

THE CHEMISTRY OF CUPCAKES

What happens when you eliminate an ingredient from a cupcake recipe?

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Introduction

Can baking cupcakes be a science fair project?

Yes, baking is chemistry. Chemistry is one of the main branches in science. People who study chemistry are called chemists. Chemists study the changes when substances are combined. These chemical reactions occur in baking when the ingredients are combined and again when heat is added.

What is baking?

Baking is the process of cooking food in an oven. This is one of the oldest cooking methods. Ancient civilizations used a stone or brick oven fired with wood to bake bread. Baking products are usually made with flour, water, and a leavening agent. Other ingredients include oils, eggs, milks, and sweeteners.

The history of cupcakes

Over 5,000 years ago, ancient Egyptians baked cakes using a flour-based bread sweetened with honey. The word “cake” can be traced back to the 13th century. The earliest description of a cupcake was in a cookbook published in 1796 that has a recipe for “a light cake to bake in small cups” – a cup cake. Before cupcake pans were invented, people used teacups, small bowls, and ramekins to make these cakes in cups.

What do I already know about baking?

I have watched many baking shows and have baked many delicious desserts, such as: galettes, cookies, cupcakes, and cakes. I know that baking involves mixing wet and dry ingredients. I know that the amount of each ingredient must be measured. I also know that heat from the oven bakes the cupcakes. I know that flour makes baked goods rise and become fluffy. I know that sugar makes things sweet. I know that vanilla adds flavour. I am curious about the specific role each ingredient plays in a recipe and how important it is not to forget an ingredient.

Leavening Agent

A leavening agent is a substance that causes batter to rise by producing carbon dioxide gas. Baking powder and baking soda are leavening agents. Flour and baking powder react with acids in ingredients such as milk to form bubbles of carbon dioxide. These bubbles get trapped in the batter as it bakes. You can see these air spaces in the cupcakes when you cut the cupcake in half, which results in a light and fluffy cupcake.

Maillard Reaction

This reaction happens when heat is added to sugar and proteins. It results in browning, new flavours, and aromas. Toasting bread is an example of the Maillard reaction.

Question

What happens when you eliminate an ingredient from a cupcake recipe?

Hypothesis

If one ingredient is eliminated from a cupcake recipe, then the resulting cupcakes will look or taste different, because each ingredient matters in the recipe.

Materials

- Oven
- Cupcake pans
- Baking cups
- Mixing bowls
- Wooden spoon
- Spatula
- Measuring cups
- Electric mixer
- Oven mitts
- Cooling rack
- Knife
- Spoons
- Flour (original, all purpose)
- Sugar (white, granulated)
- Baking powder
- Salt (kosher)
- Eggs
- Milk (2%, cow's milk)
- Vegetable oil
- Vanilla extract (pure)

Experimental Procedure

1. Bake cupcakes according to the recipe below.
2. Make notes about the batter in the observation table before placing the mixture in the oven.
3. Once the cupcakes have been removed from the oven, make notes in the observation table about the cupcakes.
4. Once the cupcakes have cooled for five minutes, remove the cupcakes from the pan and cut one cupcake in half. Make notes in the observation table.
5. Taste the cupcake and add notes to the observation table.

6. Repeat steps 1-5, eliminating one ingredient each time, for a total of nine different batches of cupcakes.
7. Repeat entire procedure twice more, for a total of three trials.

Cupcake Recipe

Ingredients

Full Recipe	Half Recipe
2 cups (240 g) flour	1 cup (120 g) flour
2 cups (400 g) sugar	1 cup (200 g) sugar
1 tsp (4 g) baking powder	½ tsp (2 g) baking powder
½ tsp (6 g) salt	¼ tsp (3 g) salt
2 eggs	1 egg
1 cup (250 mL) milk	½ cup (125 mL) milk
⅔ cup (160 mL) vegetable oil	⅓ cup (80 mL) vegetable oil
1 tsp (5 mL) vanilla extract	½ tsp (2.5 mL) vanilla extract

Instructions

1. Preheat the oven to 350 degrees Fahrenheit (177 degrees Celsius) and prepare a cupcake pan with baking cups.
2. Add the flour, sugar, baking powder, and salt to a large mixing bowl and combine with a wooden spoon for 30 seconds. Set aside.
3. Add the egg, milk, vegetable oil, and vanilla extract to a medium mixing bowl and combine with an electric mixer on low speed for 30 seconds. Use a spatula to scrape the edges of the bowl as required.
4. Add the wet ingredients to the dry ingredients and combine with an electric mixer on low speed for 30 seconds. Use a spatula to scrape the edges of the bowl as required.
5. Spoon the mixture into the baking cups until they are half full.
6. Place the pan in the oven and bake for 25 minutes.
7. Remove the pan from the oven and place on a cooling rack for five minutes.
8. Remove cupcakes from baking pan.

