# BREAD SCIENCE

## The Chemistry and Craft of Making Bread

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Two Blue Books ✷ Carrboro, North Carolina

# Contents

# Note to the reader on the organization of this book

I have set up *Bread Science* to be as much like a reference book as possible, enabling readers to open to a section of interest without needing to read the whole book. Chapters three through seven, which describe the process of bread-making, go in chronological order, to aid beginners. *Bread Science* focuses on learning about the process of bread-making instead of individual recipes. In that sense it is not a traditional cookbook—it contains only basic recipes intended to illustrate the concepts discussed.

I dedicated a separate chapter to bread science so as not to confuse readers trying to focus on the practical aspects of bread-making in later chapters. Thus, chapter two contains a more complete description of the different aspects of science occurring in dough. This science is referred to in relevant places throughout the book, but with less detail. I have included all scientific terms in the glossary.

In chapter two, references are given to research papers. Wherever possible, I have referenced the source documenting the original research, not just a paper that refers to it. This was not always possible: some papers were unavailable or not written in English. The bibliography lists the major papers on each aspect of bread science and is a good place to begin if you would like to read more.

Some readers may find chapter two daunting or a bit overwhelming. If you are eager to get to bread-making, skip chapter two for now and dive right in to the practical chapters. You can return to the science later, perhaps while you are munching on a freshly-baked slice of bread.

# Introduction

The obvious way to make bread is to find a recipe in a book and follow it. Chances are it will work well enough, but making bread this way confines the baker to one recipe, gives him or her no understanding of how to fix problems that arise, and perpetuates the myth that he or she needs a "good recipe" to begin with. In short, following a recipe is not an empowering way to make bread.

The alternative method explored in this book is more akin to what our ancestors might have done, working with basic recipes to learn about the process of bread-making, with the added benefit of decades of scientific research enabling us to understand the inner workings of the process. Think of the method as starting from the beginning—each time you make dough you see what happens to it and learn something new about the process. The information provided in this book will help you learn faster and understand how and why bread "works." From there, any recipe will be conquerable.

Reading about bread will not be enough though; the only way to get to know dough and bread is to have your hands in it—practice. Do not be intimidated—mistakes and "failures" are just opportunities to learn. (Besides, messed up bread often still tastes good!) Take data when mixing your dough—use the data sheet on page 145. Remember what the dough feels like. Write notes for next time in order to remember what to do the same way or differently.

Good bread is not the result of one brilliant mind; it came about by trial-and-error, over the centuries. And it was done by ordinary people; it does not require special talents or an advanced degree. Re-learning the process from the beginning is surprisingly simple. In this day, making bread "by hand" might seem like a lost art, but it remains accessible to anyone who wishes to try it.

Tabouli with a baguette, Snow Camp, NC, 2003

# Chapter 1
# Bread-making Basics

This chapter contains information on some basic concepts in bread-making that will help you get off to a good start.

## The basic bread recipe

The basic bread recipe is the "lowest common denominator" of bread recipes—the simplest one possible. It gives new bread makers a simple recipe to use and illustrates that all recipes are derived from the same place. There is no secret to them—they all have basically the same percentages of water, yeast, and salt, adjusted to account for the other ingredients. (The percentages, which may seem odd, are described in the following section "Baker's percent.")

What makes good bread is the attention given to the dough, not the recipe. This is especially true for bakers working in distinct climates. A world-famous recipe from a California bakery might need adjustment when used in the humid eastern Carolina summer with a different brand of flour and different water. Bakers make adjustments by paying attention to the dough's characteristics.

The basic bread recipe for a one kilogram (about two pound) loaf of bread is

| | Percent | Weight |
|---|---|---|
| White flour | 100% | 0.580 kg |
| Water | 70% | 0.406 kg |
| Instant yeast* | 0.7% | 0.004 kg |
| Salt | 2% | 0.012 kg |
| Total | 172.7% | 1 kg |

This recipe is converted to cup and teaspoon measures in the following section "Weight versus volume."

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* If fresh yeast is used, the amount of yeast is about 2% or 0.012 kg.

If you slap together this recipe, do not knead it enough, stick it in the refrigerator overnight because you are too tired to bake it, and then put it in a conventional oven without knowing if it is ready to bake, you will still produce bread **that tastes good!** From there, you can use your knowledge of bread-making to improve the result—to get more volume (i.e., bigger bread) or a nicer-looking crust, for example. The important thing is just to get started!

