Gluten-free baking: what is happening inside the bread?

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Introduction

In the Western world, leavened bread has been a staple food for many centuries, and today, Western style bread is consumed all over the world. Once a person is diagnosed with celiac disease, wheat and rye are forbidden, and this eliminates all these delicious conventional breads from the diet. Luckily, dietitians, scientists, but mainly celiacs and their relatives and friends with a talent in cooking and baking have developed abundant gluten-free (gf) recipes, including bread recipes. The authors of the present article have been working on the scientific end of gluten-free breadmaking for many years. We do not want to teach gluten-free baking to people, who already know how to cook and bake. However, we would like to contribute to building bridges between science and real life. If, after reading this article, you understand only a few aspects of gluten-free breadmaking better than you did before, we are already happy. If we could help you to further improve your recipes or make better choices when buying commercial mixtures, we would be really pleased.

The gluten-free bread: it starts with choices

When you bought – or baked – normal bread, you could choose among a large selection: fluffy white pan bread or less fluffy, but healthier wholemeal bread, soft crust or crispy crust, sourdough bread or plain yeast leavened bread, multigrain bread, bagels, muffins, biscuits,… Maybe – like the authors – you knew that wholemeal is healthy, but still liked white toast? In gluten-free breadmaking, you are confronted with a similar amount of choices:

1. Do you want to add egg to your gf bread? Or, in the contrary, do you think it makes the bread taste like cake, increases cholesterol, or are you even allergic to egg protein?
2. Do you want fluffy, well-aerated gf bread, or are you content with denser (maybe very dense?) bread containing more gf wholemeal flours, because you want to live healthy? Do you even prefer the taste of ingredients like brown rice, sorghum, buckwheat, amaranth or bean flours over the plain taste of starch and white rice?
3. What is your attitude towards additives like xanthan gum or HPMC (hydroxypropyl methylcellulose)?
4. Are there other ingredients, which you cannot tolerate, e.g. milk or soy?
5. Do you want to try new things or are you content, once you have found something that tastes acceptable for you?

Eggs and their functions in baking

When we whip egg white, egg yolk or whole eggs, they foam. Foam is air entrapped between thin liquid films composed of water and protein. This entrapment of air (gas holding) by egg is a great benefit in gf breads (gluten is a main factor in providing gas holding in wheat bread). When we cook or fry eggs, they become hard (technically called ‘heat-coagulation’). In wheat bread, gluten coagulates and helps in the setting after baking. In gf breads, eggs do a similar thing, helping the crumb to become firm and keep its leavened, sponge-like structure. Eggs also contribute color and aroma, which may or may not be desirable in bread – people may like yellowish bread with a cake-like flavor or prefer the color and flavor of pure grain. You may notice that many commercial gf

bread mixes require the addition of egg. The same is true for many recipes in gf cookery books. If you develop your own recipes, here are some hints:
If you are concerned about cholesterol, egg white alone can be used, also in the form of commercial dried egg white.
If you want to avoid egg altogether but still want to have similar benefits, egg replacer may sound like a good idea. However, one popular commercial egg replacer contains methylcellulose and carboxymethylcellulose. From a food technologist's point of view, these are very beneficial, safe ingredients. If, however, you object to anything artificial (like HPMC), you should be aware that you might get these ingredients unknowingly with the egg replacer. Another commercial egg replacer – obviously designed for vegetarians, not celiacs – contains soy flour and wheat gluten. As usual, it is thus important to carefully read the list of ingredients. Finally, eggs are a common allergen. If you are allergic, you will most likely already know about it and avoid egg. Companies may also tend to make gluten-free bread acceptable for not only celiacs, but also people with various food allergies to have a dietary product suitable for an even larger group of people. Thus, egg and also soy and milk (further common food allergens) may be excluded from the ingredients.

