept simple, such as taking reasonable steps to keep doors locked to prevent unauthorized external access. Cameras can also be an effective control element. Make personnel aware of the risk so they will question any unknown person in the facility.
- Rust and peeling paint are foreign material risks. Are steps being taken to minimize these risks by inspecting and cleaning ovens, proof boxes, ceilings, fans, etc.?
- Allergen cross-contamination is a risk if peanuts, tree nuts, dairy products, soy, fish, shellfish, or eggs are used in the facility. Are steps being taken to minimize or eliminate the risk, such as using proper labeling, cleaning, segregation, scheduling, separate equipment, etc.?
- Worker turnover creates a risk for the operation. Is there an adequate new hire training program to assure that new employees are aware of the food safety risks in their work area and know how to work in a safe manner around food products?

- Is there a trained food safety operator managing the program? FSMA requires that every food manufacturing facility have at least one qualified person who manages the food safety program. Experience can be helpful, but it is best to have at least one person attend a week-long training program to become certified as a qualified food safety operator. These courses are comprehensive and deep. When the person returns to work, remind them of the need to keep the process simple!

Preventive Controls

After identifying the risks, and doing what is reasonable to reduce or eliminate them, the next step is to put in place preventive controls. Preventive controls are needed whenever a risk cannot be eliminated. The purpose of the control is to manage the risk in order to prevent failure and enable rapid detection when a failure has occurred. FSMA avoids the confusion of designating control points as critical or noncritical. Effective controls are needed at all points where there is a risk of failure. Controls can be simple, such as visual inspection in the case of cleaning or temperature measurement to verify that the baking process is adequate to kill pathogens. Food manufacturers should consider how failure can occur and how it can be detected quickly. What corrective actions can be taken in the event of a failure to minimize or eliminate loss to the customer? Effective action could mean putting suspect product on hold until sufficient information on the failure can be gathered to assess what steps are needed to prevent loss to the customer. Some risks will not be controlled in the process and will be passed on to the customer. FSMA requires that customers be notified in writing of this fact. The customer then has the responsibility to implement an effective control for the risk and must advise the manufacturer that they have done so, closing the compliance loop. The same applies to the manufacturer. Suppliers may pass certain risks on to the manufacturer, and it is the responsibility of the manufacturer to implement an effective control. For example, wheat flour is a raw agricultural commodity (RAC) that may be contaminated with pathogenic microorganisms. The traditional milling process is not capable of controlling this risk unless additional processing is performed, such as a heat or sterilization treatment. If a manufacturer receives an RAC ingredient, they must implement an effective control to destroy pathogens that may be present. Baking is an adequate and validated control. The manufacturer need only reference the AIB International "Kill Step Validation" studies in their food safety plan and verify that their products are exceeding the time and internal temperature profiles defined in the studies.

Food Safety Plan

FSMA requires that every food manufacturing facility have a food safety plan. This is simply a list of the programs that have been implemented as a result of a risk assessment. It is not necessary to include the risk assessment or the program details; it is only necessary to list these. Manufacturers should be prepared to show FDA inspectors the details of their programs in case they are asked to do so. The food safety plan must include the list of programs and the employee training performed (both new hire and refresher training). The details should be included in the program documentation, including the procedure, utensils, and tools used; chemicals and concentrations used; frequency of performed procedure; failure detection; documentation of failures and corrective actions; and specific training performed for the program. For example, prerequisite programs such as chemical control should be listed in the food safety plan. In the program details, separate from the plan, list all of the details on what chemicals are included, how the inventory is controlled, what documentation is required, training topics, failure records (spills), and corrective actions that will be taken in the event of a failure. The food safety plan is simply a comprehensive list of the programs that have been implemented to manage food safety. Having the information listed all in one place makes it easier for the manufacturer and the FDA to understand and assess how food safety is being managed every day.

Assessment Versus Audit

FSMA is a paradigm shift for the food industry and for the FDA. The shift is from a food safety model based on audits to one based on assessments. In an audit model, there are predefined standards and practices. These standards are defined by the FDA in the Current Good Manufacturing Practices (CGMPs) and in the model Food Code. It is relatively easy to perform an audit and comply with the audit model, as the standards are defined and do not change often. The problem with the audit model is that compliance with the standards today does not provide assurance of compliance in the future—an audit provides a snapshot in time. Also, the standards may not be complete or adequate for all facilities and may become obsolete in an ever-changing environment.

Under the assessment model, the standards are defined by the manufacturer and embedded in programs and practices that assure compliance over extended periods of time. The programs are flexible and adaptable to the specific and changing needs of the manufacturer. Performing an assessment will be much more difficult for the FDA. In fact, it is likely that the assessment model will be more difficult for the FDA than for the food industry to implement.

Validation and Verification

FSMA introduces the requirement to validate and verify practices to assure adequacy and compliance. Validation proves that a practice is effective and must be performed at least every three years to assure that the practice is adequate to perform the desired task. For example, a cleaning and sanitizing practice for a mixer must be shown to be effective. The procedure for the practice should be performed exactly as written, assessed to determine whether it was effective, and the results documented. Keep it simple—a visual inspection may be adequate. Verification confirms that the practice is being performed according to the documented procedure every time the practice is used. Again, keep it simple—the person performing the procedure can check off the steps and initial it when the job is done to verify that they followed the procedure. A supervisor can follow up and initial the document as well to provide additional verification.

Verification is usually easy, whereas validation can be difficult. The food industry does not know how to validate some procedures and neither does the FDA. The FDA is relying on the industry to develop validation methods. This will take time. Do what you can and keep it as simple as possible.

FDA Inspections

As a food manufacturer, you need to be prepared for an FDA inspection. One person who will work with the inspector while they are in the facility should be identified, as well as an alternate in case the first person is not available. When the inspector arrives, welcome them and bring them to a room where they can set up and you can meet in private. You should ask what kind of inspection will be conducted and whether the FDA is following up on a specific issue. You should be prepared to show your facility registration. The inspector may also ask to see records such as procedures, policies, consumer complaints, training records, or even formulas.

When the inspector asks to see proprietary documents, there are several options. It may be best to give them what they need, not necessarily what they want—no one wants a disgruntled FDA inspector in their facility. On the other hand, you do not want your competitors to gain access to proprietary information through a FOIA request for sensitive documents. Ask the inspector why they want to see a certain document. Usually they want to see a formula, for example, to confirm that the ingredients match the label. They do not need all of the percentages to do this, so ask whether they will allow blacking out of some of the formula percentages, leaving the ingredient names for them to see. They generally will agree, as this gives them what they need while protecting proprietary information. You can also ask the inspector to look at the document, but to please not take copies. As a last resort, if you really don't want to give them a document for some reason, you can ask them to make the request in writing. They almost never do.