Of course, you may want to use a fancier recipe. The scores of great recipes in cookbooks are a bit more exciting than the basic bread recipe. The rules of bread-making still apply—fancier recipes all evolved from a basic recipe like this one.


Pataha Flour Mill, Pataha, WA, 2003

# Chapter 2
# Bread Science Basics

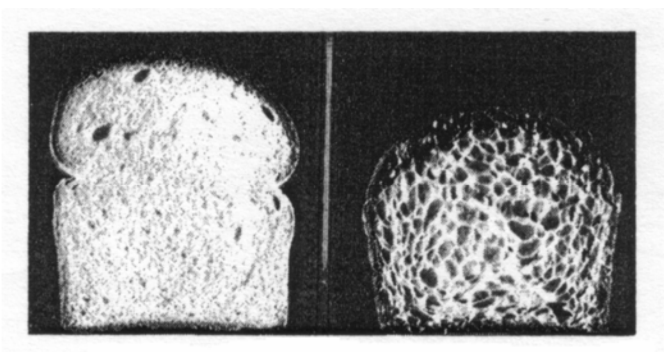
This chapter is about the science of bread-making, organized by subject. References to specific research studies are located at the end of each section.

## Gas retention

The commonly held view of gas retention in dough is that gluten, like a balloon, traps carbon dioxide gas produced by fermentation. Recently, however, this idea has been reconsidered and challenged. The emerging picture is one in which lipids and protein work together to hold gas in dough.

### Early research

Several studies by a research group in the 1940's looked at gas production and retention in dough. In one study, they examined how gas bubbles originate in dough. They could exist in the wheat kernel or flour, the yeast could create them, they could be added during mixing, or they could be added during punching, folding, and shaping. The researchers mixed dough under different conditions—for example in a vacuum versus in air, or while under a high pressure that squeezed out all gas bubbles. They concluded that gas bubbles are only added to dough during mixing. The pre-existing bubbles are negligible, and the yeast do not make new ones. Punching, folding, and shaping dough subdivide existing bubbles but do not create new ones.[1]



Mixing in air (left) versus mixing in vacuum (right). Lacking the air bubbles added to dough during mixing, the dough mixed in vacuum did not rise properly. Picture reproduced from J.C. Baker and M.D. Mize, *Cereal Chemistry* **18** (1941) 19-34 with permission of the American Association of Cereal Chemists.

Later, the physics of bubbles provided an explanation. The equation relating the gas pressure inside a bubble (P) to the bubble's radius (r) is $P = 2\gamma/r$, where $\gamma$ is the tension on the outside of the bubble. Thus to produce a new bubble, which would begin with a radius of zero, the pressure inside would have to be infinite. This is why yeast cannot produce new bubbles of carbon dioxide. Instead, the $CO_2$ they produce goes into solution in the dough, coming out as a gas when it encounters a bubble that already exists.

Another early study, which perhaps led to the "gluten balloon" picture, looked at the structure of the gas bubble. Dough was centrifuged and a layer of bubbles separated out. These bubbles were removed, analyzed, and found to contain a good amount of protein. Analysis of baked dough showed that the films around bubbles contained protein but not starch—picric acid, which stains protein yellow, produced a change in the film color, but iodine, which stains starch blue, did not.

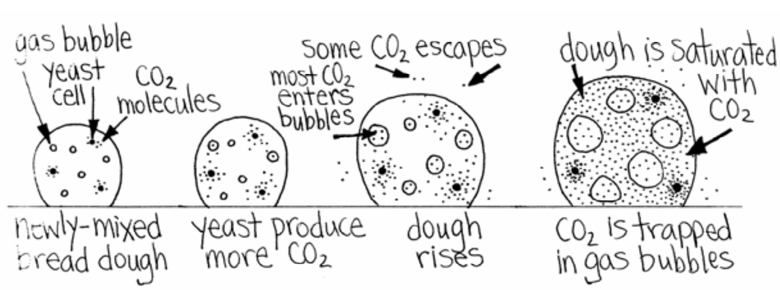
They looked at an undeveloped dough and compared it to a properly developed one. The undeveloped dough had a dull color and doughy gas bubble walls that stained blue with iodine. It did not hold gas well. The developed dough, with bubble walls of protein, had a shine to it and could expand during baking to contain the gas in the bubbles. This led to the conclusion that as the dough developed, it drew protein to the bubble walls. Thus when the dough expanded, as it rose and in the oven, there was enough protein available to allow the bubbles to expand without breaking.[2]