Variables

Controlled: type of ingredient (for example: same type of flour, same type of milk, etc), amount of each ingredient in each batch, amount of time for mixing dry ingredients, amount of time for mixing wet ingredients, amount of time for mixing batter, amount of time in oven, temperature of the oven, placed the cupcake pan on the same rack in the oven each time, same oven each time, amount of time for cooling before tasting

Manipulated: the eliminated ingredient for each batch, only one ingredient eliminated each time

Responding: the batter with each batch and the baked cupcakes (appearance, texture, taste)

Observations/Results (Data Collected)

Trial #1				
Type of Cupcake	Batter	Baked Cupcake	Taste and Texture	Sample Size
Control (All Ingredients)	Smooth, thick, pale yellow	Golden, fluffy, light	Delicious, delicate, sweet, perfectly formed	10 cupcakes
No Flour	Smooth, runny, pale yellow	Did not rise, overflowed, bubbly, burnt, unformed, wet, smells awful	Jelly consistency, flavour is good, lumpy custard, sweet, sticky	9 cupcakes
No Sugar	Beige, very thick, sticky	Cracks, looks more like bread than cake	Not sweet	10 cupcakes
No Baking Powder	A bit runny, pale yellow	Not golden, less rise	Denser, not as many pockets of air, tastes like control	11 cupcakes
No Salt	Slightly runny, pale yellow	Golden, looks identical to control	Very similar to control	12 cupcakes
No Egg	Thick, pale yellow, looks like control	Golden, looks like control, did not rise as much, looks a little underbaked	A little chewy, a little underbaked, still flavourful	12 cupcakes
No Milk	Batter did not form, looks like crumbly cookie dough, you can see the sugar crystals	Golden, lumpy, crumbly, sunk in the middle	Crunchy on the outside, chewy on the inside, sweet, like a crumble	12 cupcakes
No Vegetable Oil	Paler, like control	Golden, like control, light, fluffy	Tastes different but still good, looks fluffy but is chewy	12 cupcakes
No Vanilla	Identical to control, smooth, pale yellow	Identical to control, golden	Fluffy, identical to control, sweet but lacks flavour	12 cupcakes

Trial #2				
Type of Cupcake	Batter	Baked Cupcake	Taste and Texture	Sample Size
Control (All Ingredients)	Pale yellow, smooth, a little thick	Golden, fluffy, rose nicely, good structure	Delicious, fluffy, pleasant aroma, delicate moist, sweet	12 cupcakes
No Flour	Pale yellow, runny	Lumpy, sticky, no structure	Sweet and clumpy	6 cupcakes
No Sugar	Beige, sticky, not smooth like control	Cracks, large air bubbles, dense	Not as much flavour	7 cupcakes
No Baking Powder	Smooth, pale yellow, identical to control	Flatter, did not rise as much, dense, not golden	Good flavour, sweet, still dense	12 cupcakes
No Salt	A little thick, same to control	Light, air bubbles, golden	Tiny less sweet, still has good flavour	12 cupcakes
No Egg	Smooth, thicker, pale yellow	Sunk in the middle, a little dense	Chewy, appears light and airy but is dense	10 cupcakes
No Milk	Crumbly, sugar did not dissolve	Crumbly a bit underbaked, crusty	Hard, crunchy, sugar visible, crumbly	12 cupcakes
No Vegetable Oil	Smooth, pale yellow	Did not rise as much, feels sticky, golden	Still flavourful, chewy, dense	12 cupcakes
No Vanilla	Pale yellow, smooth	Golden, fluffy, air bubbles visible	No vanilla aroma or flavour	12 cupcakes