Remember, they have a job to do too and treating them with respect goes a long way toward avoiding confrontation. If they find something wrong, they may issue a 483 form. This is an official notice of a deficiency. You must respond to it in writing within 30 days to advise them of how you will or already have corrected the deficiency. Make sure to correct it permanently, because the next time they visit the facility they will check to see whether it was corrected. If it was not corrected and they find a repeat violation, this is when they will get tough and shut down facilities.

Conclusions

If you have questions or need help, reach out. The FDA has published numerous guidance documents on various aspects of FSMA compliance. AIB International, the American Bakers Association (ABA), and even competitors can be good sources for help with compliance. Food safety compliance is not a competitive advantage. A failure anywhere impacts all manufacturers negatively. Having said that, finding a way to comply with FSMA in an efficient manner that does not burden your staff can indeed be a competitive advantage. Keep it simple!

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AACC International Approved Methods Technical Committee Report: Collaborative Study on Determination of Total Dietary Fiber (Digestion-Resistant Carbohydrates per Codex Definition) by a Rapid Enzymatic-Gravimetric Method and Liquid Chromatography

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Summary

A method for measurement of total dietary fiber (TDF) (1,2), as defined by the Codex Alimentarius Commission (ALINORM 09/32/26 [4]), was validated for plant materials, foods, and food ingredients. The method measures insoluble dietary fiber (IDF) and total soluble dietary fiber (SDF), including SDF that precipitates from 78% aqueous ethanol (SDFP) and SDF that remains soluble in 78% aqueous ethanol (SDFS). AACCI Approved Method 32-60.01 (Integrated Method for Total Dietary Fiber [9]) is an update on AACCI Approved Method 32-45.01 (Total Dietary Fiber (Codex Alimentarius Definition) [1,7,8]) that is designed to address issues identified by analysts using AACCI 32-45.01 over the past eight years.

Values for higher molecular weight dietary fiber (HMWDF; IDF plus SDFP) were determined gravimetrically for samples that did not contain resistant starch(es) (RS) and were essentially the same as those obtained using AACCI Approved Methods 32-05.01 (Prosky method) (1,12) and 32-07.01 (Lee method) (1,6). The HMWDF values obtained for most samples containing RS were similar to those obtained using AACCI 32-45.01, with the exception of samples containing RS type 2 (RS2; native, high-amylose maize starch) and RS type 4 (RS4; phosphate cross-liked native starches), for which significantly higher dietary fiber values were obtained.

The method was evaluated through an AACC International and ICC collaborative study. Sixteen test samples (eight blind duplicates) with a range of traditional dietary fiber, RS, and nondigestible oligosaccharide contents were assayed by thirteen laboratories. All laboratories returned valid data. In total, only 4 sets of data from the 104 sets submitted were statistically excluded as outliers. Dietary fiber content ranged from 6.79 to 60.6%; within-laboratory variability (s_r) ranged from 0.29 to 0.74 (1.22 to 6.34%, relative); and between-laboratory variability (s_R) ranged from 0.57 to 4.67 (2.64 to 13.38%, relative).

Introduction

A method for measurement of TDF (1,2), as defined by the Codex Alimentarius Commission (ALINORM 09/32/26 [4]), was validated for plant materials, foods, and food ingredients. The Codex definition for dietary fiber adopted in June 2009 (4) includes carbohydrate polymers that are not hydrolyzed by the endogenous enzymes in the small intestine of humans, including RS. This definition also includes oligosaccharides with degrees of polymerization ≥3. The decision on whether to include these oligosaccharides in the dietary fiber value provided on product labels was left to the discretion of national authorities.

A method (7) designed to support implementation of the Codex definition published in 2007 (3) was successfully evaluated in an interlaboratory study (1,8) and approved as AACCI 32-45.01 (1). In this method TDF is measured by summing the quantity of a digestion-resistant food fraction, including IDF and SDF that precipitates in the presence of 78% aqueous ethanol (SDFP), and the SDF that remains soluble in 78% aqueous ethanol (SDFS). Subsequent applications of this method to a range of food products and ingredients identified several issues:

1) Incubation with pancreatic α-amylase (PAA) and amyloglucosidase (AMG) enzymes for 16 hr does not simulate likely physiological conditions. In AACCI 32-45.01 (1), samples are incubated with a solution of PAA and AMG at 37°C and pH 6.0 for 16 hr (the digestion step parallels the incubation conditions employed in AACCI 32-40.01 for measuring RS) (1). A more likely residence time for food in the small intestine is 4 ± 1 hr (McCleary et al. [9,10] and referenced literature).
2) Most commercially available fructooligosaccharides (FOS) contain the trisaccharide fructosyl-β-(2-1)-fructosyl-β-(2-1)-fructose (inulinotriose; F3), which cannot be measured using the Sugar-Pak high-performance liquid chromatography (HPLC) column (Waters).
3) During hydrolysis of products that are high in nonresistant starch, resistant maltodextrins are produced that are incorrectly measured as dietary fiber (9,10).
4) Phosphate cross-linked starch (RS4, e.g., Fibersym [MGP Ingredients]) content is underestimated.
5) Long incubation times with PAA and AMG require the incorporation of sodium azide in buffers to prevent undesirable microbial growth. Although the azide concentration employed is low (0.02%, w/v), it is still considered a health and safety concern for analysts working with the chemical.

AACCI 32-60.01 (9) employs the same basic biochemistry and enzymes (PAA, AMG, and protease) that are used in AACCI 32-45.01 (1), but it resolves each of the issues described above. In particular, with an incubation time of 4 hr, it more closely simulates likely physiological conditions. Additionally, HPLC is performed using TSKgel® G2500PW$_{XL}$ col-

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umns (Tosoh Bioscience LLC) for gel permeation chromatography (5) with in-line deionization (11).

Precollaborative Ruggedness Testing

To allow the analysts to familiarize themselves with the method, evaluate the protocol, and identify potential problems, four samples were sent to each collaborator with the request that they perform a single analysis on each sample. All key reagents, including the components of the Rapid Integrated Total Dietary Fiber assay kit (Megazyme), anion and cation resins, and the required polypropylene tubes, were supplied to each analyst together with the samples. The key steps and processes required to perform the method effectively were highlighted, e.g., preferred incubation bottles, methods for suspension of samples during incubations, and HPLC equipment. To minimize calculation errors, collaborators were asked to use a Mega-Calc Excel (Microsoft Corp.) spreadsheet (Megazyme) to compute results. The results obtained for the TDF content of the four samples, including statistical analysis, are shown in Table I. The between-laboratory variability (s_R) ranged from 1.10 to 3.40% TDF (RSD_R = 5.64 to 9.28%), which is consistent with statistics reported for analyses of similar samples utilizing other dietary fiber methods (13).

