Emulsions and Foams

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Introduction:

There are many benefits of including eggs in a healthy diet. Eggs are a cheap and good quality source of protein for many people. Eggs have a PDCAAS (Protein Digestibility Corrected Amino Acid Score) of 1.0, meaning the quality and digestibility of the amino acids in eggs is 100 percent in human nutrition. Eggs have all nine essential amino acids required by humans in adequate amounts, and they are all digestible in the average healthy person (1). Eggs also include every vitamin with the exception of vitamin C, as well as many minerals such as phosphorus, choline and selenium (2).

Eggs are also useful in making various food products through acting as a texturizer to create foam, act as a thickening agent, a food coloring, and an emulsifier.

Eggs can aid in the formation of a foam (a type of colloid—consisting of gas cells dispersed through a solid or liquid continuous phase), due to their naturally occurring proteins. Egg whites contain albumen proteins like ovalbumin, ovoglobulin, onlabumin and ovomucin. Ovalbumin, ovoglobulin, and onlabumin are sensitive to heat and pH, and can unfold when exposed to higher temperatures, allowing them to trap air bubbles within the water phase of a foam. The intermolecular bonds surrounding the proteins help to keep the unfolded protein in place. The entrapment of air bubbles in the proteins helps create the foaming effect of foods such as meringue. Proteins like ovomucin also aid in foaming because of their fibrous form. When beating, the fibers can be cut, which in turn increases the solubility of the egg whites, and creates a stronger network along the water-liquid interface of the foam, stabilizing it (3).

Eggs can act as a thickening agent by providing coagulating properties when heated. The proteins in eggs denature at high temperatures and begin to harden. When cooking, if agents like sugar are added to the eggs, the coagulation temperature can be increased. This is helpful in baking, as higher temperatures are used, and eggs can provide structure to the product without becoming too hard. They can also serve as a thickening agent in sauces without curdling.

Eggs can act as a food colorant by adding a yellow or orange hue to foods. Eggs contain carotenoid pigments that give them the traditional yellow yolk color. However, depending on the diet of the hen, the yolk color can have a richer or more pale color. Additionally, the diet of a hen can influence not only the color of the yolk, but also the nutritional value of the yolk.

Egg yolks contain compounds known as lecithins and lysolethicins. Lecithin is a phospholipid (phosphatidylcholine) that has strong polar and non polar properties. lysolethicin results from the partial hydrolysis of lecithin to remove a fatty acid. The polar and nonpolar properties of the phospholipids help to create a barrier that impedes contact between oil droplets, and makes what's known as an emulsion.

An emulsion is a temporarily stable mixture of normally incohesive fluids, like oil and water, created by dividing one phase into very small droplets. The polar and non polar properties of each fluid, with the addition of energy (whisking or beating) work together to form a layer coating the interfaces of each other, stopping contact between the oil droplets, and preventing the separation of the two liquids. An emulsifying agent is used most often in order to design cohesiveness throughout a product that normally would separate or otherwise interact undesirably. Emulsifiers keep food products like salad dressing and ice cream from separating out, and helps foods retain moisture and structure. Examples of other emulsions would be mayonnaise or butter. Mayonnaise is considered an oil-in-water emulsion, meaning there are oil droplets suspended in water. A water-in-oil emulsion, like in butter, means there are water droplets surrounded in oil.

Purpose:

The purpose of the meringue experiment was to evaluate the effects of sugar and cream of tartar in the formation of egg white foam, as well as compare traditional meringue to one made with aquafaba. Another purpose of this experiment is to evaluate how these variations affect the taste and texture of meringue.

Hypothesis:

I hypothesized that the egg white foam with sugar and cream of tartar would form stiff peaks that hold their shape while baking. I also hypothesized that the baked meringues would have a crunchy outside and malty inside, creating the most desirable sensory aspects. Cream of tartar lowers the pH and acts as a stabilizer to the foam, while sugar helps to increase the viscosity of the foam by binding with the water in the mixture and preventing the foam from draining too quickly.

Hypothesis:

I hypothesized that the egg white foam with cream of tartar and no sugar would not form as stiff peaks, and would drain faster, flattening when baked. I also hypothesized that the baked meringues would have no sweetness and be very fragile, overall tasting salty. Without the sugar, the foam will not have the additional stability from the hydrogen bonding to water, allowing the foam to drain faster and loose shape.

