FODMAP Reduction in Yeast-Leavened Whole Wheat Bread

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Fermentable oligo-, di-, and monosaccharides and polyols (FODMAPs) are small, osmotically active molecules that are poorly absorbed in the small intestine and rapidly fermented by bacteria in the large intestine (2). Fructose, lactose, fructo-oligosaccharides (such as fructan present in wheat), galacto-oligosaccharides, and polyols all belong to the FODMAP family (2,16). There is evidence that the intake of FODMAPs induces abdominal symptoms such as pain, bloating, nausea, and disturbed bowel habits in people suffering from irritable bowel syndrome (IBS) (3,12,13,22). IBS is a chronic functional gastrointestinal disorder, with a prevalence of up to 12% in the European population and between 7 and 15% in the global population (4,7,23). In several studies, a diet low in FODMAPs alleviated symptoms in ~70% of IBS patients (5,9,11,12,17,18, 23). Based on research findings, patients suffering from IBS are advised to follow a diet that is low in FODMAPs, which entails avoiding consumption of wheat and wheat-based products such as bread. Indeed, wheat-based products contain relatively high amounts of fructan and are a major source of FODMAPs in Western diets (6,8,26). Avoiding consumption of wheat-based products can have a negative effect on health and well-being, however, because these products are also a major source of energy, as well as dietary fiber, vitamins, and minerals.

The wheat grain fructan content ranges from 0.7 to 2.9%, and wheat bran contains higher levels than does the corresponding flour (6). During fermentation of bread dough, fructan is partially hydrolyzed to glucose and fructose by invertase, which is secreted by *Saccharomyces cerevisiae* baker's yeast and retained in the yeast cell wall (10). Despite degradation of fructan during breadmaking, ranging from 50 to 80%, fructan levels in wheat (and rye) breads are nearly always higher than the cutoff value (0.2 g/serving) that is considered to pose a risk for inducing symptoms in IBS patients (19,25,27,28).

Because wheat-based foods are nutritious dietary staples and avoiding their consumption may result in nutritional deficiencies, adaptations of the breadmaking process that enable complete degradation of fructan are desirable. Processes that incorporate whole wheat (wholemeal) to create breads that are poor in FODMAPs but rich in dietary fiber are preferable. Different strategies to reduce fructan, and hence FODMAP, levels in whole wheat products are summarized below. These strategies could lead to the development of low-FODMAP breads and provide IBS patients with the opportunity to consume bread as part of their diets and gain the nutritional benefits it offers.

Yeast-Based Technologies

In contrast to *S. cerevisiae* strains, *Kluyveromyces marxianus* yeast strains can degrade wheat grain fructans by more than 95% after a 2 hr fermentation period (Fig. 1) (20). The mechanism behind this very fast and efficient degradation is the secretion of inulinase. Similar to invertase, inulinase degrades fructo-oligosaccharides, but the enzymes differ in their specificity toward high molecular weight inulin-type fructan. The S/I ratio (relative activities toward sucrose and inulin) is higher for invertase than for inulinase due to the low specificity of invertase toward fructose polymers with a high degree of polymerization (DP), such as inulin (14). Additionally, inulinase is produced by *K. marxianus* in both a cell wall-associated form and a secreted form, whereas invertase produced by *S. cerevisiae* is always retained in the cell wall and is not secreted into the bread dough (14,15). The retention of invertase in the cell wall could limit its accessibility to the substrate (fructan). The combination of the higher specificity of inulinase toward fructan with a higher DP and the secretion of inulinase into the dough could explain why *K. marxianus* is able to more efficiently degrade wheat grain fructans than is *S. cerevisiae.*

Because *K. marxianus* strains are not able to consume maltose (1,24), which is the major fermentable sugar source in lean dough, alternative sugars or sugar-releasing enzymes should be included in the bread formulation to ensure sufficient production of CO_2 and optimal loaf volume (21). In a study by Struyf et al. (21) both sucrose and amyloglucosidase addition resulted in breads that were optimally leavened by *K. marxianus* and had

