Annie Wu
ENGL1180C: Writing with Food
Food Science, V.2

Optimizing sugar ratios for macaron taste and structure

Abstract:

Macaron recipes are numerous and varied in their recommendations for amounts of almond flour, sugars, and egg whites. Particularly, recipes vary in their ratios of confectioners' sugar to granulated sugar. Sugar is a key component in macaron shells as it contributes both to flavor and structure of the finished product. While it is commonly assumed that granulated sugar functions to strengthen the meringue while confectioners' sugar contributes to lightness of texture and formation of the macaron "foot," little empirical evidence is available to support these claims. In this study, various sugar ratios will be tested to determine effects on macaron structure and taste; macaron shells will be qualitatively evaluated based on commonly acknowledged structural features: symmetry and height of the foot, shell surface, interior structure, texture, and smoothness of bottom. In addition, shells will be assessed based on taste and functionality when assembled using a simple ganache-based filling. The goal is to determine the ideal sugar ratio that will yield macarons with an optimal structure and flavor profile.

Introduction:

The French macaron has garnered much popularity in recent years. A sweet, meringue-based confection, the classic French macaron recipe consists of almond flour, granulated sugar, egg whites, and confectioners' sugar. Macarons are commonly filled with jams, ganaches, or buttercreams; the finished macaron consists of a sandwich of two shells stacked with tops facing outward and the filling acting as an edible "glue" in between, much like an Oreo. As the macaron has grown in popularity, there have been increasing efforts among baking enthusiasts and macaron-lovers to elucidate the recipe "secrets" that will produce macaron-perfection.

Anatomy of a Macaron

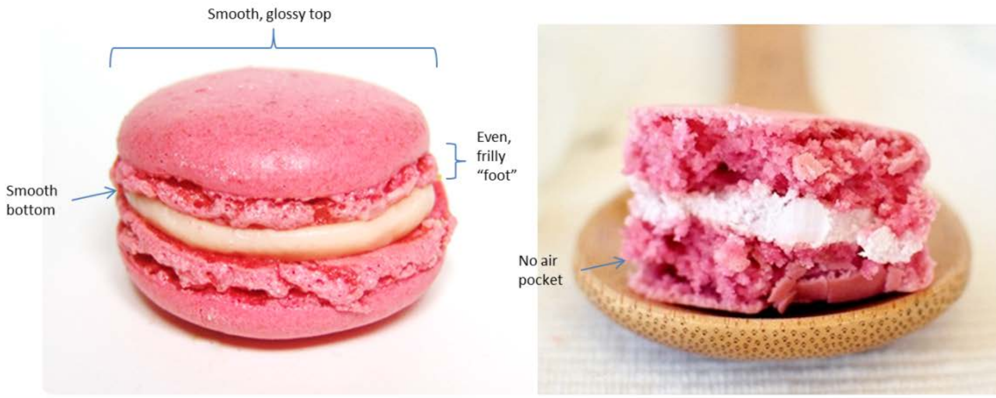

Figure 1. Anatomy of a macaron.

A macaron is essentially a meringue-based cookie. It contains no baking soda or baking powder, and achieves rise upon baking due to steam released from the whipped egg whites. A properly formed macaron features a flat base, a frilly edge around the base referred to as the "foot," and a smooth, glossy top (Fig 1). The texture of the shell should be light and airy with a slight chew, but not tough. A cross-section should yield an even, spongy structure with no obvious air pocket between the surface and the rest of the shell. The standard size for a macaron shell is roughly 3.00-5.00 centimeters in diameter and 0.75-1.00 centimeters in height.

Variation in recipes

While only four ingredients make up the basic macaron recipe, variations range impressively across blogs, books, and magazines. A fundamental distinction among recipes is that of the French vs. Italian Meringue. The Italian Meringue consists of a sugar syrup that is created through bringing sugar to a boil with water to create a hot syrup, which is drizzled into the egg whites as they beat into a meringue, producing a glossier, more stable foam. The French Meringue, on the other hand, does not require heating of the sugar; egg whites are beaten until foamy and granulated sugar is slowly incorporated as the whites continue to get beaten until it forms a stable meringue. While both recipes yield decent products, restaurants tend to prefer the Italian Meringue method for its consistency. For the purposes of this study, variations on the French Meringue recipe will be tested, as it is the method more commonly used among bakers at home.