Hypothesis:

I hypothesized that the egg white foam with sugar, but no cream of tartar would form stiff peaks over a longer period of time and hold the majority of its shape while baking. I also hypothesized that the baked meringues would have a crunchy outside, and a somewhat chewy inside, overall tasting very sweet due to the lack of tartaric acid. Without cream of tartar, the foam will not have a reduction in pH, thus the proteins in the mixture will still have a charge and the foam will not be as stable, and there will be no acidic flavor to combat the sweetness.

Hypothesis:

I hypothesized that the use of aquafaba to make meringue would create a slightly less stable, yet still stiff foam that drains faster than traditional meringue, flattening a little while baking. I also hypothesized that the baked meringues would have an airy, crunchy texture, and a sweet taste. Aquafaba does not have the same types of proteins as egg whites, and thus does not create as strong of intermolecular forces to stabilize the foam it creates.

Purpose:

The purpose of the mayonnaise experiment was to evaluate how different emulsifying agents, olive oil and canola oil, affect the flavor and texture of traditional mayonnaise, as well as compare traditional mayonnaise to vegan mayonnaise made with aquafaba. Another purpose of this experiment is to evaluate how these variations affect the taste and texture of mayonnaise.

Hypothesis:

I hypothesized that the mayonnaise made with olive oil would have a smooth, silky texture, with an earthy flavor due to the natural favor of olive oil, and it would be fairly stable due to the composition of the fatty acids.

Hypothesis:

I hypothesized that the mayonnaise made with canola oil would have a silky texture, with an eggy, tangy flavor due to the neutral flavor of canola oil and addition of mustard, and have good stability due to the uniform composition of fatty acids.

Hypothesis:

I hypothesized that the mayonnaise made with aquafaba would be thin and watery, with a tangy flavor, and overall not very stable.

Methods:

<u>Baked Meringue</u>

In order to prepare the meringues, an oven was preheated to 250 degrees fahrenheit, and 140g of room temperature egg whites, and ¾ cups of aquafaba, for each variation were whisked on medium-low speed in a stand mixer, for a total of 3 egg white variations and 1 aquafaba. ½ a teaspoon vanilla extract was added to each variation. Next, salt was added to all variations except the aquafaba. ¼ teaspoon cream of tartar was added to the control, aquafaba, and no sugar variations. Once the mixtures started to foam, the speed of the mixer was increased to medium.

Sugar was added one tablespoon at a time to the sugar containing variations (control, sugar/no cream of tartar, and aquafaba) for a total of ¾ of a cup sugar added to each, waiting for each dose to fully dissolve before more was added. After passing through the "soft plop" stage, and the "soft-peak" stage was observed, the mixer was increased to medium-high speed. Once the "firm peak" stage passed and the "stiff peak" stage was reached, the egg whites/aquafaba mixture was spooned (roughly an inch apart) onto a baking sheet lined with parchment paper, using a leveled tablespoon. The meringue was baked for 60 minutes at 250 degrees fahrenheit, or until the outside was crisp and the inside dry. Once fully baked, they were left in the oven with the door cracked open to cool completely.

The remaining egg whites/aquafaba foam were observed for any changes in texture and overall appearance.

Some of the foam was then placed under a microscope and observed.

After the cookies were cooled, they were evaluated for sensory characteristics.

Measurements of Peaks

To determine the “soft plop” stage, egg whites were observed to hold onto the whisk, but not form peaks. The “soft peak” stage was identified by egg whites forming small peaks that fall over and melt back into the bowl. The “firm peak” stage was identified as egg whites/aquafaba that held its shape, but folded over when on the tip of a whisk. The “stiff peak” stage was identified as egg whites/aquafaba forming peaks that stood up straight and appeared glossy and smooth.

Mayonnaise:

Traditional-

To make traditional mayonnaise, 1 egg yolk, 15mL of vinegar, 2g of salt, and 1g of mustard were blended together with an electric egg beater for 15 seconds. Next, 60 mL of either olive or canola oil was added in 10mL increments, and beaten for 2 minutes after each addition of oil. The last 80mL of oil was added in 20 mL increments, and beaten for 2 minutes after each addition, using 140mL of oil in total.

A sample of each mayonnaise variation was observed under a microscope.

The mayonnaise was then evaluated for sensory characteristics.

Vegan Mayonnaise-

To make vegan mayonnaise, 45mL of aquafaba was bended until the liquid started to thicken. 10mL of mustard, 12 whole chickpeas, and 15mL of lemon juice was then added, and blended until it was completely smooth using a hand mixer. Next, with the mixer running, 60mL of canola oil was added in 10mL increments and beaten for 2 minutes after each addition. The remaining 60mL of canola oil was added in 20mL increments beating for 2 minutes after each addition, for 120mL of canola oil in total. 60 mL of olive oil was added slowly while continuously whisking the mixture. Salt was added at the end. The mixture was observed under a microscope and then evaluated for sensory characteristics.

