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Review

Improvers and functional ingredients in whole wheat bread: A review of their effects on dough properties and bread quality

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ABSTRACT

Background: Despite the associated health benefits of whole grains, consumption of whole grain products remains far below recommended levels. Whole wheat bread is often associated with many distinctive attributes such as low loaf volume, firm and gritty texture, dark and rough crust and crumb appearance, bitter flavor, and reduced shelf-life. There is a need to improve its quality and sensory characteristics so as to increase consumer appeal and, ultimately, increase the intake of whole wheat bread. The inclusion of various ingredients improves dough and bread properties.

Scope and approach: This review examines the effects of enzymes, emulsifiers, hydrocolloids, and oxidants on the properties of whole wheat bread and dough, with particular attention to effects on loaf volume and hardness. Wheat gluten and other plant materials are also discussed. Gaps in the research into whole wheat bread are identified, and future research needs are recommended.

Key findings and conclusions: Xylanase reduces the water absorption of whole wheat flour and increases loaf volume and crumb softness by hydrolyzing ararbinoxylans. α-amylase can be beneficial under certain conditions. Phytase may activate endogenous α-amylase. G4-amylase is promising but needs validation by further research on its effect on loaf volume, crumb hardness, and staling. Vital wheat gluten overcomes many of the challenges of whole wheat bread production and is found in the majority of commercial whole wheat breads. Emulsifiers DATEM and SSL can improve the volume, texture and staling profile of whole wheat bread. Several types of improvers are generally needed in combination to provide the greatest improvement to whole wheat dough and bread.

1. Introduction

Whole grain wheat flour has gained considerable attention as a breadmaking ingredient due to its nutritional and health benefits. Compared to refined wheat flour, whole wheat flour contains higher levels of vitamins, minerals, fibers (e.g., non-starch polysaccharides including arabinoxylans), antioxidants, and other phytochemicals such as carotenoids, flavonoids, and phenolic acids (Jonnalagadda et al., 2011; Slavin, 2004; Zhou, Su & Yu, 2004). Whole grain intake has been linked to health benefits such as decreased risk of chronic diseases including cardiovascular disease, diabetes, cancer, and obesity, and all-cause mortality (Jacobs, Meyer, Kushi, & Folsom, 1998; Jonnalagadda et al., 2011; Slavin, 2004). The 2015–2020 Dietary Guidelines for Americans recommend that at least half of all grain intake comes from whole grains (USDHHS/USDA, 2015). However, in the U.S., the average intake of whole grains is less than 1 oz. equivalent per day (USDHHS/USDA, 2015). Barriers to increasing whole grain consumption are often texture and sensory related, but also include higher cost of whole grain products, confusion in identifying whole grain foods, and lack of knowledge regarding the health benefits of whole grain consumption (Bakke and Vickers, 2007; Kantor, Variyam, Allshouse, Putnam, & Lin, 2001).

Whole wheat flour produces dough and bread with characteristic differences compared to refined wheat flour. Effects associated with whole wheat bread production and their causes have been reviewed (Doblado-Maldonado, Pike, Sweley, & Rose, 2012; Gan, Ellis, Vaughan, & Galliard, 1989; Heiniö et al., 2016) and include low loaf volume, increased crumb hardness, coarse texture, darker color, and distinctive flavor and aroma. These attributes may not be appealing to consumers accustomed to white bread, which is made from refined flour.

Reasons suggested for the effects of non-endosperm components on bread quality are fiber-gluten interactions (Noort, van Haaster, Hemery, Schols, & Hamer, 2010); dilution of gluten protein by the bran and non-endosperm protein; competition for water by the water-soluble and

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water-insoluble fiber constituents leading to insufficient hydration of gluten proteins and starch; physical effects of bran particles, fiber, and arabinoxylans on the gluten network; and higher levels of ferulic acid (Heiniö et al., 2016). The germ contributes reducing compounds such as glutathione which degrade breadmaking ability (Every, Morrison, Simmons, & Ross, 2006; Lai, Davis, & Hoseney, 1989). The germ also contains high levels of non-polar lipids, which have various effects on the dough and bread throughout the entire breadmaking process, and tend to destabilize gas cells and thus decrease loaf volume (Pareyt, Finnie, Putseys, & Delcour, 2011). The fiber, or non-starch polysaccharide fraction, of whole wheat is composed primarily of arabinoxylans, and also includes arabinogalactans, cellulose, β-glucans, glucomannans, and lignins (Hille & Schooneveld-Bergmans, 2004). These compounds, broadly referred to as hemicellulose, are found in plant cell walls. Whole wheat flour contains approximately 4–7% of the hemicellulose fraction, whereas white flour contains roughly 3% (Hille & Schooneveld-Bergmans, 2004). Arabinoxylans are classified as either water-extractable or water-unextractable, with the former producing beneficial effects in dough and bread and the latter generally considered detrimental to quality (Goesaert et al., 2005). The interaction of water-unextractable arabinoxylans with wheat gluten changes the rheological properties and network structure of dough (Ma, Wang, Xu, & Lu, 2009).