Another study looked at the role of fat during baking. Solid fats (like shortening) helped bread—they resulted in bigger volume, better flavor, and better texture—while liquid fats (like oil) did not. It was the state of the fat that mattered, because one fat was tested in both solid and liquid forms (by doing the experiment at different temperatures) and had good or bad effects depending on its form.[3]

**Questioning the "gluten bubble" model**

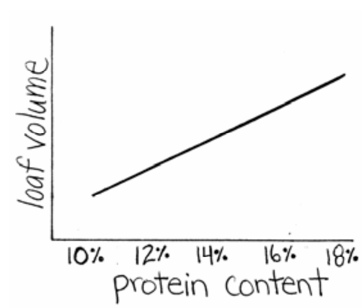
In 1984, R.C. Hoseney questioned the long-accepted picture of gluten acting like a balloon to trap $CO_2$. Gluten that prevented gas from leaving a bubble would also prevent gas from entering the bubble in the first place. He offered the explanation that gaseous $CO_2$ stays in a bubble because the surrounding dough is saturated with dissolved $CO_2$, continually produced by the yeast. The gaseous $CO_2$ stays a gas because the dough is already "full" of dissolved $CO_2$. The gaseous $CO_2$ cannot dissolve into the dough and escape.

When the $CO_2$ is produced, it diffuses through the dough until it finds a bubble to enter. Some diffuses to the edge of the dough and escapes to the atmosphere, where gas pressure is relatively low. Due to the distance to the edge, however, most $CO_2$ molecules settle for a nearby, higher pressure gas bubble in the dough.[4,5]




**The role of lipids, surface tension, and proteins**

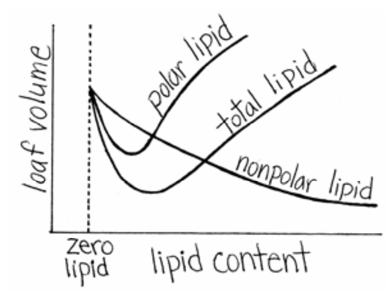
It has long been known that the protein content of flour has a direct effect on the size of bread produced with it. Plots of loaf volume versus protein content show how volume increases with protein.[6] (Keep in mind that these doughs were made in a science lab.



Processing conditions were much different than those in your kitchen, and other characteristics, like flavor, were not considered. Even though extreme protein contents show huge results, you would never want to use flour with 18% protein at home!)

The role of lipids in producing bigger loaves is also of interest. Dough has a small amount of lipid in it naturally. Lipid can also be added in the form of shortening or butter (solid lipid) and oil (liquid lipid). To examine the role of the natural lipid in dough, flour can be "defatted" to produce a lipid-less dough.

Research in the 1970's concluded that natural lipids do not affect dough properties while it is mixing but do stabilize the rising dough's foam-like structure. Researchers made dough with defatted flour and then added the lipid back. The plot of loaf volume versus lipid content had a minimum—at first the lipid hurt the volume, but when enough was added it helped. This result was a mystery. The lipid was also separated into polar and non-polar parts, comparable to the solid and liquid lipids of earlier studies, and the polar part was shown to cause the helpful effects on loaf volume, while the non-polar part hurt loaf volume.[7]




Other papers discussed the importance of surface tension on gas bubbles in dough. These were theoretical treatments with lots of big equations relating things like the pressure in a bubble, the bubble size, and the forces on the edge of the bubble. Different models were proposed. One concluded that surface tension, a force resisting bubble expansion, had a greater effect on bubble size than the gluten's elasticity,[8] while the other said the surface tension mattered little.[9]