Table 1 summarizes some of the most commonly cited variables in macaron recipes. Variations range from those involving ingredients – i.e. consistency of almond flour – to those involving equipment – i.e. double vs. single baking sheet – to those involving technique – i.e. measuring ingredients by volume or by weight.

VARIABLE	RECOMMENDATIONS
Almond flour	finely ground preferred, or grind in food processor with confectioner's sugar
Oven temperature	ranges 275-315 F depending on oven
Pre-baking resting period	0 - 2 hours depending on humidity
Addition of salt in meringue	may increase strength of meringue
Baking pan	double pan recommended for decreasing heat from bottom
Silpat vs. parchment	Silpat preferred for even baking
Measuring ingredients	measuring with kitchen scale highly recommended for accuracy
Aging egg whites	may increase strength of meringue by increasing protein to water ratio
Extent of folding	fold wet with dry ingredients until consistency of slow-flowing magma
The weather	humidity of atmosphere cannot be too high or else shells will not dry
Baking times	15-20 min depending on dryness of shells, oven temperature

Table 1. Variation in macaron recipe recommendations.

Technical considerations take center stage in the majority of articles on macaron recipe optimization. By contrast, much of the literature has little to offer on the extensive variation found across recipes with regard to ingredient ratios. A sampling of macaron recipes was taken from well-frequented blogs and websites, and ingredients were normalized to reflect relative mass per gram of egg white (Table 2). While proportions of almond flour per gram of egg white remained similar across recipes (range 0.76-1.30, average 1.10, std. dev. 0.17), proportions of confectioners' sugar and granulated sugar exhibited greater inter-recipe variation (range 1.30-2.25, std. dev. 0.30; range 0.25-1.20, std. dev. 0.29). When recipes were plotted according to the ratio of *total* sugar mass to almond flour mass, however, many of the ratios fell within the same range (Fig 2).

	Almond Flour	Confectioners' Sugar	Granulated Sugar	Egg White	Recipe Additions
All Recipes	0.94	2.11	0.42	1.00	
Brave Tart	0.80	1.60	0.50	1.00	salt (pinch)
Canelle et Vanille	1.25	2.25	0.25	1.00	cocoa (0.15), lemon, salt
David Lebovitz	0.76	1.50	1.00	1.00	cocoa (0.39)
Dejana-Baker's Corner	1.14	1.70	0.70	1.00	
Giver's Log	1.08	1.94	0.65	1.00	
Jo the Tart Queen	1.30	1.30	1.20	1.00	
Martha Stewart	1.13	1.59	0.42	1.00	
Not So Humble Pie	1.25	2.25	0.28	1.00	egg white powder (0.05)
Serious Eats	1.14	2.05	0.27	1.00	salt (pinch)
Sweetney	1.08	1.93	0.64	1.00	
Syrup and Tang	1.30	1.60	0.80	1.00	
The Galley Gourmet	1.10	2.00	0.35	1.00	salt (pinch)
AVERAGE:	1.097692308	1.832307692	0.575384615	1	
STANDARD DEVIATION:	0.173452868	0.30285183	0.294012907	0	

Table 2. Variation in macaron recipe ingredient ratios. Recipes were normalized per 1 gram of egg white.

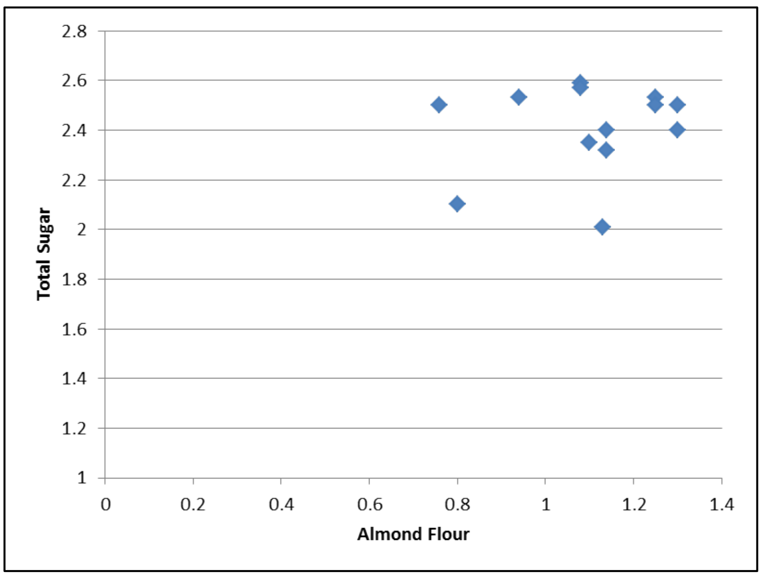

Figure 2. Similarity in total sugar to almond flour ratios. Values are relative mass proportions to 1 gram of egg white.