As results were received from the collaborators, it became clear there were some problems and misunderstandings associated with the method protocol, particularly with regard to measurement of the SDFS fraction using HPLC. To clarify the reasons for these problems, the collaborators were surveyed regarding

a) The method used to shake or stir the samples during the 4 hr incubation with PAA and AMG: 2mag submersible stirrer (2mag AG) with stirring in bottle; shaking water bath in orbital motion; or shaking water bath in linear motion with containers held at an ~45° angle to ensure that all sample was continually suspended.
b) The HPLC columns used: TSKgel® G2500PW$_{XL}$ columns or other—if other, which columns. A copy of the HPLC trace for sample 4 (Heinz baked beans) was requested so separations, etc. could be checked.
c) The internal standard used: if a glycerol internal standard was not used, how was the SDFS quantified?
d) Any changes made to the method: details were requested so deviations in the results could be explained and the flexibility of the method could be determined.
e) Any particular problems experienced with the method: details were requested so they could be considered and addressed before the full study was initiated.

Table I. Study data for precollaborative evaluation of AACCI Method 32-60.01 for determination of total dietary fiber[a]

	Total Dietary Fiber (%, w/w)			
Laboratory[b]	A	B	C	D
1	12.46	62.32	20.46	22.24
2	10.93	66.0	19.34	21.5
3	9.95	51.32	18.56	21.88
4	13.1	62.9	19.7	23.2
5	11.40	60.39	19.64	23.23
6	11.48	58.95	18.00	21.25
7	12.53	62.67	21.00	21.22
8	13.04	57.74	19.52	22.17
9	13.04	60.46	19.79	22.78
10	12.34	61.17	19.57	22.74
11	11.57	59.83	19.63	23.57
12	12.28	60.23	20.97	16.85
13	9.86	60.38	16.58	20.07
Mean of lab averages	11.85	60.33	19.44	21.75
s_R	1.10	3.40	1.20	1.77
RSD_R (%)	9.28	5.64	6.15	8.13

[a] Samples: A = whole meal bread; B = high-amylose maize starch (Hylon VII, Ingredion); C = carrots lyophilized; D = baked beans (Heinz) washed and lyophilized.

[b] s_R = reproducibility standard deviation; RSD_R = reproducibility relative standard deviation.

For the gravimetric determinations of HMWDF, no specific problems were identified by the collaborators. Measurement of SDFS was more challenging. Collaborators were asked to prepare standardized solutions from supplied glycerol and D-glucose prepared by the collaborator. The response factors (D-glucose and glycerol) varied between laboratories, so the decision was made to provide the D-glucose and glycerol solution in a stable, ready-to-use form for the full collaborative study. The response factors obtained with glycerol at 10 mg/mL and D-glucose at 5, 10, or 20 mg/mL were essentially the same. Thus, all standardization was subsequently performed with solutions of D-glucose at 10 mg/mL and glycerol at 10 mg/mL.

Upon completion of the precollaborative study and implementation of necessary method protocol adjustments, the full collaborative study was initiated.

Collaborative Study Protocol

Eight food samples were selected for the collaborative study, and because the main focus of the study was to evaluate complex food samples containing RS and nondigestible oligosaccharides, samples high in these components were chosen. The samples included legumes, phosphate cross-linked starch (RS4), whole grain products, and food products enriched with RS and nondigestible oligosaccharides. Moist samples were freeze-dried. All samples were ground to the method-specified size, homogenized, and mixed thoroughly before being subdivided into glass vials that were then sealed and capped. Samples, copies of the method, electronic report sheets, Excel-based calculators, sample storage instructions, and an adequate supply of enzymes, reference standards, and resins were shipped to collaborating laboratories using express overnight shipment.

Thirteen laboratories completed the study and reported a full set of results. Two laboratories advised the study director that they lacked access to TSKgel® G2500PW$_{XL}$ HPLC columns. These collaborators completed all the steps through concentration of the SDFS fractions and then shipped the concentrates to the study director's laboratories, where the concentrates were deionized and chromatographed on TSKgel® G2500PW$_{XL}$ columns. The results were then submitted back to the collaborators for calculation and reporting.

Statistical Analysis

Data from the collaborative study were evaluated statistically according to AACC International protocols using software supplied by AOAC International. Of the 104 valid pairs of assay results reported for TDF content, laboratories 1, 2, 4, 5, 6, 7, 8, 9, 10, and 11 had no statistical outliers. Laboratories 3 and 13 had one statistical outlier each, and laboratory 12 had two statistical

Table II. Interlaboratory study results for determination of total dietary fiber in foods

Lab	Sample[a,b]															
	A	D	B	F	C	J	E	H	G	N	I	M	K	O	L	P
1	58.70	59.44	25.26	24.42	30.82	29.56	6.07	6.31	16.91	17.33	19.59	19.91	21.03	21.23	10.36	10.60
2	68.04	69.30	23.82	25.67	30.64	31.19	7.19	7.97	17.26	17.24	21.84	21.48	22.23	21.29	10.00	10.71
3	55.02	54.89	24.11	24.48	28.52	28.73	8.16[c]	6.40[c]	15.12	14.21	17.49	18.38	21.60	21.65	11.84	10.45
4	62.17	61.36	23.87	22.92	28.70	28.40	6.73	6.74	15.42	15.32	19.45	19.74	20.00	21.15	11.29	11.38
5	62.07	62.25	23.46	24.46	29.26	29.21	7.21	6.79	15.94	16.30	18.78	18.69	20.74	20.67	10.49	11.33
6	62.37	62.94	23.02	23.23	29.42	29.59	7.15	6.44	16.40	16.52	20.12	20.40	21.22	21.46	10.37	10.52
7	67.56	69.00	23.78	23.88	28.74	28.90	6.39	6.45	15.78	15.86	17.83	17.12	21.17	20.14	11.44	10.81
8	56.91	55.42	22.78	24.39	28.88	29.34	6.31	6.32	16.26	15.35	20.28	20.05	20.52	19.83	8.98	9.39
9	62.83	60.75	24.49	24.66	30.16	30.12	8.10	8.34	17.37	16.71	20.13	20.66	21.80	21.54	11.60	12.32
10	56.43	56.00	23.61	23.79	29.53	29.69	7.36	7.86	16.46	16.79	18.45	18.41	21.02	21.32	10.20	12.79
11	61.16	60.12	22.25	23.69	29.17	28.39	6.40	5.79	16.75	16.47	21.13	21.08	21.14	21.13	11.25	10.61
12	54.98	55.28	21.81	21.37	31.90[c]	28.07[c]	4.88	5.03	15.16	14.86	15.01	15.33	18.24[g]	18.66[g]	10.11	10.91
13	65.83[c]	61.37[c]	23.19	23.82	28.70	29.11	7.54	7.65	16.56	15.45	20.03	19.79	21.44	20.74	9.92	10.03

[a] Samples: A and D = phosphate cross-linked starch (Fibersym, MGP Ingredients); B and F = kidney beans (canned, washed, and lyophilized); C and J = bran cereal; E and H = defatted cookies containing FOS (fructooligosaccharides); G and N = oat bran; I and M = defatted cookies containing polydextrose and RS2 (resistant starch type 2); K and O = dark rye crispbread; L and P = whole meal bread.