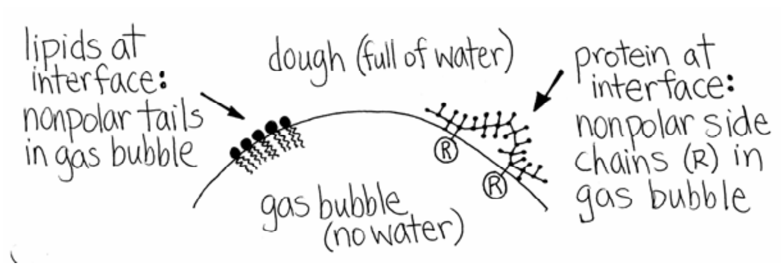
In 1989, Ewart discussed how protein could hold gas in dough with no mention of the flour's lipids. Since he had proposed that glutenin in dough is linear, he suggested that the linear molecules overlapped to form sheets. The sheets were elastic because of the proteins' ability to unfold when stretched. This elasticity resisted the uncontrolled expansion of gas cells. Although this sounds like Ewart is supporting the "gluten balloon" picture, he is not necessarily saying that the gluten prevents the gas from escaping, just that gluten's strength is important for resisting expansion.

**The liquid film hypothesis**

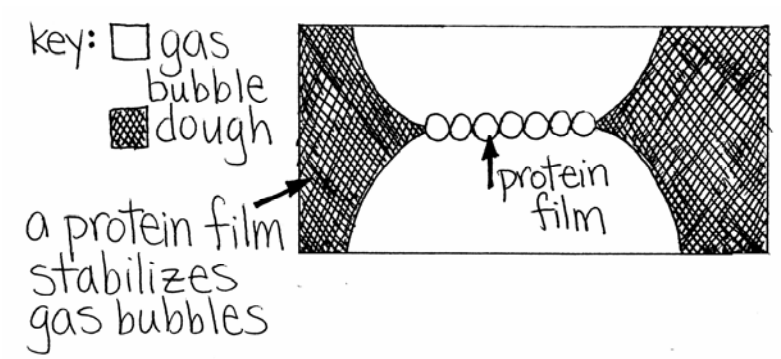
Research in the 1990's used an electron microscope to look at slices of bread dough at different stages of the bread-making process. Researchers watched as gas bubbles got bigger and bigger during proofing. After fifty minutes, they observed breaks in the bubble walls, but gas was still retained. Something was holding the gas in. They proposed that gas was retained by some form of liquid film. Upon baking, the dough solidified and the gas bubble walls ruptured completely, releasing the gas.

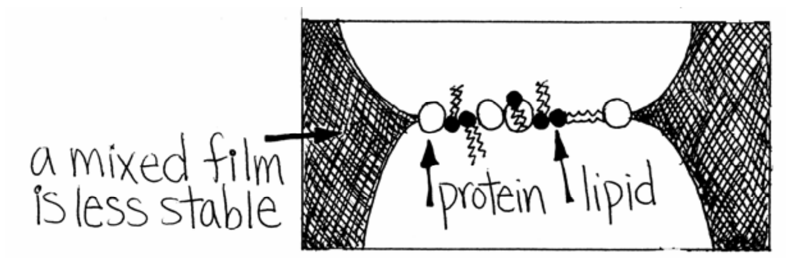

Ordinarily, the starch and protein network of dough holds gas in; this is adequate at lower gas pressures. The liquid film stabilized gas bubbles and helped them survive longer because it was more extensible than the starch and protein. It also reduced the surface tension of the bubble.

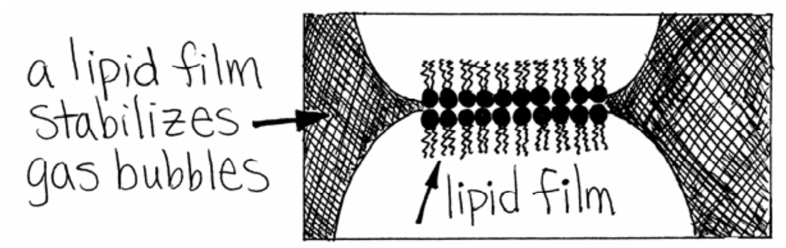
Possibilities for the film's composition included "surface active lipids," with their polar head and non-polar tails that stabilize them at interfaces, and proteins, which can use an interface to stabilize their non-polar side chains. The water soluble proteins, i.e., the non-gluten proteins of flour, were suggested.[10] These possibilities are shown below.



