Flavor and mouthfeel of pseudo-cocoa liquor: Effects of polyphenols, fat content, and training method

Terianne Y. Hamada | Allison Brown | Helene Hopfer | Gregory R. Ziegler

Abstract

Current theories of astringency propose that this sensation is a result of delubrication in the oral cavity due to precipitation of salivary proteins. Astringency, commonly described as a drying or puckering sensation, is a main driving factor for rejection of certain foods. Previous studies have shown that fat plays a role in moderating astringency in foods. To investigate the role that polyphenols and fat play in astringency perception, we used modified cocoa powders to produce pseudo-cocoa liquor systems that were rated for taste and flavor attributes on generalized Labeled Magnitude Scales by semi-trained consumers. Our results show significant differences among the cocoa liquors, resulting from acetone-water extraction of free polyphenols and fat content variation. No significant differences resulted from training with oil-based vis-à-vis water-based reference solutions.

Practical Applications

Astringency is a prominent sensation commonly experienced by individuals who consume cocoa and chocolate products. It is of the utmost importance to the cocoa and chocolate industry because consumers typically reject products that are highly astringent. Therefore, study of the perception of astringency and the role that polyphenols and fat play would benefit our understanding of these fat-based products. Training with aqueous-based references, which was easier than oil-based references, yielded equivalent results.

1 | INTRODUCTION

Astringency is a complex sensation defined by the American Society of Testing and Materials as “the complex of sensations due to shrinking, drawing, or puckering of the epithelium as a result of exposure to substances such as amines or tannins” (1989). Studies have shown that astringency can be an important driving factor for the rejection of certain foods and beverages (Dinnella, Recchia, Tuorila, & Monteleone, 2011; Lesschaeve & Noble, 2005). Cocoa is a common dietary source of astringent compounds, mainly polyphenols (Jaganath & Crozier, 2009; Kim & Keeney, 1983; Lee, Kim, Lee, & Lee, 2003; Martin, Goya, & Ramos, 2013). The prevailing theory behind astringent perception of polyphenolic compounds is that they bind to salivary proteins, causing aggregation and precipitation (Bajec & Pickering, 2008; Lyman & Green, 1990). This results in delubrication of the oral tissues and the perceived drying or roughing qualities of astringency (Bajec & Pickering, 2008; Lyman & Green, 1990). However, this theory suggests that relubrication can be facilitated by the addition of fat, which is contradicted by the well-perceived astringency of cocoa liquor (typically 50% fat) (Des Gachons et al., 2012; Fleming, Ziegler, & Hayes, 2016b; Luna, Crouzillat, Cirou, & Bucheli, 2002). Thus, other researchers have proposed that astringency is the result of a receptor-based mechanism, similar to sweet, bitter, and umami tastes (Schöbel et al., 2014). With evidence to support both sides, researchers are faced with the challenge of elucidating the true mechanism and consistently defining the sensation. In 1991, Lee and Lawless broadened the definition of astringency to include the distinct subqualities such as drying, roughing, and puckering (Lee & Lawless, 1991). Bajec and Pickering (2008) reported that along with these three subqualities, astringency is also commonly associated with two
side tastes: sour and bitter. Although these qualities may be distinct, it can be difficult for consumers or even trained panelists to perceive them independently (Fleming, Ziegler, & Hayes, 2016a).

The first objective of the present study was to examine the contribution of bound polyphenols to taste and astringent qualities. Most studies on polyphenols, in general, focus on the study of readily extractable or free polyphenols (Bruna, Eichholz, Rohn, Kroh, & Huyskens-Keil, 2009; Sadilova, Carle, & Stintzing, 2007; Wollgast & Anklem, 2000). Bound polyphenols comprise the phenolics that are not readily extractable by organic solvent–water mixtures. In cocoa, these polyphenols are bound within the matrix of the plant material by fibers, proteins, and other carbohydrates, and require hydrolysis to be extracted (Shahidi & Yeo, 2016). Previous studies have shown the existence of bound phenolics in cocoa; however, no study, in so far as we know, has investigated their contribution to taste, flavor, and mouthfeel of cocoa-based products (Dai, 2017; Fleming et al., 2016a; Misnawi, Jinap, Jamilah, & Nazamid, 2004). Thus, research of this kind is worthwhile and may contribute to understanding of the role that polyphenols play in taste, flavor, and mouthfeel, especially with regard to astringency.