[b] Values followed by "c" were removed based on Cochran's test; values followed by "g" were removed based on the lowest average in the single Grubb's test.

Table III. Interlaboratory study results for determination of total dietary fiber in foods[a]

Parameter	Sample[b]							
	A and D	B and F	C and J	E and H	G and N	I and M	K and O	L and P
Number of labs/analysts	12	13	12	12	13	13	12	13
Mean (%)	60.62	23.70	29.37	6.79	16.15	19.28	21.09	10.76
s_r	0.74	0.67	0.36	0.29	0.39	0.29	0.43	0.68
s_R	4.67	0.99	0.78	0.91	0.85	1.74	0.57	0.86
RSD_r (%)	1.22	2.81	1.22	4.32	2.41	1.51	2.05	6.34
RSD_R (%)	7.70	4.17	2.64	13.38	5.29	9.01	2.72	8.02

[a] Statistical evaluation performed according to AOAC International statistics format. s_r = within-laboratory variability; RSD_r = within-laboratory relative variability; s_R = between-laboratory variability; RSD_R = between-laboratory relative variability.

[b] Samples: A and D = phosphate cross-linked starch (Fibersym, MGP Ingredients); B and F = kidney beans (canned, washed, and lyophilized); C and J = bran cereal; E and H = defatted cookies containing FOS (fructooligosaccharides); G and N = oat bran; I and M = defatted cookies containing polydextrose and RS2 (resistant starch type 2); K and O = dark rye crispbread; L and P = whole meal bread.

outliers, for a total of four statistical outlier pairs. The raw and statistically paired data from the blind duplicate results for TDF are shown in Tables II and III, respectively.

Results and Discussion

Raw data for the dietary fiber collaborative study, with Cochran and Grubbs outliers noted, are shown in Table II. Results of statistical analysis, after the removal of outliers, are shown in Table III. The samples tested in this collaborative study were chosen to be challenging, with an emphasis on analyzing complex products containing RS and nondigestible oligosaccharides. As shown in Table III, within-laboratory variability (s_r) for TDF ranged from 0.29 to 0.74, and between-laboratory variability (s_R) ranged from 0.57 to 4.67. Comparison of statistical analyses showed the level and range of variability in results for the current method were similar to those for previously adopted dietary fiber methods (Table IV) and were most likely influenced in all cases by the significant number of technique-dependent manual operations performed (13). For the current method, repeatability, reproducibility, and Horwitz ratio (HorRat) values were within the range of performance characteristics typically obtained with other dietary fiber methods. In previously adopted methods, between-laboratory variability (s_R) ranged from 0.04 to 9.49, and between-laboratory relative variability (RSD_R) ranged from 1.58 to 66.25 (Table IV).

In AACCI 32-60.01, as in AACCI 32-45.01 (1), food digestion in the small intestine is simulated by gentle shaking or stirring of the sample, with enzymatic digestion at 37°C and pH 6.0. The major difference between AACCI 32-45.01 and 32-60.01 is a reduction from 16 to 4 hr for incubation with the PAA and AMG solution to better simulate the likely residence time for food in the small intestine. RS is the most difficult dietary fiber component to measure accurately because the value obtained is dependent on the incubation conditions—time, temperature, pH, and enzyme concentrations. These variables were optimized for AACCI 32-45.01 to assure the values obtained for samples containing RS were in agreement with values obtained for ileostomy studies (7,8). Experience with the method since adoption of AACCI 32-45.01 has shown that values obtained for phosphate cross-linked starches (RS4) are underestimated when using these conditions. To ensure that values obtained for samples containing RS (RS2, RS3, and RS4) when using a 4 hr incubation were in agreement with known values obtained for ileostomy studies, the concentrations of both PAA and AMG were increased to levels above which further increases in activity (as much as fourfold) produced no further decreases in the levels of measured RS (9). PAA was increased from 2 to 4 kU/test, and AMG was increased from 0.14 to 1.7 kU/test. Under these conditions, the dietary fiber values for many RS-containing samples using AACCI 32-60.01 were similar to those obtained using

Table IV. Comparable AACC International and AOAC International method data[a]

Method[b]	Title	s_r	RSD_r	s_R	RSD_R	HorRat
AACCI 32-05.01	Total Dietary Fiber	0.15–0.99	0.56–66.25	0.27–1.36	1.58–66.25	0.76–17.46
AACCI 32-20.01	Insoluble Dietary Fiber	0.41–2.82	0.86–10.38	0.62–9.49	3.68–19.44	1.73–8.68
AACCI 32-07.01[c]	Soluble, Insoluble, and Total Dietary Fiber in Foods and Food Products	0.36–1.06	1.50–6.62	0.41–1.43	1.58–12.17	0.74–4.66
AACCI 32-06.01	Total Dietary Fiber—Rapid Gravimetric Method	0.18–1.01	1.48–14.73	0.22–2.06	4.13–17.94	1.84–4.62
AOAC 993.19	Soluble Dietary Fiber in Food and Food Products	0.49–1.15	1.74–5.93	0.79–2.05	2.41–7.01	1.13–2.83
AACCI 32-25.01	Total Dietary Fiber—Determined as Neutral Sugar Residues, Uronic Acid Residues, and Klason Lignin (Uppsala Method)	0.32–2.88	1.80–6.96	0.52–4.90	4.80–11.30	2.32–4.20
AACCI 32-41.01	Total Dietary Fiber in Foods Containing Resistant Maltodextrin—Enzymatic-Gravimetric Method and Liquid Chromatography Determination	0.02–1.63	1.33–6.10	0.04–2.37	1.79–9.39	0.77–3.32
AACCI 32-40.01	Resistant Starch in Starch Samples and Plant Materials	0.08–2.66	1.97–4.12	0.21–3.87	4.48–10.90	1.44–3.74
AACCI 32-45.01	Total Dietary Fiber (Codex Alimentarius Definition)	0.41–1.43	1.65–12.34	1.18–5.44	4.70–17.97	1.91–6.49
AACCI 32-50.01	Insoluble, Soluble, and Total Dietary Fiber (Codex Definition) by an Enzymatic-Gravimetric Method and Liquid Chromatography	0.47–1.41	2.43–8.60	0.95–3.14	6.85–14.48	2.85–5.51
AACCI 32-60.01[d]	Integrated Method for Total Dietary Fiber	0.29–0.74	1.28–6.69	0.58–4.59	2.65–13.42	1.08–4.46

[a] s_r = within-laboratory variability; RSD_r = within-laboratory relative variability; s_R = between-laboratory variability; RSD_R = between-laboratory relative variability; HorRat = Horwitz ratio.
[b] Sources: AACC International (1) and AOAC International (2).
[c] Samples were not dried and/or were desugared only.
[d] Current method.