Results:

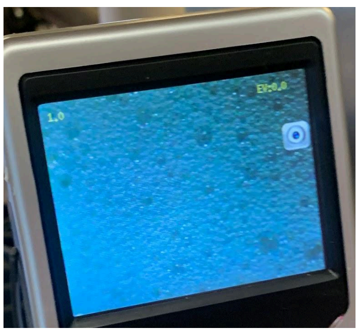
  Control	 Control	 No Cream of Tartar	  No Cream of Tartar	 No Sugar	 Aquafaba
 Control		 No cream of tartar		 No Sugar	 Aquafaba

Figure 1

The different variations of foams including comparisons of the same variation made by different cooks, with batch one to the left and batch two to the right. The foam appearance under a microscope is pictured below. They are ordered control, control, no cream of tartar, no cream of tartar, no sugar, and aquafaba/vegan (Left to Right).

The control meringue had smooth, stiff peaks with a glossy appearance. The first control foam had a taller appearance than the second control. Both have very consistent appearing surfaces, with no large air pockets or rough texture. The microscope pictures show very small, compact bubbles making up the foam.

The no cream of tartar variation had a more textured outside appearance with large air pockets and no glossy shine. The first batch had less stable peaks than the second. Under the microscope, the foam had air bubbles of varying size.

The no sugar variation had a very airy, unstable outside appearance. It does have strong peaks, however, it has many air pockets and no smooth shine to it. Under the microscope, the foam had very large bubbles.

The aquafaba variation had a smooth, glossy appearance. It does not have as stiff of peaks as the control. Under the microscope, it had varying bubble size, with jagged edges on some.

The baked control meringues did not have a very dense or soft texture, or have any moisture. The first batch had a hard and sticky texture, and no crunch. The second batch had a malty, almost chalk-like feel when bitten into.

The baked meringues with no cream of tartar had a more dense texture when bitten into, with no moist component. The second batch was more malty, and dissolved in your mouth, while the first had a hard outside, but stuck to your teeth. They were both very sweet.

The no sugar variation had a very airy and fragile texture. It crumbled very easily and almost immediately dissolved when bitten into, similar to cotton candy. It had no moisture, and a salty, almost buttery flavor.

The aquafaba variation was not very dense when bitten into. It had a crunchy and flakey texture, with a small amount of moisture. Overall, it was fairly sweet.

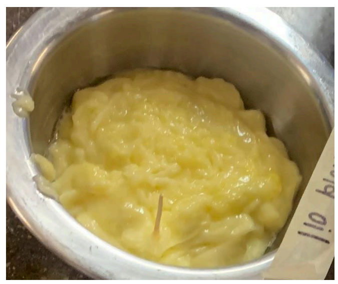
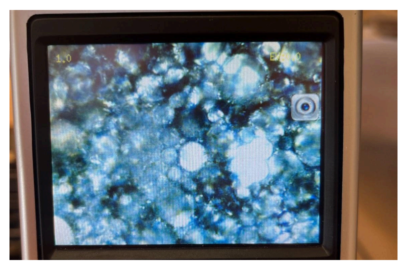
 Olive oil	 Canola oil	 Aquafaba/Vegan
 Olive oil	 Canola oil	 Aquafaba/Vegan
		

Figure 2

The different variations of mayonnaise and their appearance under a microscope are pictured. The same variations made by different groups, with batch one depicted above, and batch two below it are shown as olive oil, canola oil, and aquafaba/vegan (Left to Right).

The olive oil mayonnaise had a yellow color, and had a thin, creamy texture, with a sour, earthy aftertaste. Overall, both had very smooth, creamy mouthfeel and good cohesiveness. The first batch of olive oil variation was thinner and had a stronger sour aftertaste. The second variation was more structured and thick. Under the microscope, the emulsion had very few droplets visible.

The canola oil mayonnaise was yellow and had different outcomes between the two batches. The first batch was very thin, oily, and had no aftertaste. It did have somewhat of an eggy flavor. It also had a smooth creamy mouthfeel. The second batch was much thicker and had a whipped appearance. It also had a very sour taste, and a fluffy, thick mouthfeel. Both batches had good cohesiveness. Under the microscope, the emulsion had medium sized oil droplets.

The aquafaba mayonnaise was very yellow and watery looking. Both batches were thin. The second batch had visible chunks in texture, and was not cohesive. Under the microscope, the emulsion had what appeared to be many droplets very close together.