How to get fluffy gf bread

In terms of fluffiness, white rice flour or isolated starches (e.g. corn starch) in combination with hydrocolloids (preferably HPMC) work best. Table I lists a recipe from the literature (Nishita et al., 1976)[1]. Please note that bakers like to base everything on flour, so flour is always 100%, and the other ingredients are added on top, i.e. as percent of the flour weight ('baker's percent').

Table I: White rice bread (Nishita et al., 1976), slightly modified

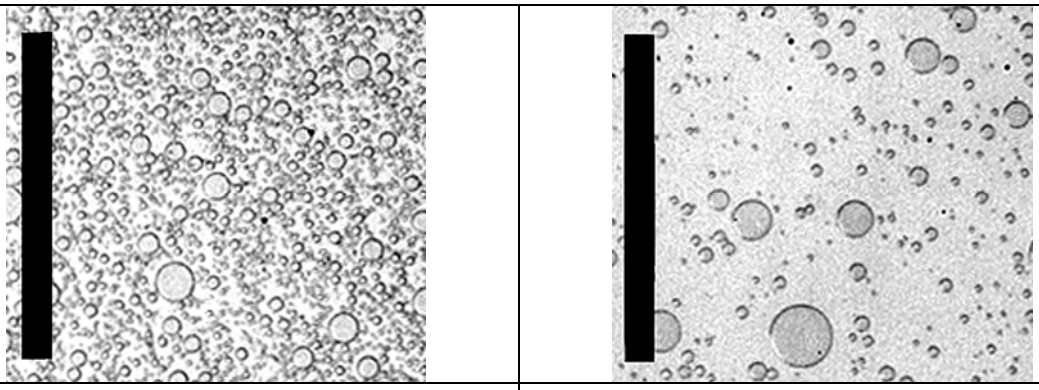
Ingredient	Amount (% by weight)
White rice flour	100
Compressed yeast	3
Table salt	2
Sugar	7-8
Vegetable oil	6
HPMC[2]	3
Water	75

We could produce a bread of similar fluffiness to that of Nishita et al. (1976) from corn starch (100%), dry yeast (2%), table salt (2%), sugar (4%), HPMC (2%) and water (88%) (Fig. 1). Both, the rice bread and the corn starch bread were prepared with a simple procedure involving mixing, proofing in pans and baking. Both breads had a regular crumb and a so-called specific volume over 5 ml/g. The specific volume characterizes fluffiness and values over 5 ml/g are comparable to those of white wheat pan breads.

[1] Nishita, K.D., Roberts, R.L., Bean, M.M., Kennedy, B.M. (1976) Development of a yeast-leavened rice-bread formula. Cereal Chemistry 53: 626-635.
[2] Methocel K4M, food grade, Dow Chemical Company, Midland, MI, USA (see also http://www.dow.com/methocel/food/index.htm)

Fig. 1: Bread from corn starch and 2% HPMC

Now, why is HPMC so beneficial? Basically, HPMC stabilizes foams, similar to egg white and thus improves gas holding in gf bread. At the same time, it is a thickener that prevents particles (e.g. rice flour particles or starch granules) from settling. Xanthan gum is a thickener, but it does not really stabilize foam. Thus, it has some beneficial effects for gf bread, but usually HPMC performs better. Fig. 2 shows that upon mixing with water at high speed, HPMC forms a foam made up from many small bubbles, while xanthan gum only traps some isolated bubbles due to the thickness of the solution.



2% HPMC in water (mixed at high speed)	2% xanthan gum in water (mixed at high speed)

Fig. 2: Superior foam stabilization of HPMC (scale bar 5 mm)

Similar to white breads made from wheat, white rice breads and especially starch breads lack nutrients and especially fiber. In particular for starch breads, there is also the problem, that they are very easily digestible – too easily. The result is a quick and sudden increase in blood glucose ('high glycemic index'), which is a stress for the body and thus unhealthy.