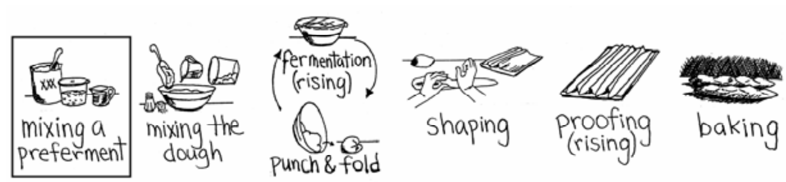

They later proposed that lipids and proteins were both working as a liquid film at the edge of the gas bubble. The lipids and proteins competed for space at the edge. This explained the mysterious minimum in the plot of loaf volume from the 1970's. In the lipid-less dough, gas bubbles were stabilized by a protein film. When some lipid was added, it was not enough to form a lipid film, but it displaced some protein, resulting in a weaker, mixed film. This caused worse gas retention, smaller loaves, and thus the dip in the plot. When enough lipid was added to produce a solid lipid film, the loaf volume increased. These cases are illustrated below.[11]






[1] Baker, J.C. and M.D. Mize. "The origin of the gas cell in bread dough." *Cereal Chemistry* **18** (1941) 19-34.
[2] Baker, J.C. "The structure of the gas cell in bread dough." *Cereal Chemistry* **18** (1941) 34-41.
[3] Baker, J.C. and M.D. Mize. "The relation of fats to texture, crumb, and volume of bread." *Cereal Chemistry* **19** (1942) 84-94.
[4] Hoseney, R.C. *Principles of Cereal Science and Technology*. St. Paul, Minnesota: American Association of Cereal Chemists, 1986 226.
[5] Hoseney, R.C. "Gas retention in bread doughs." *Cereal Foods World* **29** (1984) 305-308.
[6] Hoseney, R.C. (1986) 228.
[7] MacRitchie, F. and P.W. Gras. "The role of flour lipids in baking." *Cereal Chemistry* **50** (1973) 292-302.
[8] Carlson, T. and L. Bohlin. "Free surface energy in the elasticity of wheat flour dough." *Cereal Chemistry* **55** (1978) 539-544.
[9] Bloksma, H. "Effect of surface tension in the gas-dough interface on the rheological behavior of dough." *Cereal Chemistry* **58** (1981) 481-6.
[10] Gan, Z., R.E. Angold, M.R. Williams, P.R. Ellis, J.G. Vaughan, and T. Galliard. "The microstructure and gas retention of bread dough." *Journal of Cereal Science* **12** (1990) 15-24.
[11] Gan, Z., P.R. Ellis, and J.D. Schofield. "Gas cell stabilization and gas retention in wheat bread dough." *Journal of Cereal Science* **21** (1995) 215-230.




# Chapter 3
# Preferments

This chapter explores preferments, starting with the question, what is a preferment? Many people have never heard this term, but using a preferment improves dough drastically, both in flavor and in handling. And once you understand them, using a preferment is easy!

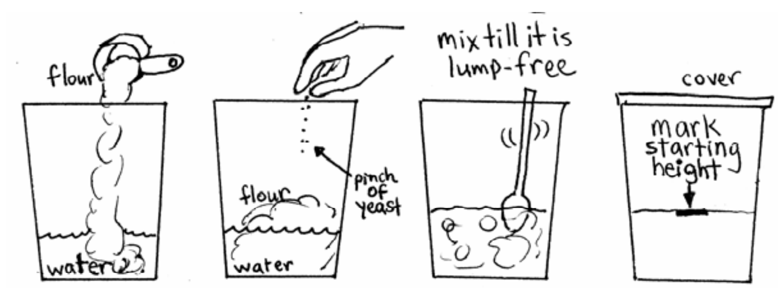
## Poolishes & sponges: what they are, how to mix them

A poolish is a mixture of flour, water, and yeast. Equal weights of flour and water are used, giving a pancake-batter consistency. A sponge is a similar mixture with a higher percentage of flour, giving a dough-like consistency.