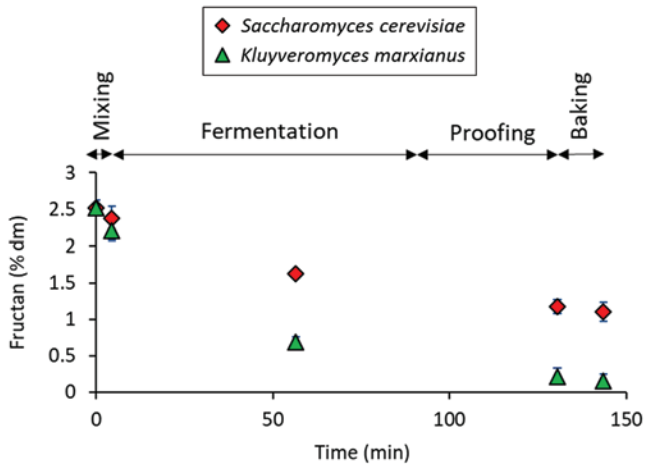

Fig. 1. Evolution of fructan levels in whole wheat (wholemeal) dough during breadmaking with two different yeasts. The diamonds represent fructan levels in dough fermented with *Saccharomyces cerevisiae.* The triangles represent fructan levels in dough fermented with *Kluyveromyces marxianus*. Fructan level is represented as a percentage of weight based on dry matter. The first time point ($t = 0$) shows the fructan level in wholemeal. (Adapted from Struyf et al. [21])

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a low FODMAP content resulting from degradation of up to 95% of the fructan. The use of mixed cultures of *S. cerevisiae* and *K. marxianus* is also a proven strategy for ensuring maximum CO_2 production rates and enhanced degradation of fructan without the need for addition of sugars or enzymes (20).

Enzyme-Based Technologies

Enzymes offer another option for reducing FODMAPs in bread. Instead of using alternative yeast species, an inulinase solution can be added to enhance degradation of wheat grain fructans during fermentation. In a study by Struyf et al. (20) the addition of an enzyme mixture containing both exo- and endo-inulinase produced by *Aspergillus niger* resulted in rapid degradation of fructan, with >95% degradation after 2 hr of fermentation. The resulting glucose and fructose are consumed by the baker's yeast (*S. cerevisiae*), resulting in optimal leavening. The rate and extent of fructan degradation depends on the enzyme mixture dosage. Relatively high dosages are necessary to reach a degradation efficiency higher than 95% (Fig. 2).

Changing Process Parameters

Adaptation of specific steps in the breadmaking process can also be used to increase fructan degradation. For example, longer fermentation times can be utilized to allow the invertase secreted by *S. cerevisiae* more time to degrade the fructan. Prolonging dough proofing times (>4 hr) allows a degradation of up to 90% of the fructan, diminishing FODMAP levels in the bread (Fig. 3) (28).

Similar to the results of a longer proofing time, increasing yeast dosage results in lower fructan levels, which can be explained by the higher invertase activity correlated with a higher yeast dosage (Fig. 3). Excessive amounts of yeast are not desirable in breadmaking processes, however, because high amounts of yeast are associated with excessive CO_2 production, leading to dough collapse and negative changes in flavor characteristics.

Selection of a wheat variety with low fructan levels offers another option for minimizing fructan levels in the end product. Studies have revealed that fructan levels vary substantially among different wheat varieties. Huynh et al. (8) studied different wheat varieties and found significant genotypic variations, with fructan contents ranging from 0.7 to 2.9% of grain dry weight. There was no evidence of strong interactions between genotype and environment: the fructan contents of field-grown grains were positively correlated with those of glasshouse-grown samples of the same cultivar.

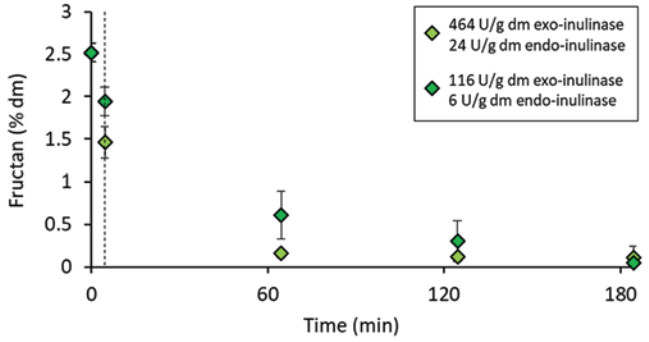

Fig. 2. Fructan levels in whole wheat (wholemeal) bread dough samples with different endo- and exo-inulinase mixture dosages as a function of fermentation time. Fructan level is represented as a percentage of weight based on dry matter. The first time point (t = 0) shows the fructan level in wholemeal. The vertical dashed line indicates the time point after mixing (t = 4.5 min). (Based on unpublished results from the host laboratory)