AACCI 32-45.01. The notable exceptions were native, high-amylose maize starch (e.g., Hylon VII, Ingredion), for which measured TDF increased from ~46 to ~60%, and phosphate cross-linked native wheat starch (Fibersym), for which measured TDF increased from ~30 to ~60%.

It is essential to ensure that increased levels of enzyme, especially AMG, do not lead to hydrolysis of other dietary fiber components, such as FOS, galactooligosaccharides, or resistant maltodextrins. Studies confirming this were reported previously (9,10). After incubation with PAA and AMG, the pH of the incubation mixture was increased to ~8.2 followed by temporary heating of the sample to ~100°C to inactivate the PAA and AMG and promote protein denaturation, ensuring efficient protein hydrolysis by protease after cooling of the solution to 60°C. The fraction containing HMWDF was recovered gravimetrically after alcohol precipitation of the SDFP, and combining this result with the water–alcohol soluble fiber (SDFS) content determined by HPLC completed the assay.

Reducing the incubation time with PAA and AMG from 16 to 4 hr has the added advantage of removing the risk of microbial contamination of the sample during extended incubation and alleviating the need to add sodium azide to the incubation buffer. Although the PAA and AMG in the current method are dissolved in buffer containing sodium azide, its presence is not essential and can be omitted if the enzyme solution is kept on ice before use and is used soon after its preparation. The use of sodium azide is still recommended, however, for the maltodextrin chromatographic standard and the glucose and glycerol reference solutions, because these solutions may be prepared and stored for several years before use.

In AACCI 32-60.01, the concentrates containing SDFS from the samples are analyzed using TSKgel® G2500PW$_{XL}$ gel permeation HPLC columns preceded by in-line removal of anions and cations. The in-line deionizing cartridges (Bio-Rad) have a limited capacity and are only able to deionize 25–30 samples before they are exhausted. To reduce the cost associated with the expensive cartridges, the concentrates are deionized in a polypropylene tube containing anion and cation exchange resins prior to use, resulting in 90–95% removal of ions and extension of the life of the HPLC deionization cartridges by 10–20 times the usual number of injections.

In the current method, SDFS is analyzed on TSKgel® G2500PW$_{XL}$ gel permeation columns with a glycerol internal standard. If the sample being analyzed contains glycerol, diethylene glycol is a suitable alternative internal standard. In AACCI 32-45.01, a Sugar-Pak column is employed; however, with this column a significant component of hydrolyzed fructans (i.e., inulinotriose) elutes at the same point as disaccharides and, thus, is not measured as dietary fiber. FOS are completely separated and measured on TSKgel®G2500PW$_{XL}$ columns.

Based on the HPLC chromatographic traces supplied by the collaborating laboratories, several of the HPLC systems did not operate optimally, as evidenced by the significant upward slant of the baseline of the chromatogram during a run. This indicates that the column was partially blocked, and operating pressure was likely higher than the recommended level. Backwashing the column more than 24–48 hr prior to its continued use would reoptimize column performance.

Collaborator Comments

No negative comments were received concerning the ease of use of the method; however, one collaborator did notice an allergic reaction to the PAA and AMG powder mixture. Therefore, the protocol now includes an option whereby an analyst who is not allergic can suspend the enzyme powder mixture in an ammonium sulfate solution to produce a stabilized liquid form that reduces the risk to susceptible analysts. One collaborator did not have access to the deionizing precolumns, so they deionized the samples according to the specifications in AACCI 32-45.01. The same collaborator did not have a water bath with an orbital motion and, thus, was advised to position the incubation containers at an ~45° angle, relative to the direction of shaking, to ensure that the sample did not settle to the bottom of the container during incubation. One collaborator asked for further advice on where to distinguish between SDFS and disaccharides on the HPLC pattern.

Acknowledgments

The study directors wish to thank the collaborators for all their efforts in completing this study: Nancy Ames, Sean Austin, Jodi Cox, Delphine Curti, Saskia Iilians, Yulai Jin, Susan McCarthy, Vincent McKie, Helena Pastell, David Plank, Hayfa Salman, Toyohide Nishibata, Peter Sanders, Alessandro Santi, and Mikihiko Yoshida. The study directors also thank all of the organizations that supported this effort: Agriculture and Agri-Food Canada (Canada), CRDS (Central Department for Research & Development Services) (Belgium), Eurofins Food Testing (Netherlands), Finnish Food Safety Authority Evira (Finland), AEGIC (Australian Export Grains Innovation Centre) (Australia), Japan Food Research Laboratories (Japan), Kellogg Company (U.S.A.), Matsutani Chemical Company (Japan), Medallion Laboratories/General Mills (U.S.A.), Megazyme (Ireland), and Nestlé Research Centre (Switzerland). Finally, the study directors thank the chairs and members of the AACCI Dietary Fiber and Other Carbohydrates Technical Committee for valuable editing of this report and the associated AACCI method document.

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Spotlight on Lauren Brewer

AACC International members each have their own story, and we want to highlight all of their amazing accomplishments. "Spotlights" is a series of individual and institutional member interviews capturing the unique stories of our many volunteers and their journeys with AACCI.

Lauren Brewer
General Mills
Member for 10 years

Q: What is your current position and what type of work do you do?

A: I am a senior professional for General Mills in the Innovation Technology and Quality team. I work with my cross-functional partners to build products that the consumer really loves. Being in R&D, I develop products from idea to consumption, making sure that they are designed as safe, high quality offerings for one of our many brands.

Q: When and how did you first decide you wanted to work in cereal grain science?

A: I went into undergraduate school as a food science major and loved it. During my first internship, I saw that everyone who had a job I wanted had a graduate degree. Therefore, I knew I wanted to continue my education. This may age me, but I chose cereal grain science because grain was at the base of the food pyramid—it was the foundation, and I knew I wanted my expertise to be in the foundation of the global diet.

Q: When did you join AACCI and why?

A: During my first AACCI Annual Meeting, I was a graduate student and invited to a CPG company-sponsored, "high-tech" symposium to speak on near-infrared spectroscopy. I thought for this organization to trust and invite me to this meeting, as well as to have people in my presentation room listening and learning and asking questions after a 40 minute presentation on confocal microscopy, this is a worthwhile group. I joined the organization the following year.

Q: Why did you decide to volunteer with AACCI? How did you get involved, and what has been most rewarding about this experience?

A: There is an old Danish saying, "If you decide to do anything, do it well, because the hassle is the same." I was still a student at the time and wanted to help with any divisions or sections that really needed someone to help drive change, so I volunteered to be the Young Cereal Chemist Conference chair—later learning that the North American students had never held their own conference before, but the EU students were on year 10 (at the time). But, I did it. I think we had approximately 40 students at the conference, including one who came from a university in Mexico. The people who I met during that experience, as well as the many other experiences I have had with AACCI, have been worth all the time invested.

