THE CHEMISTRY OF CUPCAKES

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

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Science Fair Report
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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

<table>
<thead>
<tr>
<th></th>
<th>Full Recipe</th>
<th>Half Recipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour</td>
<td>2 cups (240 g)</td>
<td>1 cup (120 g) flour</td>
</tr>
<tr>
<td>Sugar</td>
<td>2 cups (400 g)</td>
<td>1 cup (200 g) sugar</td>
</tr>
<tr>
<td>Baking powder</td>
<td>1 tsp (4 g)</td>
<td>½ tsp (2 g) baking powder</td>
</tr>
<tr>
<td>Salt</td>
<td>½ tsp (6 g)</td>
<td>¼ tsp (3 g) salt</td>
</tr>
<tr>
<td>Eggs</td>
<td>2 eggs</td>
<td>1 egg</td>
</tr>
<tr>
<td>Milk</td>
<td>1 cup (250 mL)</td>
<td>½ cup (125 mL) milk</td>
</tr>
<tr>
<td>Vegetable oil</td>
<td>⅔ cup (160 mL)</td>
<td>⅓ cup (80 mL) vegetable oil</td>
</tr>
<tr>
<td>Vanilla extract</td>
<td>1 tsp (5 mL) vanilla extract</td>
<td>½ tsp (2.5 mL) vanilla extract</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Trial #1</th>
<th>Type of Cupcake</th>
<th>Batter Description</th>
<th>Baked Cupcake Description</th>
<th>Taste and Texture Description</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (All Ingredients)</td>
<td>Smooth, thick, pale yellow</td>
<td>Golden, fluffy, light</td>
<td>Delicious, delicate, sweet, perfectly formed</td>
<td>10 cupcakes</td>
<td></td>
</tr>
<tr>
<td>No Flour</td>
<td>Smooth, runny, pale yellow</td>
<td>Did not rise, overflowed, bubbly, burnt, unformed, wet, smells awful</td>
<td>Jelly consistency, flavour is good, lumpy custard, sweet, sticky</td>
<td>9 cupcakes</td>
<td></td>
</tr>
<tr>
<td>No Sugar</td>
<td>Beige, very thick, sticky</td>
<td>Cracks, looks more like bread than cake</td>
<td>Not sweet</td>
<td>10 cupcakes</td>
<td></td>
</tr>
<tr>
<td>No Baking Powder</td>
<td>A bit runny, pale yellow</td>
<td>Not golden, less rise</td>
<td>Denser, not as many pockets of air, tastes like control</td>
<td>11 cupcakes</td>
<td></td>
</tr>
<tr>
<td>No Salt</td>
<td>Slightly runny, pale yellow</td>
<td>Golden, looks identical to control</td>
<td>Very similar to control</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td>No Egg</td>
<td>Thick, pale yellow, looks like control</td>
<td>Golden, looks like control, did not rise as much, looks a little underbaked</td>
<td>A little chewy, a little underbaked, still flavourful</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td>No Milk</td>
<td>Batter did not form, looks like crumbly cookie dough, you can see the sugar crystals</td>
<td>Golden, lumpy, crumbly, sunk in the middle</td>
<td>Crunchy on the outside, chewy on the inside, sweet, like a crumble</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td>No Vegetable Oil</td>
<td>Paler, like control</td>
<td>Golden, like control, light, fluffy</td>
<td>Tastes different but still good, looks fluffy but is chewy</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td>No Vanilla</td>
<td>Identical to control, smooth, pale yellow</td>
<td>Identical to control, golden</td>
<td>Fluffy, identical to control, sweet but lacks flavour</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td>Trial #2</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td></td>
</tr>
<tr>
<td><strong>Type of Cupcake</strong></td>
<td><strong>Batter</strong></td>
<td><strong>Baked Cupcake</strong></td>
<td><strong>Taste and Texture</strong></td>
<td><strong>Sample Size</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Control (All Ingredients)</strong></td>
<td>Pale yellow, smooth, a little thick</td>
<td>Golden, fluffy, rose nicely, good structure</td>
<td>Delicious, fluffy, pleasant aroma, delicate moist, sweet</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Flour</strong></td>