Summary

Patients suffering from IBS should follow a very strict diet that is low in FODMAPs. To accomplish this they must avoid consumption of most cereal products. Removal of cereal products from the diet has negative health effects, however, because cereal grains are a major source of energy, dietary fiber, vitamins, and minerals in the diet. To enable IBS patients to consume nutritious whole wheat breads without negative health effects, the FODMAP levels in these breads must be reduced. Different strategies can be applied for this purpose, including the use of an alternative yeast species for fermentation (*K. marxianus*) or the addition of enzymes such as inulinase. When addition of alternative ingredients is not desirable, adaptations to the breadmaking process, such as a prolonged proofing time, may be utilized to reduce FODMAP levels.

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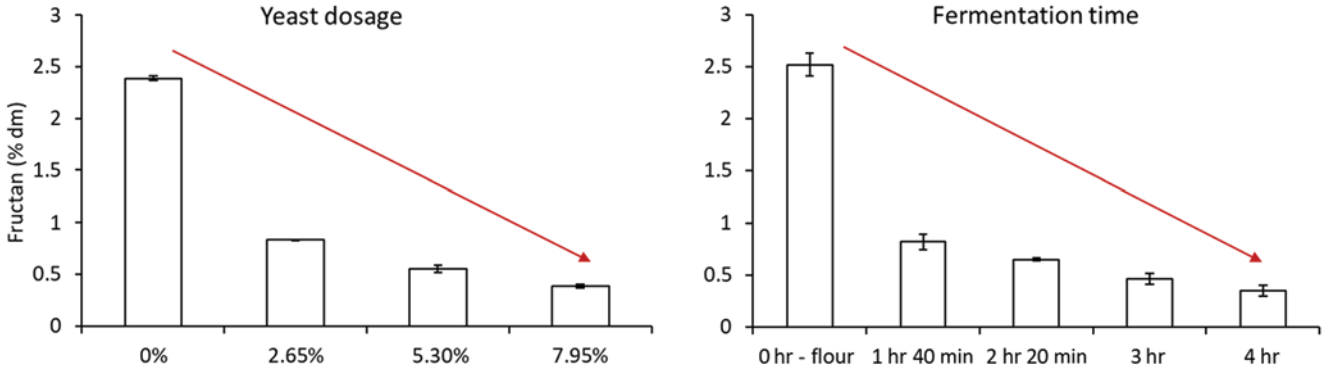

Fig. 3. Fructan levels in whole wheat (wholemeal) bread prepared with different dosages of *Saccharomyces cerevisiae* (left) and with different fermentation times (right). Fructan level is represented as a percentage of weight based on dry matter. (Based on unpublished results from the host laboratory)

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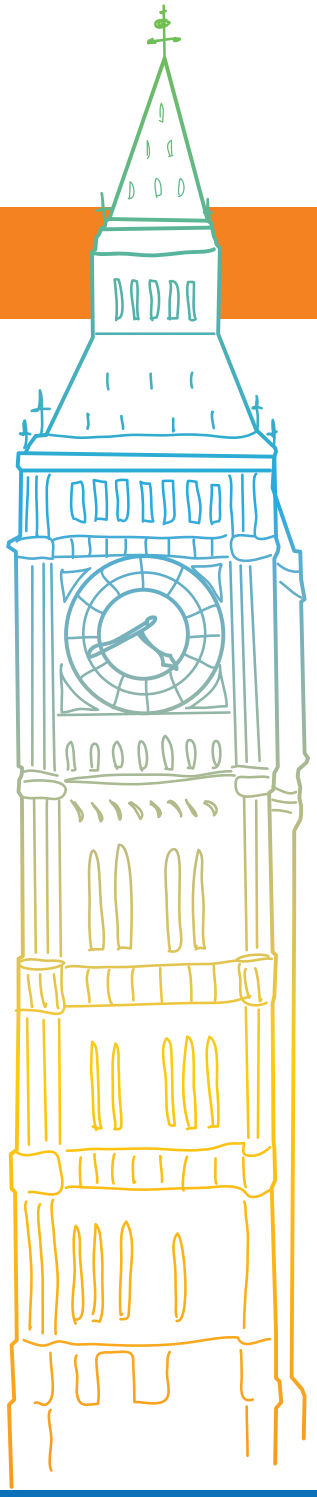

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