Based on the delubrication mechanism of astringency, we hypothesized that in addition to free polyphenols, bound polyphenols would contribute to the astringent subqualities of cocoa. Although bound polyphenols are chemically and/or physically bound by carbohydrates and proteins in cocoa, they may still be able to bind and precipitate salivary proteins, albeit not as effectively as free polyphenols. We further hypothesized that bound polyphenols would not contribute to the astringent side tastes, bitter and sour, because access to taste receptor active sites is hindered by their size.

Due to its prominence in beverages such as tea, coffee, and wine, astringency is most often studied in aqueous-based systems (Scharbert, Holzmann, & Hofmann, 2004). However, astringency is equally important in fat-based systems such as chocolate. In a food matrix like chocolate or cocoa liquor, fat may play an important role in astringency perception due to its ability to act as a lubricant. Thus, our second objective was to determine the effect(s) of varying fat content in a pseudo-cocoa liquor model. Assuming the delubrication mechanism of astringency, we hypothesized that increasing fat content would reduce the perceived intensity of the subqualities of astringency but would not affect the side tastes. Increasing fat content should provide lubrication to reduce the drying and roughing but not influence the interaction of polyphenols with sour or bitter taste receptors.

Similar to Fleming, Ziegler, and Hayes (2016b), we provided a brief training for our consumer panelists prior to testing. The goal of this training session was to familiarize participants with the attributes to be rated—Bitter, Sour, Sweet, Umami, Salty, Astringent, Drying/roughing, Puckering, Mouthfeel, and Cocoa flavor—and the generalized Labeled Magnitude Scale (gLMS) (Bartoshuk et al., 2003). To quantitatively measure the differences in perceived attribute intensity, the gLMS was used. The gLMS is a semantically labeled scale with a top anchor of “Strongest Sensation of Any Kind” and has been shown to be a robust quantification measurement for perceived intensity of astringency (Fleming et al., 2016a). The generalized nature of the gLMS increases the validity of results, thus allowing for meaningful comparisons between groups and individuals (Bartoshuk et al., 2003).

A third objective of this study was to determine whether the training reference matrix would affect the results. Typically reference solutions for taste and mouthfeel attributes are water based, due in part to the fact that most taste and mouthfeel reference standards are water soluble but not oil soluble. However, we hypothesized that for a high-fat food matrix such as chocolate, the use of a reference matrix that was closer to the sample matrix (cocoa liquor is around 50% fat) would produce more robust results. Thus, in the second experiment of this study, liquid references for training were presented in oil rather than in water.

2 | MATERIALS AND METHODS

2.1 | Defatting cocoa powder

Natural cocoa powder (NCP, 10–12% cocoa butter by mass; Gerkens Cacao, Cargill, Minneapolis, MN) was defatted prior to phenolic extraction (Dai, 2017). A 5:1 (v/w) ratio of hexanes (ACS grade 99.9%, Fisher Chemical) to cocoa powder was used to remove cocoa butter from the samples. Samples were mixed at room temperature in an Erlenmeyer flask on a DS-500 orbital shaker (VWR, Radnor, PA) for 15 min at 300 rpm, and subsequently filtered under vacuum using No. 4 Whatman filter paper (GE Healthcare, Buckinghamshire, UK). Extraction with hexanes was repeated a total of three times. The defatted powder was air-dried overnight in a fume hood, then placed in a vacuum oven at 80°C for 24 hr, to yield the defatted cocoa powder (DFCP) fraction that contained the free and bound polyphenol fractions.

2.2 | Removal of (free) polyphenol fraction

Free phenolics were removed from DFCP using a 70:30 (v/v) mixture of acetone (ACS grade, 99.5+%; Alfa Aesar) and nanopure water (18 MΩ-cm; Barnstead NANOpure ultrapure water system, Lake Balboa, CA). A 5:1 (v/w) ratio of extraction solvent to DFCP was used. The cocoa powder and solvent were mixed at room temperature using an orbital shaker, for 15 min at 300 rpm, followed by vacuum filtration using No. 4 Whatman filter paper. This extraction was repeated a total of four times. The remaining powder was air-dried overnight in a fume hood and placed in a vacuum oven at 80°C for 24 hr to yield the fraction of the cocoa powder that is free of cocoa fat and the acetone extracted cocoa powder (AECP) (Dai, 2017). All samples were analyzed for residual solvents and were found to be below acceptable limits as set forth by USP (USP40, 2016).