Much of the variation across recipes, therefore, appears to stem from variation in ratios of confectioners' to granulated sugar. To further assess these differences, the relative proportion of each type of sugar to 1 gram of egg white was plotted graphically to generate a regression that exhibited a moderately strong inverse relationship between proportions of each sugar (Fig 3).

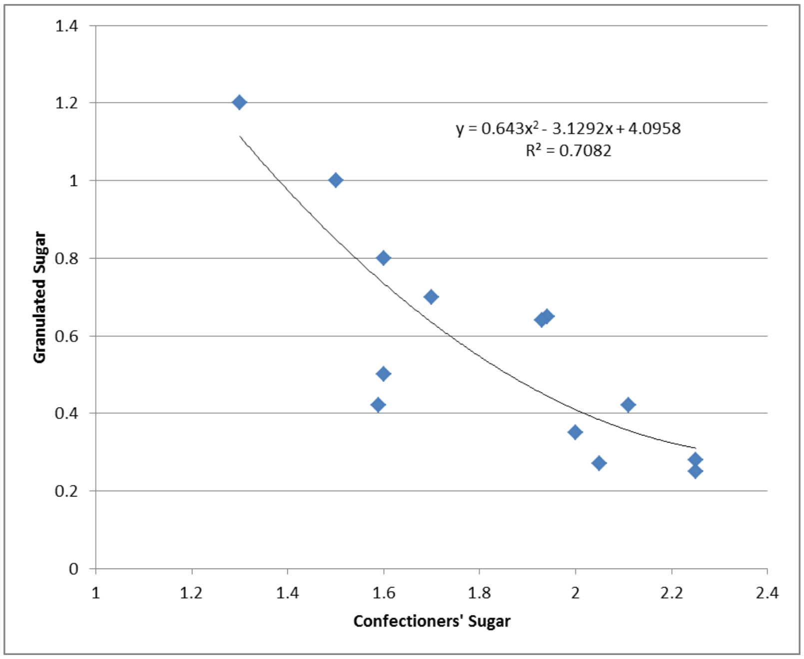

Figure 3. Inverse relationship of granulated to confectioners' sugar across macaron recipes. A polynomial regression yielded a moderately strong inverse correlation between proportions of granulated and confectioners' sugars (R^2 = 0.7082).

These observations highlight sugar proportions as a key point of variation with potential for recipe optimization. Developing a better understanding of how variation in sugar proportions affects macaron taste and structure will facilitate one's ability to reproduce the ideal macaron.

Science of the Meringue

Sugar in macaron shells contributes not only to flavor, but also to structure. A critical step in macaron making is the beating of egg whites to form a medium-stiff meringue. Harold McGee describes a meringue as an "egg white foam": upon beating, egg white proteins unfold and join together to form a "reinforcing network" consisting of "bonds between positively and negatively charged parts of molecules, between water-like parts, between fat-like pars, and between sulfur groups."[1]

[1] Harold McGee, *On Food and Cooking: The Science and Lore of the Kitchen*, (New York: Scribner, 1984, 2004), 102.

A medium-stiff meringue forms soft yet sturdy peaks. Structurally, this is the point at which egg white proteins have formed just enough bonds with each other to form loose "cages" around water droplets present in the mixture, creating a stable matrix of water droplets held within a protein structure. When overbeaten, egg white proteins develop too many bonds with each other, causing the protein cages to become too tight and to "squeeze" the water droplets out of the matrix, resulting in separation of egg whites from the moisture in the foam.

Various tactics are employed to stabilize a meringue. One strategy is to introduce sugar into the mix. Sugar helps "stabilize the egg-white foam by increasing the viscosity of the water present in the foam," making the foam thicker and less likely to collapse when folded in with other ingredients.[2] Additionally, one can prevent overbeating by introducing agents that interfere with bond-formation. One option is to use metal ions to disrupt sulfur bonding. French bakers have a history of using copper bowls for making meringues, a technique rooted in good chemical sense: copper ions have a tendency to form tight bonds with reactive sulfur groups, effectively preventing egg whites from binding too tightly to each other to cause separation of proteins from moisture in a meringue.[3] Another option is to use acid to interfere with protein-protein interactions: the addition of a small amount of acid (such as lemon juice or cream of tartar) increases the number of hydrogen ions in the mixture, which interact with free sulfur groups to decrease S-S binding.[4]