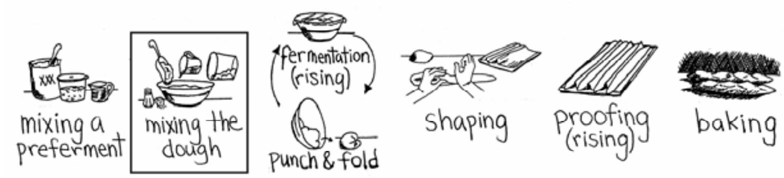
Both poolishes and sponges work well. Why use a poolish versus a sponge? I have made the same bread with each preferment and not seen any obvious difference. Some people believe a more acidic flavor develops in a sponge.

To mix a poolish (or a sponge), use a see-through, covered container. (A see-through container is ideal for monitoring the height and gas content of the poolish.) Make sure the container is big enough—the poolish is going to double or triple in volume. My preference—cheapo plastic containers—is shown in the following pictures.†

First add water. Then add the flour. Add the yeast on top of the flour and swirl to disperse it into the flour. Use your hand or a spoon to mix the poolish, squashing any flour lumps. At first you will feel stringy flour globs throughout the mixture. When these are gone, you will find smaller lumps to squash. Mix until there is no dry flour left. After mixing, cover the preferment and burp the lid to remove air; otherwise, gas production may cause it to pop off. Mark the starting height of the poolish on the side of the container.

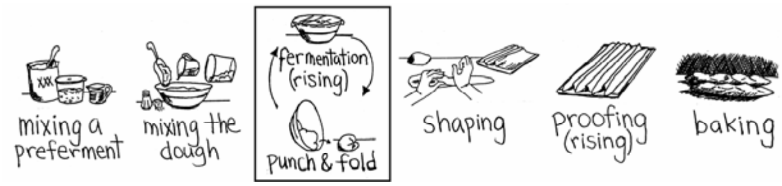



† Are metal containers bad to use? I have not read this, but since metals often do react with acid, it is probably best to use a plastic container.



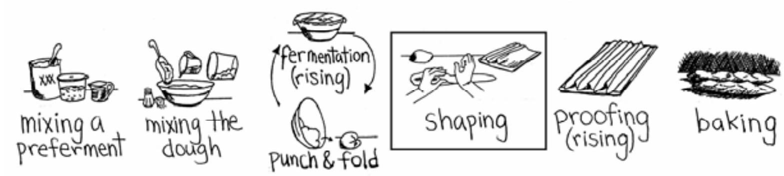

# Chapter 4
# Mixing the Dough

Mixing the dough is where bread-making gets exciting—once the dough is mixed, all the chemical reactions begin going full swing. These reactions were discussed in chapter two. Understanding how they relate to the mixing process will make you more comfortable with your dough. You will know what is going on inside, why you are kneading, and what to look for as your dough develops. Dough chemistry is reviewed in the overview of this chapter. Practical aspects of mixing dough follow.




# Chapter 5
# Fermentation

Chapter five describes the details of fermentation, the time between mixing and shaping the dough. It may seem like not much is happening—after all, watching dough rise is comparable to watching grass grow. But attention to a few points can make a big difference in your final bread.




# Chapter 6
# Dough Shaping

When it comes to shaping dough into baguettes and batards, there is only so much you can learn from pictures. Skill at shaping comes with practice! The techniques described in chapter six will get you off to a good start, however, describing both what to do and what not to do when you are shaping dough.

The steps of shaping: batards

1. Start with a pre-shaped round. Put the smooth side down on a lightly-floured table. This will become the smooth outer surface of your bread. Flatten the dough by smacking it with your flat hand. Stretch it slightly to get an oval shape.
2. Position the dough vertically—this is anti-intuitive, since you will be making a horizontal shape. Fold the top third of the oval down and in. Use your hands at angles—picture a triangle between your hands. Do not just flop the dough over; push on it to tighten the outside of the fold.


The first fold when shaping a batard. Fold the dough over and in, tightening the outside of the fold. Note the triangle between the fingers and thumbs of the hands. (above right and to the left)

What not to do (right): pulling the dough outward instead of folding over and in will move dough towards the ends of the batard, resulting in the "barbell batard" with fat ends and a skinny middle. Once the middle is too thin, it is nearly impossible to fix!