The aquafaba mayonnaise was a dark yellow color and had differing outcomes between the batches. The first batch had a very strong mustard flavor and a smooth mouthfeel. It also had good cohesiveness. The second batch had little flavor and a grainy mouthfeel. It also had poor cohesiveness, with chunks throughout.

Discussion:

Meringues

I expected the control to be the most stable. It has sugar to stabilize it and reduce draining in the foam, and intermolecular forces between the hydroxyl groups of the sugar and interactions with the proteins and water in the egg whites around it to entrap air. It also has cream of tartar to reduce the pH of the egg white, helping it stabilize, and form stiff peaks. The foam itself , in Figure 1, also looks glossy, smooth, and has well developed peaks. Under the microscope, in

Figure 1, the foam has small, evenly spaced and consistently sized bubbles of air, implying it has a dense, consistent texture and does not flatten or collapse inside. Without sugar to help stabilize the foam and reduce drainage, or cream of tartar to lower the pH and prevent coagulation and hardening of the egg whites, the other variations should not be as desirable texturally or flavor wise.

The first batch of control meringues has a chalky, malty texture. The second batch has a hard and sticky texture, clinging to your teeth after chewing. The first batch of control meringues has the best texture overall. It holds its shape and has a crunchy, malty texture. This is likely because it has both sugar and cream of tartar in it to help get these stabilizing characteristics. The sugar acts as a stabilizer by binding its hydroxyl groups with the water in the mixture, increasing the viscosity and therefore lowering the drainage of the foam. The cream of tartar helps to lower the pH of the mixture, in turn reducing the charge of the proteins in the egg whites, and reducing coagulation and hardening of the foam. The cream of tartar also helps add some acidity to the flavor, cutting the sweetness of the sugar added. The second batch of meringues may have a hard and sticky texture as opposed to a malty crunchy texture because it was overwhipped or the sugar was added too quickly. Over whipping the mixture can cause it to lose moisture and lead to collapsing foam. If sugar is added too quickly, this can also cause the foam to collapse from weight, or not get as evenly dispersed and dissolved, which may have led to the hard, sticky texture experienced when chewing the baked meringue.

The first batch of no cream of tartar variation, in Figure 1, has a hard outside and also sticks to your teeth. The second batch has a dense, malty, crunchy texture. The second batch was similar in texture to the first control batch. This was not expected, but the technique with which the foam was created may have created a more stable foam. Whipping the egg white foam with enough energy and without overwhipping could have helped create a more stable foam. Additionally, if the sugar was added slowly, that may have helped the foam retain its volume and hold air bubbles, despite not having the tartaric acid to help unfold the proteins to capture air more effectively. The first batch may have a hard outside and feel sticky because without cream of tartar, the egg whites did not experience a reduction in pH, and thus the proteins did not unfold, sticking together and making the foam as a whole tougher. Both batches are very sweet. The sweetness is likely due to the overpowering of the sugar, not having any acidity from the tartaric acid to balance out the flavor.

The no sugar variation has a light, airy texture, and is very fragile. Without sugar, the egg whites don't have the intermolecular forces between the sugar hydroxyl groups and the water in the mixture to increase the viscosity of the foam and stop drainage. Drainage while baking may cause the fragility of the meringues, as most of the moisture of the cookies was lost during that time. The drainage and inability to keep small, compact air bubbles in the mixture is also observed under the microscope seen in Figure 1. Under the microscope, the foam has much larger bubbles compared to the other variations. The cookies are able to still keep some volume thanks to the cream of tartar allowing the proteins in the egg whites to lose their charge and hold open enough to trap some air bubbles and stabilize the mixture. The cookies are not sweet, and almost have a savory, buttery flavor. Without sugar, there is nothing to make the cookies sweet. Still having cream of tartar however helps to add to the savory flavor of the meringue.

The aquafaba variation has a flakey, crunchy texture, with some moisture. Aquafaba contains albumins and globulins, similar to egg whites, that help to capture air bubbles and create a stable foam. In addition, aquafaba has other carbohydrate compounds including saponin (4); an amphiphilic glycoside that also aids in stabilizing foams by creating more intermolecular forces between the water and sugar in the mixture. With the cream of tartar lowering the pH of the proteins and unfolding them, and the sugar adding intermolecular forces between the hydroxyl groups and water molecules to hold the unfolded proteins in place for air to get trapped, aquafaba forms a desirable foam. Under the microscope, as seen in Figure 1, the aquafaba has uniform bubbles, and an almost jagged shape. The stability of the sugar and cream of tartar helps form the consistent bubbles. The jagged surroundings of the bubbles may be due to the intermolecular forces interacting more strongly with the water and various carbohydrate compounds in the mixture, as opposed to the egg white foams, which formed bonds mostly with just the water, sugar and proteins. The baked aquafaba meringues have a sweet flavor with a slight aftertaste. The aftertaste is due to the additional compounds found in aquafaba. Saponins themselves are known to be bitter tasting, and may add to the musky aftertaste of the cookies.