Other tips in macaron recipes involve using room temperature whites, aging egg whites, and avoiding contact with oils and other hydrophobic materials. Room temperature whites facilitate protein unraveling to form networks in which water droplets can be suspended. The process of aging egg whites involves placing egg whites in a clean bowl covered with a paper towel or other breathable covering,

[2] Jeff Potter, *Cooking for Geeks*, (Sebastopol, CA: O'Reilly Media, Inc., 2010), 254.
[3] Harold McGee, *On Food and Cooking: The Science and Lore of the Kitchen*, (New York: Scribner, 1984, 2004), 103.
[4] Harold McGee, *On Food and Cooking: The Science and Lore of the Kitchen*, (New York: Scribner, 1984, 2004), 103.

and letting some of the moisture evaporate from the egg whites for a period ranging from 24 hours to 5 days. The goal of aging is to concentrate the egg proteins so that a stronger meringue can be created upon beating. Avoiding hydrophobic agents such as oils and plastic bowls (which tend to bind oils) ensures that such molecules do not interfere with the protein-air-water interface and hinder foam-formation.[5]

Aims

The goal of the proposed study was to determine the effects of manipulating sugar proportions on macaron taste and structure. Specifically, this study aimed to assess how a high proportion of granulated sugar vs. a high proportion of powdered sugar would affect the final product with regard to the following specifications: symmetry and height of the foot, texture of the shell surface, interior structure, texture, and smoothness of bottom.

Methods

Equipment	Protocol
Kitchen scale	1. Preheat oven to 295F.
Large glass bowl (Pyrex)	2. Measure aged egg whites into large glass bowl set over scale. Measure granulated sugar into small bowl.
Large mixing bowl with seive	3. Set seive over large mixing bowl set over scale. Measure almond flour and confectioners' sugar and seive into large bowl (leave coarse bits in seive).
Small bowl	
Large (18in) vinyl piping bag	4. Pour coarse bits of almond flour into mini food processor and pulse until finely ground. Add to confectioners' sugar/almond flour mixture and whisk lightly to combine.
Round metal piping tip (1cm)	
Electric hand mixer	5. Start hand mixer on low speed and whip egg whites until foamy. Gradually add granulated sugar and beat on medium speed until medium-stiff peaks form.
Balloon whisk	
Mini food processor	6. Add dry ingredients mixture to meringue and fold gently with rubber spatula until mixture is the consistency of slow-flowing magma.
Rubber spatula	
Aluminum baking sheet	7. Transfer mixture to piping bag coupled with tip and pipe rounds 4 cm in diameter on Siplat-lined baking sheet. Rap sheet lightly on counter to remove air bubbles.
Silpat nonstick mat	
	8. Allow macaron shells to dry for 30 min in a well-ventilated area.
	9. Bake in preheated oven for 20 min.
	10. Allow to cool completely before removing from Silpat.

Table 3. Equipment and Protocol.

Macarons were prepared using standard equipment and protocol (Table 3). Two recipe variations were tested: Recipe A used a high proportion of granulated sugar while Recipe B used a high proportion of

[5] Harold McGee, *On Food and Cooking: The Science and Lore of the Kitchen*, (New York: Scribner, 1984, 2004), 104.

confectioners' sugar (Fig 4). Proportions of all other ingredients were kept unchanged between recipes. In accordance with recommendations from various sources, glass mixing bowls, Silpat baking mats, and aged egg whites were used.

INGREDIENTS	Recipe A (High Granulated)	Recipe B (High Confectioners')
almond flour	1.25	1.25
confectioners' sugar	1.60	2.10
egg white (aged 24 h)	1.00	1.00
granulated sugar	0.80	0.30
RATIO (G:C)	1:2	1:7

Figure 4. Proportions of ingredients in recipes tested. Values are relative to 1 gram of egg white.

Macaron shells were assessed according to symmetry and height of the foot, texture of the shell surface, interior structure, texture, and smoothness of bottom. Finished macarons were filled with a simple dark chocolate ganache filling and qualitatively assessed for flavor and texture.