Q: Are you a member of any AACCI Divisions? If so, which ones, and how has your work with the divisions helped your career?

A: There are a lot of AACCI Divisions that I have been a part of in my 10 years in the organization, including the Milling and Baking, Nutrition, and Carbohydrate Divisions. Whenever I am in a division or section meeting, I try to be an active member. Right now, I am an active member of the Northwest Section. Currently, we are trying to find the balance between hosting enough events to stay relevant and respecting our members' work/life balance. Sometimes we do this by partnering with other (competitive, some would say) organizations. I think this gives us an advantage. We can do more, cover more ground, and think differently. My involvement with the Northwest Section has conditioned me to do all those adaptive things in my career as well.

Q: What do you see as important issues that are shaping the field of milling and baking? How are these issues affecting cereal science and the cereal grain industry overall?

A: Whew, big question. There is game-changing legislation under way right now on flour as "ready to eat." What does that mean for farmers who are dealing with climate change and organic certifications regulations? Or, millers who have tight margins and variable income streams? Where does sullying lie in relation to utilizing crops when there are 7.5+ billion people who need to be fed? Overall, the impact of this issue is felt from field to fork. Generals Mills is historically a leader in food safety (i.e., HACCP was a collaborative effort among Pillsbury, NASA, and the U.S. Army Laboratories), and we are making remarkable strides in continuing to be that food safety industry leader.

Q: This issue of *CFW* focuses on the artisan baking trend. Do you have any perspectives on the opportunities and challenges within the artisan baking movement?

A: I would say one challenge is the standard of identity. There are few places that I go to in Minneapolis to get a good baguette. Artisan is trendy, but those who can deliver on that experience are in the season of opportunity. It is sustenance as well as an emotional sensory experience that you are paying for when you purchase artisan bread. In my mind, a good piece of bread takes me back to Lyon, France, that's why I believe that the product is worth the premium.

Q: What's next for you?

A: I plan to serve the world by making food people love; I plan to leave the world better than I found it; and I plan to send the elevator of success back down—the way it was held for me.

CEREALS & GRAINS 18

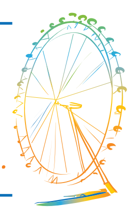
October 21 – 23
Hilton London Metropole
London, United Kingdom

Katharina Scherf, Program Team Chair for Cereals & Grains 18 (C&G 18), shares her thoughts on how the program team is working diligently to bring you something very unique as AACC International prepares to host its annual meeting in London.

What makes C&G 18 unique?

By taking place in London, attendees will have an even greater opportunity than usual to connect with European leaders in cereal science from academia, government and industry. It will be a focused event highlighting the latest changes, challenges, research and innovations along the whole value chain of cereals seen from different international perspectives. Numerous pre- and post-meeting trainings and activities are being organized to ensure that all participants get the most out of their stay in London.

The sessions will include well known, highly respected invited experts and the most recent science taken from the best technical abstract submissions.



What is different about the location this year?

Convening C&G 18 at Hilton London Metropole's modern conference facilities will give all attendees the opportunity to network with all participants and easily renew existing and make new connections. The location is also a great starting point for visiting many of the British capital's favorite attractions.

What changes have you made to programming?

Each of the three meeting days will have a specific theme, starting off with "Sustainability from Gene to Field" on Sunday on to "Safe Ingredients and Quality Products" on Monday and "Formulating for Health and Wellness" on Tuesday. The 2018 Program Team has been working hard to identify the timeliest topics ranging from precision agriculture, ancient wheats and pulses to food safety, bioprocessing, shelf life, health claims, processing for health, whole grains and nutrition, just to name a few highlights. There will be featured sessions with up to 400 participants, focus sessions with about 150 attendees and deep dives for around 50 specialists and those wanting to become one. The sessions will include well known, highly respected invited experts and the most recent science taken from the best technical abstract submissions.

Why should someone attend C&G 18?

Some highlights at C&G 18 will include the visionary and inspiring keynote speakers Professor Achim Dobermann of Rothamsted Research and Dr. Ian Roberts of the Bühler Group. Look forward to a general panel discussion with leaders from the cereal food industry and academia for ideas on how to shape the future of cereals and foster innovation. Take the unique opportunity to meet with exhibitors, learn about cutting-edge research presented as posters and talks, and connect with international experts. Last, but not least, as is typical for European scientific meetings, there will be food and coffee to enjoy during the breaks to facilitate networking even more.

What makes you excited about C&G 18?

Back when I agreed to become the Program Team Chair for 2018, I did not know yet that I would be part of the great experience of taking the annual meeting to London. Now it seems perfect to have a European perspective to bring in both young and experienced people from all fields concerned with cereals and share the value that being active in AACC International brings. I am convinced that it will be a truly international, thought-provoking, maybe a little more intimate, and inspiring meeting – an opportunity that no one should miss!

Call for Abstracts

Join industry and academic leaders from across the globe exploring, presenting, and discussing the best in cereal grain science. **Submit your abstract by April 12, 2018** to be considered for speaking opportunities and poster presentations.

The 2018 Meeting Technical Program Planning Committee will be looking for abstracts that address C&G 18's daily themes addressing the broad spectrum of grain science:

- Sustainability from Gene to Field
  - Big data approaches
  - Crop performance and quality
  - Crop protection
  - Plant breeding tools
  - Storage and postharvest loss improvements
  - Sustainable agriculture

- Safe Ingredients and Quality Products
  - Analytical method development
  - Consumer quality perception
  - Food safety, quality and regulatory
  - Milling
  - Processing innovations
  - Rheology
  - Structure-function relationships
- Formulating for Health and Wellness
  - Consumer trends and preferences
  - Communication to the consumer
  - Gluten-/allergen-free
  - Health benefits of dietary fiber
  - Health benefits of cereals and alternative grains
  - Health benefits of grain-based macro- and micronutrients

Keynote Highlights

Leading from an Illustrious Past into a Demanding Future

Professor Achim Dobermann
Director & Chief Executive
Rothamsted Research

Digitalization to Revolutionize: The Grain Value Chain of the Future

Dr. Ian Roberts
Chief Technology Officer
Bühler Group

Join us in London for Cereals & Grains 18

Cereals & Grains 18 will be held at the Hilton London Metropole located in central London.

With superb transportation links, Hilton London Metropole is located just 15 minutes from Heathrow Airport via the Heathrow Express at Paddington Station, and 10 minutes from the Eurostar terminal at St Pancras International.

The hotel is also just 10 minutes from many of London's major shopping areas, including Oxford Street, Westfield London Shopping Centre, Regent Street, Bond Street and Knightsbridge, as well as popular local attractions such as Regent's Park, Marble Arch, Madame Tussads, West End Theaters, Hyde Park and Kensington Palace.