How to get healthy gf bread

Healthy gluten-free bread requires the use of flour (preferably wholemeal) from gf grains like rice (brown rice flour corresponds to wholemeal flour) or sorghum, pseudocereals like buckwheat or amaranth, or legumes like beans or chick peas. These ingredients contribute fiber, protein, vitamins and minerals. The drawback is that the resulting breads are less fluffy. As a compromise, often isolated starches and healthy ingredients are mixed. Basically, the higher the starch content of a bread the fluffier and the less healthy it is. You can find various commercial mixes for gluten free bread that contain such mixtures. If you read the list of ingredients, remember that it is sorted from large to small percentage. ('Ingredients: Potato starch, corn starch, sorghum flour' would indicate that the mix contains more potato and corn starch than sorghum flour). Cookery books often suggest the preparation of blends (like bean flour, sorghum flour and corn starch) and the subsequent recipes use these blends together with other ingredients. Again, take a look how much flour versus isolated starch is mixed together. It will mostly be a compromise between fluffy and healthy. (Note: Tapioca flour is almost pure starch). We have worked mainly with sorghum, so here is an example of a sorghum bread (Table II, Fig. 3):

Table II: Sorghum bread (Schober et al., 2005)[3]

Ingredient	Amount (% by weight)
Sorghum flour	70
Corn starch	30
Dry yeast	2
Table salt	1.8
Sugar	1
Water	105

(Note that sorghum flour and corn starch add up to 100%; the recipe is again based on 100% flour i.e. sorghum flour plus corn starch)

The procedure was simple as described above: mixing, proofing in a bread pan, and baking. Here is a slice of the resulting bread (Fig. 3):

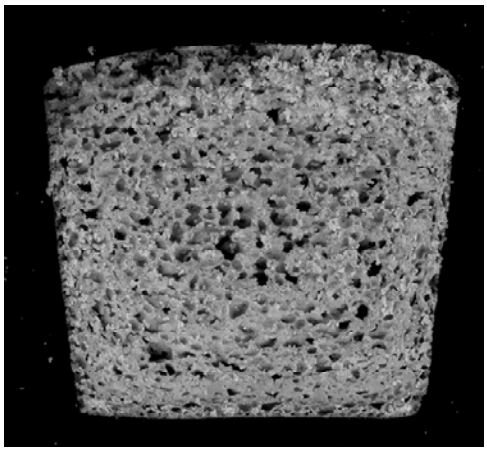


Fig. 3: Sorghum bread (Schober et al., 2005, formulated as in Table II)

[3] Schober, T.J., Messerschmidt, M., Bean, S.R., Park, S.H., Arendt, E.K. (2005) Gluten-free bread from sorghum: quality differences among hybrids. Cereal Chemistry 82: 394-404.

Note that there is a price to pay for the high percentage of flour, low content in isolated starch and the absence of additives: the crumb is irregular and the bread is dense (specific volume 1.8 ml/g). Increasing the starch content and reducing the sorghum content would most likely make it fluffier, but this would at the same time reduce the amounts in fiber, protein, minerals, and vitamins.

Additives (xanthan gum and HPMC)

When recently attending a meeting of celiacs, we noticed a mood of disapproval when mentioning HPMC. It is not our intention to convince you that HPMC is good (nor do we wish to take the side of those who think that it is bad). We want to simply describe, how xanthan gum and HPMC are manufactured and what benefits they may have. You can then decide for yourself whether you want to use them. It is also important to point out that commercial bread mixes and many recipes in gluten-free cookery books rely on xanthan gum, while some commercial gluten-free breads sold in the U.S. contain methylcellulose, a very similar substance to HPMC.

Xanthan gum is produced by a bacterium (*Xanthomonas campestris*). These bacteria are grown in a medium containing nutrients. After they have grown and produced the gum, they are killed by heating, removed by filtering, and finally the gum is isolated[4]. Thus, the finished gum does not contain living or dead bacteria and is a pure substance.

HPMC (hydroxypropyl methylcellulose) and MC (methylcellulose) are prepared by chemically modifying cellulose (as occurring in cotton wool or wood). While the chemicals used for this modification are aggressive, they do not remain in the product, as the HPMC and MC are isolated by filtration and washed with hot water. MC and HPMC are approved by the FDA[5, 6, 7].