The physical and chemical effects of the bran and germ necessitate some degree of formula and process modifications as compared to white bread. Water absorption must be increased. Vital wheat gluten, dough conditioners such as oxidizing agents, emulsifiers, and enzymes, as well as shortening and mold inhibitors are often added or their concentration is increased compared to white bread formulations (Dubois & Vetter, 1987). Phenolic compounds in bran are strongly flavored, so more sucrose is needed to attain a level of perceived sweetness equivalent to that of white bread. If employing the sponge for the sponge and dough process, more water must be used in the sponge (Dubois & Vetter, 1987). Whole wheat dough is more susceptible to overmixing due to the physical action of the bran on the gluten. To reduce the likelihood of overmixing, adjustments are made including lowered sponge/dough ratio, longer mixing times at lower speed, shortened total mixing time, and lower dough temperature. Over fermentation is also a greater risk for whole wheat dough compared to white dough. A lower sponge ratio and set temperature and decreased fermentation time help to minimize this problem. Whole wheat dough is stiff. This may cause erratic scaling. Proofing at lower relative humidity for proofing is often used to prevent excess moisture from condensing on and absorbing into the dough, which would further weaken its structure and contribute to sidewall collapse. Longer baking times and lower baking temperatures are often needed compared with white bread. The higher water activity of whole wheat breads can lead to shorter shelf life and necessitate the addition of mold inhibitors.

Wheat flour mills as well as bread manufacturers may add a variety of amounts of non-endosperm components to refined wheat flours. For example, some products consist of various amounts of bran combined with endosperm but without the germ, thus creating "germ-free and bran-rich flours." However, in order for the product to be labelled whole grain, it must include all parts of the caryopsis – the endosperm, germ, and bran – in the same proportions as are present in the intact kernel (AACC International, 1999). The effects of wheat bran presence in bread have been recently reviewed and summarized (Hemdane, Jacobs, Dornez, Verspreet, Delcour, & Courtin, 2016), and many publications exist on the use of improvers in reconstituted dough systems, where ground bran is added back to refined wheat flour. In contrast, this review focuses mainly on improvers and other functional ingredients in whole wheat dough and bread, rather than the deleterious effects of endogenous wheat components. Furthermore, it covers studies that used whole wheat flour rather than refined flour to which bran was added. Within the whole wheat bread system, there is a need to improve the quality and sensory aspects to increase consumer appeal and therefore increase the intake of whole grain bread. For breads that are inherently firmer, such as whole wheat bread, softer breads achieve higher scores for overall acceptability (Armero & Collar, 1996a). With this in mind, this review gives particular attention to crumb hardness and loaf volume, which is a strong contributor to hardness. In this review, a very large space has been given to enzymes, especially amylase, phytase, and xylanase. Other sections introduce specific emulsifiers, hydrocolloids, oxidants, and other functional ingredients such as vital wheat gluten and miscellaneous flours.

2. Enzymes

The use of enzymes in commercial applications has increased in recent years as consumers demand bakery products with more natural-sounding ingredients. Various types of enzymes can be used as alternatives to chemical improving agents, such as some hydrocolloids and emulsifiers, and those types used in bakery applications can all be declared by the single word "enzymes," a term which many consumers perceive as natural and clean label compared to additives labelled by their chemical name. Many enzymes occur naturally in flour, but several enzymes are added, specifically for their beneficial effects on dough and bread characteristics. Outcomes include increased dough handling and hydration, improved volume and/or crumb texture, reduced rate of staling, or improved nutritional qualities. Enzyme activity is affected by several factors including temperature, pH, water activity, and enzyme concentration. Commonly used exogenous enzymes include xylanase, phytase, and amylases. Table 1 presents the major findings that have been published on the uses of enzymes in whole wheat dough and bread.

2.1. α-amylase

α-Amylase is an endo-hydrolysate that catalyzes the hydrolysis of α-1,4-glycosidic bonds of starch polymers, producing low molecular weight polysaccharides and dextrins. β-Amylase decreases the molecular size/weight of these polysaccharides by cleaving the disaccharide maltose from the non-reducing end. Unlike higher glucose polysaccharides, maltose is fermentable by yeast. The resulting increase in fermentable sugars has a positive effect on yeast fermentative activity, which along with gas retention is a fundamental element of bread production. An increase in fermentative gas production, combined with the ability of the dough to retain that gas, leads to an increase in loaf volume. In 60:40 blends of refined flour and whole wheat flour, α-amylase improved the gas retention capacity of the dough, increased specific loaf volume, and decreased crumb hardness and staling rate (Matsushita et al., 2017). Remarkably, the hardness of the whole wheat-supplemented bread prepared with α-amylase was lower than that of the refined wheat control after 3 d of storage, demonstrating this enzyme's promise for improving the shelf life of whole wheat bread, which often has a shorter shelf life than refined wheat bread. The decrease in hardness and staling achieved by α-amylase is due to both the increase in low molecular weight saccharides and the increase in specific volume. The low molecular weight products of starch hydrolysis are not available for retrogradation, and these smaller saccharides also delay the retrogradation of gelatinized starch (Matsushita et al., 2017). Furthermore, those saccharides interfere with starch-protein interactions in the aging bread, which decreases firming. α-amylase retains its activity early in baking and is capable of degrading gelatinized starch, and this partially decomposed starch has a low rate of retrogradation.

α-Amylase increased loaf volume and decrease the crumb hardness of both white and whole wheat bread (Armero & Collar, 1996a). Hardness is measured by a compression test, and the two factors that influence the compressibility are the amount of surface of resistant material and the resistance of that material (Armero & Collar, 1996a). The decreased firmness was due to the increase in loaf volume, which decreases the surface of resistant material alone or in combination with

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