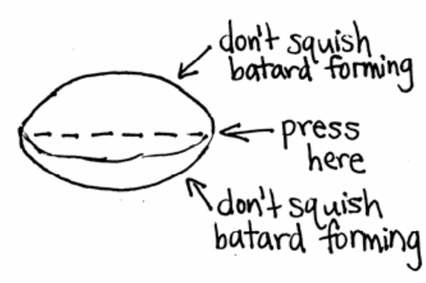
3. Press the fold shut with the heel of your hand. (Do not just poke at it with your fingers.) Use only three or four strokes. This step forces any remaining gas to move to the edges of the dough. Place your strokes close enough to the edge to be effective at moving the gas there, without being so close as to squash the shape that is forming. Do not worry about sealing the seam shut.

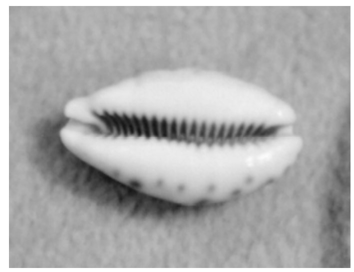

Pressing the dough shut with the heel of the hand after making the first fold.

4. Without stretching it, rotate the dough 180 degrees and repeat steps 2 and 3: first, fold the dough. Again, picture a triangle between your hands and fold down and in, not out.

The second fold of shaping a batard.

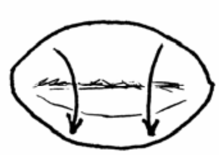
Next, press down the middle of the dough with the heel of your hand. Avoid squishing the edges where the shape of the batard is forming. At this point, the dough makes me think of a cowry shell. It has a trench down its middle, with gas built up along the edges. It can be shorter than the final batard; making it longer later on is very easy, but there is no way to make it shorter if it gets too long.

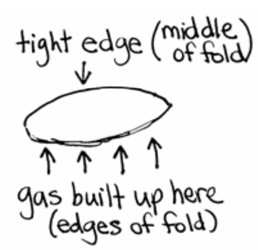


Pressing the dough shut after making the second fold (top). The result is shown (bottom left) along with a cowry shell (bottom right).

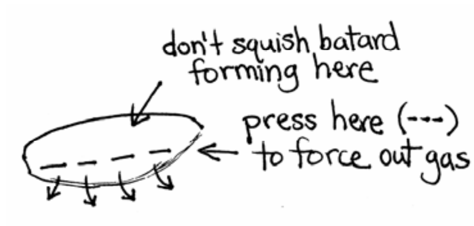
5. Use both hands to fold the dough in half, bringing together the two edges where gas has built up from the first two folds. You are tightening the outside edge of the dough—make sure it feels tight. Fold slightly inwards as you did before.

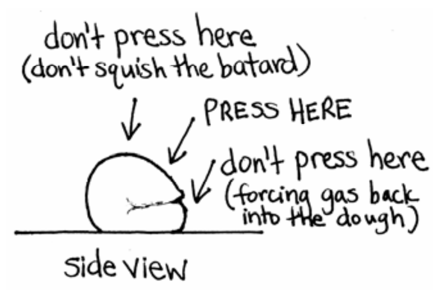





The third fold when shaping a batard.

6. Press the seam shut with the heel of your hand. Do not push right on the seam—this will force air back into the loaf. Focus on forcing out the gas that has built up along the edges. On the other hand, do not flatten the batard shape you just created. Find the place in between where your pressing is not hurting the shape but is effectively eliminating gas.




Pressing shut the batard after the third and final fold. Do not press too close to the folded edge, where you will squish the batard that is forming. Do not press too close to the open edge, or you will force gas back into the dough instead of expelling it.

7. Stop to examine your batard. Turn it smooth-side-up, with the seam down. Is it even? Is it tight enough? Use the friction between the dough and the table to continue shaping.

For example, this batard has too much dough on its left side.

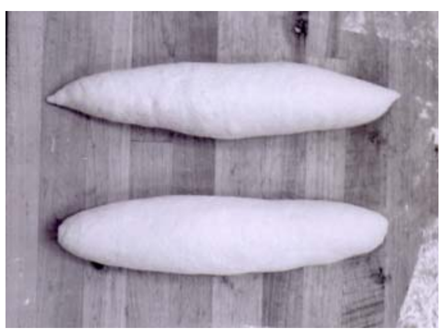
Pushing on this dough, using the friction to stretch it, spreads out the dough until both sides match.