If yolk got into the egg white foam, the fats in the yolk would interact with the protein's hydrophobic residues, and inhibit the formation of foam. The fats in the yolk prevent the protein molecules from properly bonding to one another, and thus can't hold air bubbles and form a stable foam. Egg yolks are also a common emulsifier, meaning they help liquids like oil and water mix together. In the context of creating an egg white foam, this would make the foam runny and liquidy, rather than airy and firm. Another consideration would be the added yellow color from the carotenoids in egg yolk, which may not be desirable in a meringue.

Mayonnaise

The olive oil and canola oil mayonnaise, seen in Figure 2, has varying stability and flavor. The olive oil overall has a thinner , creamier texture than the canola oil. The olive oil also has an earthy and sour aftertaste. The thinner texture may be due to the whipping technique used.

If the oil is added too fast to the mixture, it can break the phases, creating a thinner mayonnaise, and a separation between the vinegar and oil phases. The earthy aftertaste may be due to the nature of olive oil itself. Olive oil has many polyphenols and antioxidants that can contribute to an earthy flavor. The sourness is likely due to the mustard and vinegar not being fully emulsified in the mixture. The creaminess of the olive oil is likely due to its fatty acid composition (5). Olive oil has more monounsaturated and saturated fats , and less polyunsaturated fats that canola oil does, adding to a creamier texture. The canola oil mayonnaise has a thicker texture, a fuller mouthfeel, and an eggy flavor. The thickness may be due to the beating technique used, fully emulsifying the mixture, and creating a more stable outcome. It also doesn't have many other compounds in it like olive oil does, and thus has a neutral flavor, allowing the eggy taste from the yolk to be slightly noticeable. Under the microscope, the canola oil seen in Figure 2 has larger oil droplets suspended in the water. The olive oil is harder to differentiate where the oil droplets are. The lack of visible droplets in the olive oil may be an indication that the emulsion is not fully mixed together, and the droplets of fat are not dispersed entirely. The canola oil has the appearance you would expect in an oil in water emulsion—seeing oil droplets suspended in water.

The aquafaba, seen in Figure 2, has a very thin, runny texture, and a sour flavor. One of the batches made also had a grainy texture throughout it. Under the microscope, it looks like many droplets or air bubbles very close together, and of varying sizes. Compared to the traditional mayonnaises, the aquafaba does not get nearly as emulsified and thick, or have the suspended oil in water droplets seen in the canola oil, under the microscope. Aqufaba does not have the same lipid components found in the egg yolk traditionally used in mayonnaise. Without the emulsifying agent like lecithin, found in the yolk, in the mixture, aquafaba has few properties to help the oil integrate. Aquafaba has polysaccharides and proteins that help to coat the fat droplets of the oil, but lack the lecithins to effectively interact with either hydrophobic and hydrophilic phase of the mixture. Additionally, the aquafaba has a very sour flavor, taking on the mustard and lemon juice as the only flavor component. Without the lecithins to help the aquafaba and oil homogenize, the mustard and lemon juice flavor can't be encapsulated by the fat droplets and dispersed in the mixture. Additionally, the aquafaba won't be as stable, and will be more likely to coalesce, breaking the emulsion between the fat and water, and leading to the runny texture observed in Figure 2. The grainy texture of the vegan mayonnaise is either from the whole chickpeas included in the recipe, or the salt not being dissolved. Aquafaba itself is not a good mayonnaise substitute. It lacks the natural lecithins needed to create a good emulsion. If something like soy lecithin was added to the recipe, that would have the potential to greatly improve the outcome, and be more comparable to traditional mayonnaise.

In this experiment, the vegan mayonnaise used both olive and canola oil. If only olive oil had been used, I think the outcome would be slightly better texturally, however using canola oil would have had a better outcome flavor wise. Canola oil doesn't have the polyphenols and antioxidants that olive oil has, which gives it a neutral flavor. Olive oil however has a different fatty acid composition than canola oil, containing more monounsaturated and saturated fatty acids, and less polyunsaturated fats, giving it a creamier, thicker texture (5). In general, using just one oil should help create a more consistent texture and inhibit breakage of the phases by having fewer lipid compounds affecting the intermolecular forces between the proteins and polysaccharides of the aquafaba.

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