Technologically, HPMC is a better foam stabilizer than xanthan gum as shown above. Thus, breads prepared with HPMC tend to have a more regular crumb and larger volume than those with xanthan gum or without any additive (Figs 4 and 5).

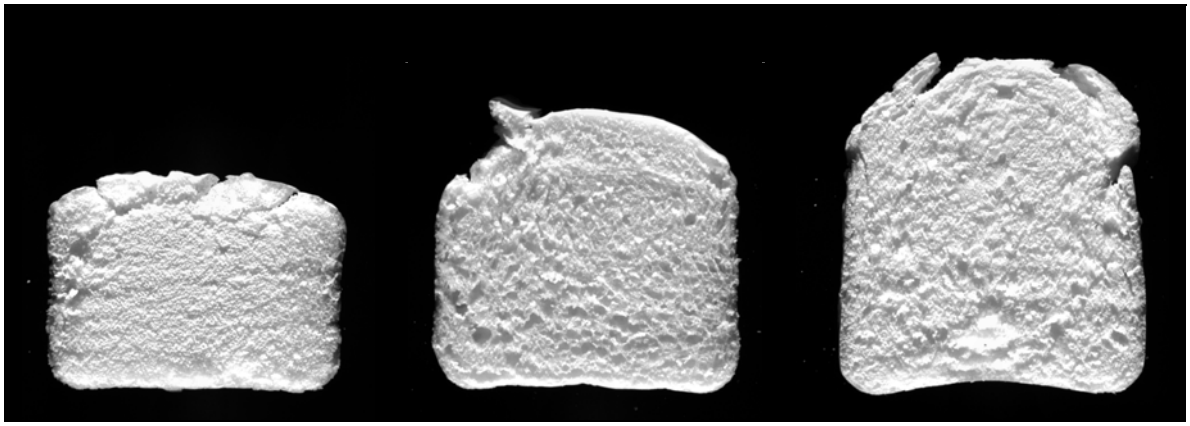


Fig 4: Starch breads (from left to right: without additives, with 2% xanthan gum, with 2% HPMC)

[4] Hoefler, A.C. (2004) Hydrocolloids. AACC International, St. Paul, MN.
[5] http://www.cfsan.fda.gov/~lrd/fcf182.html
[6] http://www.cfsan.fda.gov/~rdb/opa-g213.html
[7] Burdock G.A. (2007) Safety assessment of hydroxypropyl methylcellulose as a food ingredient. Food and Chemical Toxicology 45: 2341-2351.

A formulation based on 70% sorghum flour, 30% potato starch, and 2% HPMC, involving sourdough fermentation, resulted in a clearly improved bread relative to the bread shown in Fig. 3. The sourdough fermentation is not all that easy to perform, and we want to show this bread just as an example for how HPMC and some technological steps may improve quality (Fig. 5):

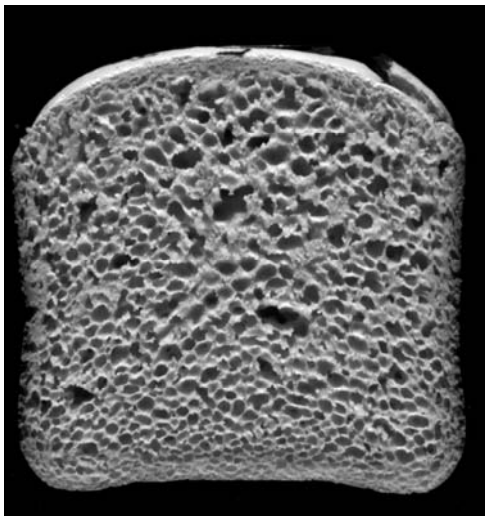


Fig. 5: Sorghum bread (70% sorghum, 30% potato starch) with 2% HPMC applying sourdough fermentation (Schober et al., 2007)[8]; specific volume 2.7 ml/g

If you decide to test any of these hydrocolloids in gluten-free formulations, it may be important to know that xanthan gum can be easily obtained commercially. In contrast, HPMC is not so easy to come by. You may try to contact the company for a sample (see footnote 2 above). Another option is to use egg replacer. As stated above, commercial egg replacer may contain methylcellulose, which is probably the closest similar product easily accessible.