Cereals & Grains 18 Technical Program Planning

Program Team Chair
Katharina Scherf
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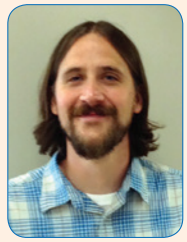

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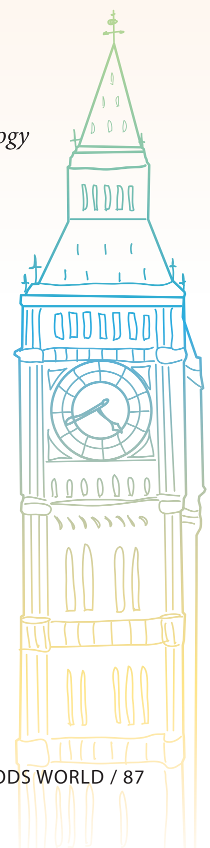

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ISU, NAMA, and AACC International Hold Open Discussion on Food Safety

On January 31, 2018, 35 representatives from industry, academia, and trade organizations gathered at the Iowa State University Economic Development Core Facility, ISU Research Park, to have an open dialogue on food safety in grain milling. The specific issues discussed were bulk grains, traceability, and potential risks that need to be addressed to prevent or mitigate pathogen concerns in the food supply chain.

The session was jointly sponsored by the Iowa Grain Quality Initiative of ISU Extension and Outreach, the North American Millers Association (NAMA) Technical Committee, and the AACC International Food Safety, Quality, & Regulatory Committee (FSQRC). The objectives of the meeting were to

1) Review the recent history of pathogen contamination in raw field crops/grains.
2) Identify sources and potential control actions for the future.
3) Identify actions that would improve tracking of bulk grains or products through the supply and utilization chain.

The recent history of pathogen contamination and associated recalls was summarized. For most food products, safety is built in via a kill step. However, consumers sometimes eat the certain flour-based products in a raw state, e.g., cookie dough, cake batter ice cream, or flour in spice blends used in dips. This consumer behavior represents a unique challenge to the industry.

The industry has begun to utilize warning labels and provide consumer education concerning the fact that flour is not a product intended to be consumed in a raw state without a kill step. The U.S. Food and Drug Administration (FDA) and Centers for Disease Control and Prevention have partnered in this education effort through publications and advisories to consumers and restaurants. At issue is the fact that the source of pathogens has not been clearly identified, making "stopping the source" a challenge.

James Dickson

James Dickson (ISU Meat Science Department) discussed Shiga toxin-producing *Escherichia coli*, especially those species found in field crops. Dickson discussed the types of *E. coli* involved: specifically, *E. coli* O157:H7 and the "Big 6" (026, 0111, 0203, 0121, O45, and O145). Testing can be done on food products, but without large-scale contamination, the sample plan is not effective. Prevention of contamination and treatment for potential contamination are possible approaches. Heat treatment of flour has been effective (as outlined in an article by Ardent Mills). The spice industry has utilized steam, gas (ethelene or propylene oxide), and irradiation. There is not yet a consensus on the best path forward. For example, heat treatment is effective against *E. coli* pathogens but may impact functional quality.

Small group discussions were held to identify key questions and research and actions that could be taken by the industry to improve preventive controls. Key gaps identified include

- Identification of the source of pathogenic organisms in grains. Is it a food safety issue? Bakers have kill steps; it is only a safety issue when grains are consumed in a raw state. Flour is not intended for consumption in a raw state.
- Clarify whether pathogenic organisms in grain are regulatory issues. The 2010 Food Safety Modernization Act (FSMA) requires identification of hazards as part of FSMA-compliant food safety plans.
- What is the route of entry of the pathogen into the supply chain? To date, specific sources of entry have not been identified. Does this occur in the field or at the elevator, mill, or food processor?
- What is the cost of traceability? Currently, outside of specific IP practices, the industry cannot trace bulk grain or flour back to the field. Is the cost of improving traceability greater than the cost of treatment or mitigation?
- Education is needed for all stakeholders.
- Can other industries (e.g., the produce industry) provide potential solutions?
- Collaboration by the industry could be used to develop a collection of best practices to reduce risks.

Charles Hurburgh

The afternoon discussion focused on bulk grain traceability. Charles Hurburgh (ISU agricultural engineer) led an initial review of current knowledge and efforts or projects related to bulk grain traceability. Currently, the FDA recognizes there are limits to the traceability of bulk grains. Traceability is not currently part of FSMA; however, it is 1 of 10 pending regulations. Hurburgh acknowledged the potential accuracy and the challenges involved.

Inherent to current bulk grain practices is blending of grain or flour to meet quality and functional performance specifications. Blending creates a significant food safety challenge because grain from one field can be spread over many batches of flour.

Small groups assembled to talk about concerns related to bulk grain traceability. Key observations included

1) There is a need for common terminology.
2) Bin flow models and grain flow models would enable better understanding of the cross-blending of grains.
3) Better tools are needed, such as integrated traceability software solutions: common software to allow flour or grain to be traced from point to point in the supply chain—a handoff of the history. Digital data handoffs can only work if there are well-defined, accepted terminology and protocols.
4) Breaks in the process are critical. Verification must be built in for bins that go empty. This necessitates a mechanism and time to allow clean out.
5) Are there existing best practices that can be employed? Can other industries or global regions provide insight (e.g., dairy industry or European bulk grain processors)?

Training on bulk grains and milling processed is needed for the FDA. Industry collaboration could create a model food safety plan for use in preventative control qualified individual training programs targeted specifically to grain and grain milling.

Opportunities for research and industry collaboration were identified. The next steps are for those present at this discussion and other interested parties to consider possible ways to catalyze development of traceability plans, as well as to identify prevention protocols and effective treatments that would increase food safety.

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Thank you to all our corporate members, who contribute their knowledge, expertise, and professional involvement to ensure the continued strength of the association and to promote excellence in cereal grain science worldwide. We appreciate their support and encourage you to contact them directly for detailed information on their products. Visit the AACCI Corporate Member web page for comprehensive company and contact information.

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News

Congratulations to the Incoming AACCI President-Elect and Director

AACCI members cast their ballots and will welcome incoming President-Elect Dave Braun and incoming Director Diane Gannon to the board. Dave and Diane will join the AACCI Board of Directors after the Cereals & Grains 18 meeting in London.

Dave's Views: As a current member of the AACCI Board of Directors, it has been exciting to see the changes that have been put into motion that will help us grow and prosper for years to come. The pace at which things change today is faster than ever and maintaining the position of the association as the front-runner in cereal grain science grows more challenging every year. AACCI has a great message and brand, and we need to continue to build on our current audience and develop new audiences, whether they are related to cereal sciences or new global regions. Reaching out to new partners is our mission—to provide and exchange knowledge and advance innovations across the broad disciplines of cereal grain science by facilitating research, education, collaboration, technical service, and advocacy efforts. "Create opportunities" is the first part of our mission statement—opportunities for people to get involved and to realize what an asset the AACCI organization and its members are. We are more than just a scientific society; we are in many cases family, friends, and colleagues bound by a common thread—a keen interest in grain science and industry. We are an organization that fosters relationships, collaborations, and friendships. We need to continue to provide opportunities for our members, old and new, to interact and form lasting relationships. I have a real passion for the continued success of AACCI. I have enjoyed my membership and the opportunity to serve over the past 22 years or so and will continue to do so.