Trial #3				
Type of Cupcake	Batter	Baked Cupcake	Taste and Texture	Sample Size
Control (All Ingredients)	Smooth, pale yellow, a little thick	Fluffy, golden, moist	Delicious, soft, moist	12 cupcakes
No Flour	Runny, pale yellow, sugar did not dissolve	Bubbly, did not rise, overflowed	Sweet, caramelized, like a custard, lumpy	9 cupcakes
No Sugar	Thicker than control, very sticky, less batter	Cracks, unformed, a little golden	Not sweet, still fluffy, like a biscuit	10 cupcakes
No Baking Powder	Smooth, pale yellow	Did not golden, did not rise as much	Like control, flavourful	12 cupcakes
No Salt	Same as control, a little thick	Rose, golden, fluffy	Like control, almost as sweet as control	12 cupcakes
No Egg	Thicker, pale yellow, smooth	Sunk in the middle, golden	Not as fluffy, dense	11 cupcakes
No Milk	Sugar is not dissolving, like crumbly cookie dough	Crumble, crusty, caved in, a little underbaked	Crunchy, not as sweet, sugar still visible	12 cupcakes
No Vegetable Oil	Pale yellow, smooth	Golden, air bubbles visible	Spongy, drier, chewy	12 cupcakes
No Vanilla	Smooth, pale yellow	Rose nicely, golden, fluffy,	Airy, texture same as control, no aroma	12 cupcakes

Observations Based on All Three Trials

Type of Cupcake	Batter	Baked Cupcake	Taste and Texture
Control (All Ingredients)	Smooth, pale yellow, a little thick, well combined	Fluffy, golden brown, light, airy, good structure, lots of air spaces	Delicious flavour and aroma, soft, moist, sweet, delicate
No Flour	Runny liquid, pale yellow, well combined	Bubbly, burnt, unformed, no structure, overflowed, gooey mess	Sweet, caramelized, like a custard, lumpy consistency, sticky, unpleasant aroma
No Sugar	Much thicker than control, very sticky, less batter overall, beige	Cracks, uneven, a little golden, looks more like bread than cake	Not sweet, dense, like a biscuit, dry
No Baking Powder	A bit runny, smooth, pale yellow	Did not golden as much, some air spaces visible but less than control, did not rise fully, flatter	Tastes like control, still flavourful, texture was more dense, not as light and fluffy
No Salt	Same as control, a little thick, pale yellow	Golden, light, fluffy, appears the same as control	Similar taste to control but a little less sweet
No Egg	Thicker, pale yellow, smooth	Sunk in the middle, flat on top, golden, appears a little underbaked, tight, structure collapsed in the middle slightly	Not as fluffy, dense, a little chewy, dry, still flavourful
No Milk	Sugar did not dissolve, looks like crumbly cookie dough, ingredients did not combine well	Golden and brown, sunk in the middle, caved in, a little underbaked, crumbly, coarse texture, sugar still visible	Crunchy on the outside, chewy on the inside, sweet, tastes like a crumble
No Vegetable Oil	Pale yellow, smooth	Golden, light, fluffy, air bubbles visible, did not rise as much as control	Spongy, dry, chewy, still flavourful, dense
No Vanilla	Smooth, pale yellow, looks like control	Golden brown, fluffy, light, airy, texture the same as control	Lacks flavour, still sweet but no vanilla flavour or aroma

Results (Data Analysis)

Flour

The flour contains a protein called gluten, which reacts with the wet ingredients to form a smooth batter. Without the flour, the batter was very runny. The no flour cupcake had no structure at all and did not even resemble a cupcake. It was a pile of gooey sweet lumpy custard. The chemical reaction did take place in the oven, with lots of bubbling from the carbon dioxide. But the flour forms the structure of the cupcake, so the foam had nothing to stick to and the cupcake collapsed. The flour is the skeleton of the cupcake.

Sugar

The no sugar cupcake had less of the Maillard reaction, which occurs when sugar is present. The batter was thick and sticky. The resulting cupcake lacked flavour and aroma and had no sweetness at all. Sugar helps keep the cupcake moist, so the no sugar cupcake was also dry. It was more like a biscuit that would be delicious with butter, honey, or jam.