<td>Pale yellow, runny</td>
<td>Lumpy, sticky, no structure</td>
<td>Sweet and clumpy</td>
<td>6 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Sugar</strong></td>
<td>Beige, sticky, not smooth like control</td>
<td>Cracks, large air bubbles, dense</td>
<td>Not as much flavour</td>
<td>7 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Baking Powder</strong></td>
<td>Smooth, pale yellow, identical to control</td>
<td>Flatter, did not rise as much, dense, not golden</td>
<td>Good flavour, sweet, still dense</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Salt</strong></td>
<td>A little thick, same to control</td>
<td>Light, air bubbles, golden</td>
<td>Tiny less sweet, still has good flavour</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Egg</strong></td>
<td>Smooth, thicker, pale yellow</td>
<td>Sunk in the middle, a little dense</td>
<td>Chewy, appears light and airy but is dense</td>
<td>10 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Milk</strong></td>
<td>Crumbly, sugar did not dissolve</td>
<td>Crumbly a bit underbaked, crusty</td>
<td>Hard, crunchy, sugar visible, crumbly</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Vegetable Oil</strong></td>
<td>Smooth, pale yellow</td>
<td>Did not rise as much, feels sticky, golden</td>
<td>Still flavourful, chewy, dense</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Vanilla</strong></td>
<td>Pale yellow, smooth</td>
<td>Golden, fluffy, air bubbles visible</td>
<td>No vanilla aroma or flavour</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td>Type of Cupcake</td>
<td>Batter</td>
<td>Baked Cupcake</td>
<td>Taste and Texture</td>
<td>Sample Size</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-----------------------------------------</td>
<td>--------------------------------</td>
<td>------------------------------------------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td><strong>Control (All Ingredients)</strong></td>
<td>Smooth, pale yellow, a little thick</td>
<td>Fluffy, golden, moist</td>
<td>Delicious, soft, moist</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Flour</strong></td>
<td>Runny, pale yellow, sugar did not dissolve</td>
<td>Bubbly, did not rise, overflowed</td>
<td>Sweet, caramelized, like a custard, lumpy</td>
<td>9 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Sugar</strong></td>
<td>Thicker than control, very sticky, less batter</td>
<td>Cracks, unformed, a little golden</td>
<td>Not sweet, still fluffy, like a biscuit</td>
<td>10 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Baking Powder</strong></td>
<td>Smooth, pale yellow</td>
<td>Did not golden, did not rise as much</td>
<td>Like control, flavourful</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Salt</strong></td>
<td>Same as control, a little thick</td>
<td>Rose, golden, fluffy</td>
<td>Like control, almost as sweet as control</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Egg</strong></td>
<td>Thicker, pale yellow, smooth</td>
<td>Sunk in the middle, golden</td>
<td>Not as fluffy, dense</td>
<td>11 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Milk</strong></td>
<td>Sugar is not dissolving, like crumbly cookie dough</td>
<td>Crumble, crusty, caved in, a little underbaked</td>
<td>Crunchy, not as sweet, sugar still visible</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Vegetable Oil</strong></td>
<td>Pale yellow, smooth</td>
<td>Golden, air bubbles visible</td>
<td>Spongy, drier, chewy</td>
<td>12 cupcakes</td>
<td></td>
</tr>
<tr>
<td><strong>No Vanilla</strong></td>
<td>Smooth, pale yellow</td>
<td>Rose nicely, golden, fluffy,</td>
<td>Airy, texture same as control, no aroma</td>
<td>12 cupcakes</td>
<td></td>
</tr>
</tbody>
</table>
Observations Based on All Three Trials

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