Diane's Views: The food processing world keeps turning. The global market and the professionals working in cereal-based foods continue to become more diverse in their disciplines while remaining intertwined. AACCI must be ready to integrate into this changing world and migrate its programs, policies, and focus to support the individual contributors who collectively make the science behind our industry thrive. Although individuals may shine, it is through and with others that we can be successful in sustaining the world's food supply. AACCI programs, publications, and members have been my foundation for scientific, professional, and technical support. Although businesses and markets have changed, AACCI needs to continue to exist to promote new science and advocate proven and unproven scientific tools for the professional's toolbox, so scientists can achieve success and perpetuate the cereal and grain industry. My career successes have been achieved through my ability to understand and embrace objectives and be flexible, while providing strong direction for my team. I hope to continue to apply these skills for AACCI in my role on the Board of Directors. I look forward to being an advocate for AACCI's mission, vision, and programs.

AACCI Rheology & Texture of Cereal Foods Course Held

AACCI hosted the Rheology & Texture of Cereal Foods course, March 13–15, at Purdue University, West Lafayette, IN. The course incorporated a mix of classroom and hands-on lab sessions, during which experts in the field covered the fundamental principles of cereal food rheology and how it influences texture. Attendees learned about how ingredients and processing technologies affect food system structures and how they, in turn, affect texture. They also gained hands-on lab experience using fundamental and empirical rheological methods to evaluate cereal foods.

New Members

Alexander, S. L., Samryl Enterprises, D'Abadie, Trinidad and Tobago
Dann, O. E., scientist, R&D lead for hydrocolloids, starches and sweeteners, CSM Bakery Solutions, Tucker, GA, U.S.A.
Else, A. J., Corbion, Gorinchem, Netherlands
Geisslitz, S., Kranzberg, Germany
Holt, M., Matrix Nutrition, Chandler, AZ, U.S.A.
Knowlton, K., quality manager, Star of the West Milling Co., Quincy, MI, U.S.A.
Miller, K. B., principal scientist, General Mills – Global Scientific and Regulatory Affairs, Plymouth, MN, U.S.A.
Ogilvie, O., University of Auckland, Auckland, New Zealand
Rumney, J., USA Dry Pea and Lentil Council, Moscow, ID, U.S.A.
Schiller, C., St. Charles, MO, U.S.A.
Tosh, S. M., director, School of Nutrition Sciences, University of Ottawa, Ottawa, ON, Canada
Weil, W., visiting scholar, Kansas State University, Manhattan, KS, U.S.A.
Wilkins, M. R., professor and director, University of Nebraska, Lincoln, NE, U.S.A.

Obituaries

Robert (Bob) L. Gies

Robert (Bob) L. Gies of Eagan, MN, passed away February 20, 2018, at the age of 82. Bob was a long-time member of AACCI and the International Association of Operative Millers (IAOM). Bob was preceded in death by his brothers Bill and Jack and sister Donna Slankard. He is survived by his wife of 61 years Rosalie; daughter Donna (Rich Hamer) Gies; son John (Nancy) Gies; grandchildren Anna and Will Hamer; nieces, nephews, relatives, his children's godmother Joanne Reisberg, and many other dear friends.

Bienvenido (Ben) Juliano

Bienvenido (Ben) Juliano passed away February 21, 2018, at the age of 81 in his hometown of Los Baños, Laguna, Philippines. Born on August 15, 1936, Ben showed brilliance and academic excellence at a young age. He graduated early from the University of the Philippines Los Baños with a B.S. degree in agriculture (1955) and became the youngest (at the age of 22) Ph.D. graduate in organic chemistry at The Ohio State University (1959). He returned to the Philippines and joined the International Rice Research Institute (IRRI), where he pursued his life's work from 1961 until his "retirement" in 1993.

A long-time member of AACCI, Ben was known for his outstanding contributions to research on the chemistry and technology of rice and rice food products and his extensive research on rice starch and its constituents. He authored or coauthored more than 370 scientific papers, edited and contributed to several chapters in the AACCI monograph *Rice Chemistry and Technology*, 2nd edition (1985), and wrote *Rice in Human Nutrition* for FAO (1993) and *Rice Chemistry and Quality* for PhilRice (2003). He served as an M.S. and Ph.D. theses adviser and as a member of the *Journal of Cereal Science and Food Reviews International* Editorial Board.

In recognition of his contributions, he received many awards and citations, including the Jose P. Rizal Pro Patria Award for Rice Chemistry (1976), the Japanese Society of Starch Science Medal of Merit (1982), the AACCI Thomas Burr Osborne Medal (1988), the National Research Council of the Philippines National Researcher Award in Physical Sciences (1993), and the Association of Southeast Asian Nations Outstanding Scientist and Technologists Award (1998), among others. He was elected as a member of the National Academy of Science and Technology, Philippines in 1979 and honored as a National Scientist in 2000. In 1988 he was named an AACCI Fellow.

After retiring, Ben was invited to visit cereal laboratories in Vietnam, Myanmar, China, Bangladesh, Cuba, and Taiwan to give recommendations on quality breeding programs. He helped build the grain-quality research capability of PhilRice and continued to pursue his research as a senior consultant/expert. Ben was a former member of the AACCI Rice Division and a frequent speaker on rice chemistry and quality at AACCI meetings.

Important AACCI Dates

April 2018

12. AACCI-ICC Organized Symposium: Bringing Ancient Grains to the World's Dinner Tables (at Sorghum in the 21st Century), Cape Town, South Africa

12. Cereals & Grains 18 abstract submission deadline

18–20. 17th European Young Cereal Scientists and Technologists Workshop, Warsaw, Poland

May 2018

15. *Cereal Chemistry* Asian Products Focus Issue submission deadline

24. AACCI Rice Division and University of Arkansas Rice Processing Program: Rice Quality & Evaluation Short Course: An Outreach Effort to Rice Processors, Fayetteville, AR, U.S.A.

October 2018

21–23. Cereals & Grains 18 – AACCI Annual Meeting, London, U.K.

For more information visit
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2018 Themes

January-February—Analytical
Ad Close: January 8, 2018

March-April—Baked Products
Ad Close: March 13, 2018

May-June—Health & Nutrition
Ad Close: April 30, 2018

July-August—Processing/Pre-annual Meeting
Ad Close: June 6, 2018

September-October—Grains & Pulses
Ad Close: August 10, 2018

November-December—Product Development & Innovation
Ad Close: October 30, 2018

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