Milk and soy

We have already mentioned soy and milk as potential allergens above. With milk, another problem is associated. Simplified, milk sugar (lactose) cannot be broken down when the intestine is severely damaged by untreated celiac disease. Lactose remains intact, is not absorbed and causes bloating and/or diarrhea. Once you are on a gluten-free diet and your intestine is healed, you usually can absorb and thus tolerate lactose again (Murray, 1996)[9]. Freshly diagnosed celiac patients might therefore prefer gf bread without milk (including e.g. skim milk powder), while later on, milk is frequently a perfectly acceptable ingredient.

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[8] Schober, T.J., Bean, S.R., Boyle, D.L. (2007) Gluten-free sorghum bread improved by sourdough fermentation: biochemical, rheological, and microstructural background. Journal of Agricultural and Food Chemistry 55: 5137-5146.

[9] Murray, J. (1996) The widening spectrum of celiac disease (summarized by Lyles, J.) <http://www.enabling.org/ia/celiac/spectrum.html> (Accessed Mar 16, 09)

From a technological point of view, although the benefits of milk for gf bread are sometimes pointed out, these tend to be more in the area of flavor and improved crust browning. Milk does not have the same improving effects like eggs on bread structure[10].

New products

Scientists sometimes work on new products which may appear crazy to you at the moment. Mostly, it will be a long time until the most innovative products appear on the market – or they might never make it beyond the prototype. But there may also be a great potential for tremendously improved products.

We recently took up an older idea – that certain corn proteins (zeins) can have similar technological properties as wheat gluten, provided that they are mixed somewhat above room temperature (Lawton, 1992)[11]. Corn proteins are usually regarded as safe for celiacs. Adding HPMC and corn starch besides normal ingredients (water, yeast, salt, sugar) resulted in a dough with almost the same properties as wheat dough. Our main goal was to understand the underlying principles, but a nice secondary result was that we found out that this dough can be made into soft pretzels with the same technology as wheat dough. It can also be shaped into rolls and yields very nice bread with regular crumb structure and round top (Fig. 6). Probably the most revolutionary idea was recently applied for patent (Engleson et al., 2008)[12]: chewing gum base was suggested for its gas retaining properties in combination with e.g. zein for setting the bread. While this may (or may not?) sound quite strange to you, there are indeed also natural, plant derived chewing gum bases available. The future will show…

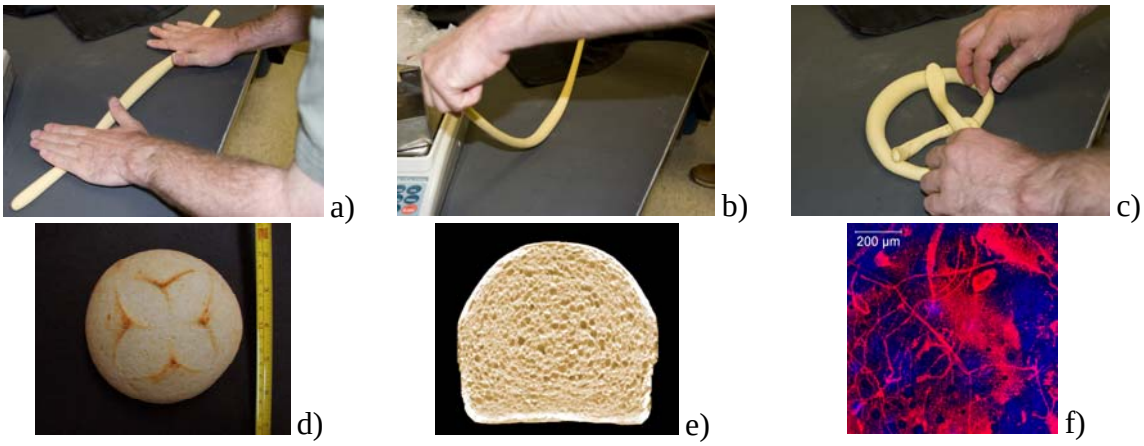

Fig. 6: Pretzel-making (a-c), a roll (d) and bread (e) from zein dough. Gluten-like structures are visible in zein dough when applying microscopic techniques (f). Zeins are corn proteins, non-toxic for celiacs.