Baking Powder

Baking powder contains baking soda, which is a base that reacts with acids in the ingredients, to release carbon dioxide gas when heat is added to the batter in the oven. These carbon dioxide bubbles cause the batter to rise. When you cut the baked cupcake in half, you can observe the spaces created by the gas. The baked cupcakes are light and fluffy. The no baking powder cupcakes were not as light and fluffy, but the taste was similar to the control cupcake.

Salt

Salt has many uses. It adds its own flavour, and it also enhances the other ingredients' flavours. Salt also toughens the batter and slows down the leavening reaction because if the batter rises too quickly it can collapse. The no salt cupcake appeared the same as the control cupcake, but the flavour of the cupcake was lacking.

Eggs

Eggs help hold all the ingredients together like a glue. Eggs also keep the batter from collapsing when it is baked in the oven and help keep the foam from collapsing as it cools. The no egg cupcake did not rise the same as the control cupcake. It was collapsed in the centre and was chewy. It appeared a little underbaked. The flavour was the same as the control cupcake, but the texture was different. It was chewy and dense, instead of light and fluffy.

Milk

Milk has many uses in baked goods. It hydrates the dry ingredients, adds flavour, contributes to browning, and softens texture. The no milk cupcake batter was very different from the control batter. The ingredients did not combine smoothly, and the sugar did not dissolve. It had the

appearance of a crumble. The batter looked like cookie dough more than cake batter. It could be formed into balls and baked as delicious cookies, but the results were not a cupcake because milk helps activate the gluten in the flour. Milk keeps the foam from collapsing as it cools. The no milk cupcake lacked structure and collapsed in the centre. It was crunchy on the outside and chewy on the inside.

Vegetable Oil

Vegetable oil adds flavour to cupcakes. It also helps break down the gluten from the flour to give a softer texture to the cupcake. The no vegetable oil cupcake had similar flavour to the control cupcake, but the texture was dense and chewy.

Vanilla

Vanilla adds flavour and aroma. Vanilla pods come from the vanilla orchid. The no vanilla cupcake resembled the control cupcake. There were no visible differences in the structure or texture, but it lacked the distinct vanilla flavour and aroma.

Conclusion

The results supported the hypothesis that each ingredient matters in the cupcake recipe. With each ingredient that was eliminated, the resulting cupcake was different from the control cupcake in appearance, texture, structure, or taste. Some ingredients made a bigger difference than others. When the flour, sugar, and milk were eliminated, the resulting cupcakes were significantly different than the control cupcakes in appearance, texture, structure, and taste. When the baking powder, egg, and vegetable oil were eliminated, they all produced cupcakes that were somewhat different in appearance, texture, structure, and taste. When the salt and vanilla were eliminated though, the only noticeable difference was in the flavour.

For future experiments, I would suggest exploring what happens when you modify one ingredient. For instance, what happens when you try the recipe using different types of flour (gluten-free flour, whole wheat flour, etc.). Or if someone had an allergy to cow's milk, could you substitute almond milk or soy milk and still get a delicious cupcake? Could you make a cupcake healthier by using less sugar or honey instead? This experiment could also be done using a cookie recipe.

Applications

Knockout Mice

One application of this experiment is that it mimics what happens in genetic engineering. Knockout mice are used in labs to study the effects of gene manipulation in a living organism. Scientists study mice that have had a specific gene knocked out. This relates to my experiment because every time that I eliminated an ingredient, I observed the changes. Scientists study the changes that happen when a specific gene is deleted. This is a benefit to humans because

knockout mice are used to study and model different human diseases such as diabetes and cancer. Knockout mice are also used to test treatments for these diseases.

Cupcake Industry

A delicious cupcake can grow into a business. In Canada alone, the retail sale of baked goods was about \$4.7 billion in 2017. Even though this includes breads, cakes, and other pastries, cakes accounted for 13% of sales, which is more than \$600 million.

Molecular Gastronomy

Molecular gastronomy is the scientific discipline that studies the physics and chemistry that occurs during cooking. These transformations are studied to create new dishes and cooking techniques. Low temperature cooking is one technique in molecular gastronomy. Liquid nitrogen can freeze ingredients on contact. You can make ice cream in seconds using this method.

Sources of Error

- Temperature of ingredients
- Amount of batter in each baking cup
- Time batter was sitting in pan before going in the oven
- Uneven heat distribution in oven
- Time from when cupcake cooled to time when it was tasted

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