Results

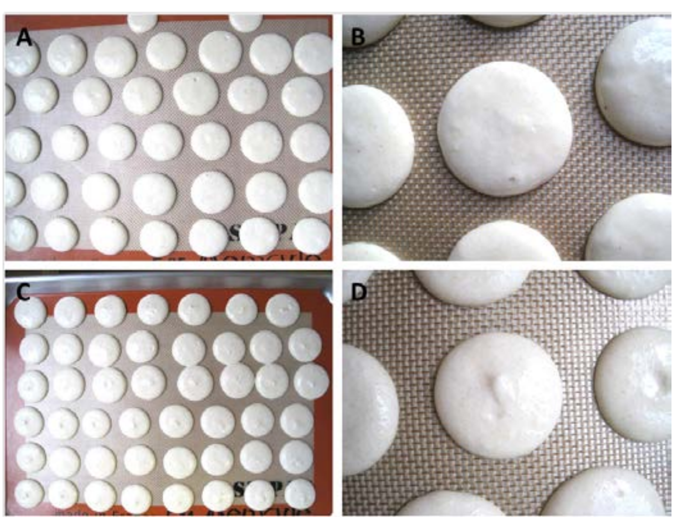

Figure 5. Macaron shells prior to baking. Recipe B (A, B) resulted in shells with smooth tops while Recipe A (C, D) produced a stiffer meringue that resulted in faint peaks after piping.

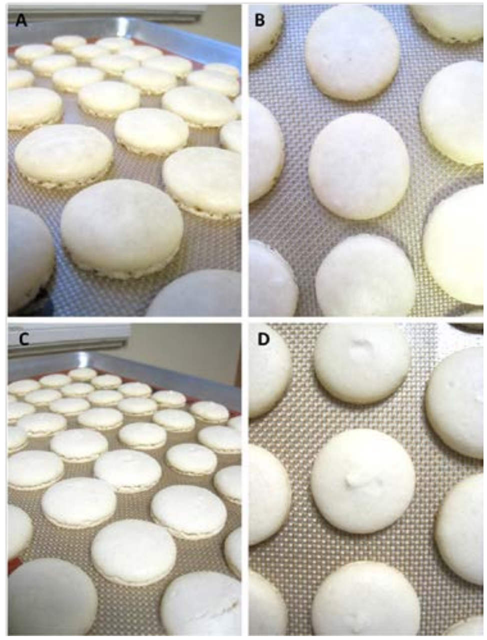

Figure 6. Macaron shells post baking. Recipe B produced generally symmetric, tall feet with smooth tops (A, B); Recipe A produced thin, asymmetrical feet with slight textural irregularities on top surfaces (C, D)

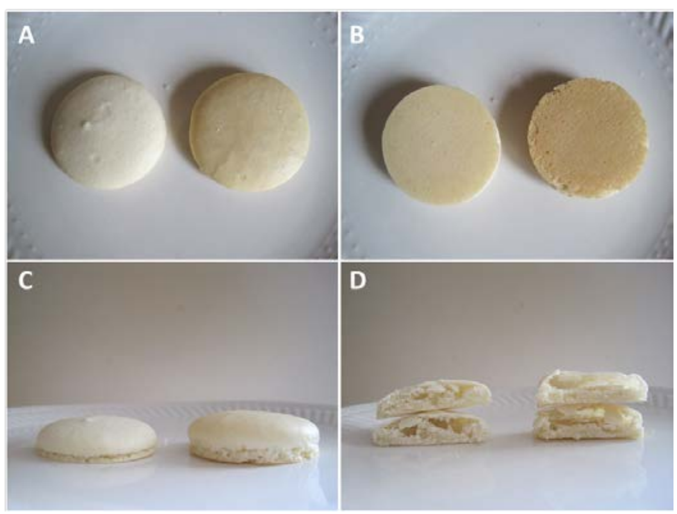

Figure 7. Texture and appearance comparison between Recipe A (left) and Recipe B (right). Recipe A produced whiter, glossier tops (A) and smoother bottoms (B). Recipe B produced taller, more symmetric feet (C). Cross section analysis revealed a spongy matrix from Recipe A, and a larger air pocket from Recipe B (D).

	Recipe A (high G)	Recipe B (high C)
FOOT SYMMETRY	poor symmetry	good symmetry
FOOT HEIGHT	low (0.2 cm)	good height (0.5 cm)
SHELL SURFACE	white and shiny	yellowish and dappled
INTERIOR STRUCTURE	small air pocket	large air pocket
TEXTURE	tough and crunchy throughout	sturdy bottom, flimsy top
BOTTOM	smooth and shiny	coarse, with small air pockets

Figure 8. Qualitative assessments of structural qualities. Recipe A scored high marks in interior structure and bottom texture; Recipe B excelled in foot structure.