[10] Similar to egg and wheat gluten, milk proteins can coagulate. The larger part of them coagulates under acidic conditions or when treated with rennet. The product – cheese – is obviously not so easily transformed into something bread-like.

[11] Lawton, J.W. (1992) Viscoelasticity of zein-starch doughs. Cereal Chemistry 69: 351-355.

[12] Engleson, J.A., Lendon, C.A., Atwell, W.A. (2008) System for gluten replacement in food products. United States Patent Application 20080038434

Troubleshooting guide for gf breadmaking

While developing various formulations and doing our experiments, we came across a lot of problems with gluten-free breadmaking, and for many, there are simple solutions. While we cannot address all possible problems, here are some of the more common ones together with solutions:

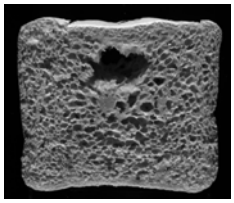

Fig. 7

1. Bread has a hole inside the crumb, and the lower part appears collapsed (Fig. 7)
Easiest solution: use a smaller bread pan. The gluten-free dough is heavy and lacks the stability of wheat dough. The larger the pan the higher the weight that pulls on the upper parts of the crumb.
This problem may also easily occur when using bread machines. Especially in machines with a tall bread pan, there is a lot of weight pulling downwards. Consider to fill the pan less high, or try to get a bread machine with a flatter pan. Alternative solutions: reduce the amount of gf flours and increase the amount of isolated starch to make the dough lighter. Try to reduce the water content.

2. The gf dough is runny and cannot be shaped.
Gf doughs tend to be runnier than wheat doughs. Simply pour them in a bread pan.

3. The bread is heavy and dense.
Increase isolated starch and reduce the amount of gf flours (see above for discussion of nutritional value). Try different water levels (generally, gf bread requires more water than wheat bread. A 1:1 ratio of water to flour, or even more water, is pretty typical. Remember that some ingredients (e.g. eggs) contain a lot of water.

4. A recipe from a cookery book, from the internet or passed on to me by a friend does not work.
There are many possible reasons. A more likely one is the gf flour. Flours from different manufacturers may differ considerably in particle size, starch and protein content, starch properties etc. Both flours may be labeled in the same way (e.g. brown rice flour), but they may be completely different. You may need to adapt the amount of water to your specific flour. Or you may simply need to change the brand of flour. If the recipe works for a friend but not for you, compare your ingredients. Are the flours similar in appearance? Get some flour from your friend and try it at home.
Another possible reason are additives. If the recipe requires for xanthan gum, do not leave it away. Two teaspoons of xanthan gum may make the difference between success and failure. Do not arbitrarily substitute one gum for another (e.g. guar gum for xanthan gum, or xanthan gum for HPMC). Any gum (xanthan gum, guar gum, HPMC) needs to be mixed very well with the other dry ingredients. Otherwise, it will form lumps when adding the water.

5. A recipe that has previously worked for me does not work any longer.
Again, there are many possible reasons, similar to point 4. You might have changed the brand of flour. However, even if it is the same brand, there may be batch to batch

differences. Maybe the manufacturer ran out of his stored grain and bought a new lot from a different place. Try to look at your dough and modify the water content.
If something in your kitchen has changed (new bread machine, oven, mixer, or simply different temperature due to the change in seasons) you might have to vary settings of the equipment, or proof time.

We wish you good success with your baking, and we are happy for comments.