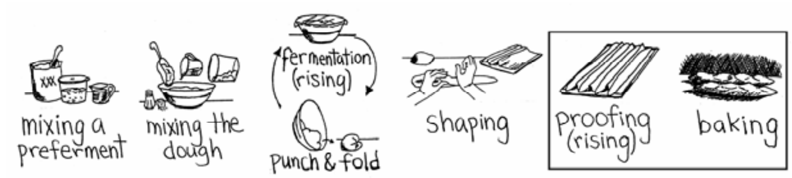
Fixing an uneven batard is not an easy step; keeping your batard symmetric from the beginning is much easier.

If the batard is even but soft and weak, add strength down the whole length of it. Pull the batard towards you with both hands, stretching the dough and adding strength on the near side. Or use both thumbs to push the batard away, adding strength on the far side. Remember to keep your hands **on the table**, pushing the dough, not rolling it.

Using the friction between the dough and the table to tighten the outer surface of the batard.

8. Use both hands to lengthen the batard (if necessary!) by rolling it on the table. Push harder on the ends to make them pointy. (The correctness of pointy batard ends is subjective. Pointy ends are favored by people who like crust. Those who like rounded ends view pointy ends as a waste of bread, and potentially dangerous, if sharp enough.) Finished batards, with pointy and rounded ends, are pictured below.






# Chapter 7
# Proofing and Baking

At last, it is time to put the dough into the oven! This final step of the bread-making process entails much more than opening and closing the oven door. Baking the dough at the correct time and having a hot enough oven are key to getting the biggest loaf possible. Scoring the dough and using steam also enable the loaf to expand, in addition to producing other effects. Baking is the baker's last and perhaps greatest chance to create an aesthetically pleasing loaf of bread.

## Modifications to improve your oven for baking

Two things make commercial bakeries' ovens superior to a home oven—their ability to retain heat and their ability to steam dough after the door is closed. (Steaming dough will be discussed in the next section.) One type of commercial oven is a *hearth oven*, where bread is baked on a slab of concrete or stone. This oven barely loses any heat when its door is open in contrast to a home oven where most of the heat escapes. Any heat lost from a hearth oven is quickly replaced by heat emanating from the oven floor. Other commercial ovens are designed to reheat quickly.

It is important to have your oven at a hot enough temperature (460°F for basic bread) when the dough enters in order to maximize oven spring. There are several ways to help a home oven reheat quickly once the dough is in.[‡]

- Put the dough in and close the door as fast as possible.
- Pre-heat the oven too hot: to 500°F instead of 460°F, for example. This way, some of the heat lost will not matter. Once the door is closed, turn the oven down to 460°F.
- Bake on a pizza stone. You **must** pre-heat the stone to the baking temperature with the oven. This will take longer, but the stone then becomes a source of heat, helping to reheat the oven once the dough is in. A second pizza stone above the bread will radiate even more heat; just make sure there is room on the sides of the oven for air to circulate.
- Pre-heat some other object with the oven and leave it in to radiate heat during baking. (Pick an oven-safe object: an old cast iron pan is one suggestion. My mom used to heat up rocks from the beach for our beds in the winter, to keep our feet warm, and they never exploded in the oven.)

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[‡] All ovens heat by convection, the transfer of heat from the hot coil or flame through the air to the food. So-called "convection ovens" increase the rate of this heat transfer with fans, helping the oven reheat quickly.

# Chapter 8
# Recipes, Storage, and Trouble-shooting

# Conclusion

Bread has a history of both sustaining great empires and inciting revolution. What can bread accomplish in our society? Artisan bread, whether made at home or in a small bakery, represents a return from the world of machine-laden mass production. It is concerned with flavor and texture, not maximizing profits for a distant corporation. Flavor must develop during a long fermentation, not be added in the form of sugar or vinegar. Bread must be sold locally and daily, not pumped full of shortening, sugars, or other preservatives and shipped across the country to sit on supermarket shelves.

Authentic artisan bread cannot be corrupted. It cannot be co-opted by the greedy. It is a gift for everyone. Slow down your busy life. Breathe deeply and exercise your arms. Learn to be more patient. Get in touch with your food. Teach your children how to knead. Eat healthily. In other words, make bread!

Ciabatta, Carrboro, NC, 2002

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