A dark chocolate amaretto ganache was used in the qualitative assessment of overall macaron flavor and structure. Both shells improved texturally upon overnight incubation in the refrigerator; the toughness of the dry shells mellowed out as they absorbed moisture from the filling. Recipe A macarons scored points on sturdiness of the upper shell and absence of air pocket; Recipe B macarons suffered from a flimsy top that shattered to reveal a large air pocket, affecting the overall cohesiveness of the macaron. Recipe B macarons were, however, evaluated to be more aesthetically pleasing with regard to foot structure and overall symmetry.

Discussion

Both granulated and confectioners' sugars contribute critically to macaron taste and structure. This qualitative study demonstrated the merits and detriments of both extremes with regard to proportions of each sugar. Overall, the high granulated sugar recipe (Recipe A) produced a stiffer meringue that, when mixed with the dry ingredients, yielded a sturdier batter and subsequently a stronger macaron. However, Recipe A suffered from impaired rise in the oven, possibly due to the effects of increased viscosity and stiffness of the protein network upon addition of more granulated sugar to the meringue.[6] By contrast, the high powdered sugar recipe (Recipe B) produced more rise, yielding a taller and more

[6] Harold McGee, *On Food and Cooking: The Science and Lore of the Kitchen*, (New York: Scribner, 1984, 2004), 104.

symmetrical foot that was more aesthetically pleasing. However, the overall texture of Recipe B macarons was compromised by the large air pocket that formed with baking, possibly due to the weaker meringue.

Future studies may consider an intermediate ratio of granulated to confectioners' sugar, perhaps testing a 1:5 ratio (1.25 almond : 2.0 confectioners' : 1.0 egg white : 0.4 granulated). Experiments from this study suggested that a stronger meringue is a key component of sturdier macarons. To achieve strength in the meringue without sacrificing rise in the oven, one may consider using a copper bowl or adding a small amount of lemon juice as insurance against overbeating the egg whites while still achieving medium-stiff peaks that do not collapse upon incorporation with dry ingredients. A quantitative analysis (i.e. average foot height, density, individual shell mass) can be considered in addition to qualitative assessments.

This qualitative study is among several of its kind in the ongoing effort among self-taught bakers and macaron-enthusiasts to optimize the basic French macaron recipe. The author hopes that such endeavors will continue to be undertaken to generate reproducible results with increasing consistency across home kitchens.

Sources

"Syrup and Tang." Accessed October 7, 2012. http://www.syrupandtang.com/200712/la-macaronicite-2-basic-technique-and-simple-macaron-recipe/.

"David Lebovitz." Accessed October 7, 2012. http://www.davidlebovitz.com/2005/10/french-chocolat/.

"Brave Tart." Accessed October 7, 2012. http://bravetart.com/recipes/Macarons.

"Not So Humble Pie." Accessed October 7, 2012. http://notsohumblepie.blogspot.com/2010/08/macaron-troubleshooting-new-recipe.html.

"Cannelle et Vanille." Accessed October 7, 2012. http://www.cannellevanille.com/2008/08/chocolate-macarons-and-tropical-storm.html.

"The Galley Gourmet." Accessed October 7, 2012. http://www.thegalleygourmet.net/2012/05/raspberry-chocolate-french-macarons-and.html.

"Serious Eats." Accessed October 7, 2012. http://www.seriouseats.com/recipes/2007/10/how-to-make-macarons-recipe.html.

"Giver's Log." Accessed October 7, 2012. http://www.giverslog.com/?p=1089.

"All Recipes." Accessed October 7, 2012. http://allrecipes.com/recipe/macaron-french-macaroon/.

"Martha Stewart." Accessed October 7, 2012. http://www.marthastewart.com/319525/parisian-mcaroons.

"Sweetney." Accessed October 7, 2012. http://www.sweetney.com/2012/05/food-love-french-macarons.html.

"Jo the Tart Queen." Accessed October 7, 2012. http://jothetartqueen.wordpress.com/2012/08/31/peanut-butter-and-jelly-macarons/.

"Dajana-Baker's Corner." Accessed October 7, 2012. http://dajana-bakerscorner.blogspot.it/2012/07/saffron-macarons.html.

Harold McGee, *On Food and Cooking: The Science and Lore of the Kitchen*, (New York: Scribner, 1984, 2004).

Jeff Potter, *Cooking for Geeks*, (Sebastopol, CA: O'Reilly Media, Inc., 2010).