2.3 | Experiment 1

2.3.1 | Sample formulation and preparation

Two sets of pseudo-cocoa liquor samples were formulated. The first set was NCP (10–12% cocoa butter by mass; Gerkens Cacao, Cargill)
adjusted to 42, 44, and 46% final fat content with canola oil (Wesson, Conagra, Chicago, IL). The second set of samples was prepared from 42% fat with canola oil and using either DFCP or AECP. The sample AECP was further mixed using a Premier Wonder Grinder (SS Premier, Diamond Trading Inc., Princeton, NJ) for 1 hr to reduce the particle size because after drying, the powder had visible chunks. Pseudo-liquors were mixed, using a spoon, with an appropriate amount of canola oil until no dry powder was visible. For the test, the pseudo-liquor was portioned out as 0.5 g samples and served with 6.35 cm makeup spatulas (Pana Brand, Beauticom Inc., Arcadia, CA) in uncovered 37-ml graduated plastic soufflé cups (Dart Container Corp., Mason, MI). The pseudo-liquors were formulated with canola oil instead of additional cocoa butter to be liquid at room temperature since astringency in cocoa liquor is not perceived until the sample has sufficiently melted, and cocoa butter-containing samples would have been solid at room temperature.

2.4 | Sensory testing

2.4.1 | Participants

Participants (n = 101; 65 females; 22–66 years old; median age = 45 years old) were recruited from the Pennsylvania State University campus and the surrounding State College, PA area. Criteria for eligibility included: no food allergies or sensitivities; no known taste or smell defects; not taking any medication known to affect taste or smell; not pregnant or breastfeeding; nonsmoker; no history of choking or difficulty swallowing; no lip, cheek, or tongue piercings; between 18 and 65 years old; and a willingness to taste chocolate sauce. Participants provided informed consent and were compensated for their time in accordance with the procedures approved by the Pennsylvania State University Institutional Review Board (protocol number 33164).

2.4.2 | Training

Testing was split into 2 days. On the first day of experiment 1 the participants received a brief 15-min training session. Training began with the presentation of references for 9 out of 12 attributes that were rated during the test (Table 1). All liquid references were presented as aqueous solutions, except the reference for Mouthcoating, which was plain canola oil. Participants were given 10 ml of each reference solution in a covered 37-ml graduated plastic soufflé cup (Dart Container Corp., Mason, MI). Instructions for references were as follows: Drying, pat gauze on tongue and areas of inside the mouth; Roughing, rub rough side of sandpaper gently on tongue in a circular motion; for solutions, sip solution, take note of sensation, and then spit out the sample. Along with the references, participants were also provided with written definitions of all attributes (Table 1), which were also provided as a drop-down menu in Compusense during the test. Although the attributes Drying and Roughing were presented independently during training, they were rated together during testing, because previous studies have shown that participants do not

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astringent</td>
<td>Common sensations experienced in the mouth when consuming any of the following foods: tea/coffee without milk, cranberry juice, unripe fruit, red wine, and/or dark chocolate</td>
<td>1.5 g/L tannic acid (Spectrum Chemicals) (in DI water)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.55 g/L tannic acid (Spectrum Chemicals) (in canola oil)</td>
</tr>
<tr>
<td>Drying</td>
<td>Lack of lubrication or friction between surfaces of the mouth</td>
<td>5.1 cm x 5.1 cm, 12ply sterile gauze pad</td>
</tr>
<tr>
<td>Roughing</td>
<td>Physical bumpiness of the tissues, not unlike coarse sandpaper</td>
<td>2.5 cm x 7.5 cm, P1500 sandpaper</td>
</tr>
<tr>
<td>Puckering</td>
<td>Tightening or drawing sensations that can be felt in the cheeks and muscles of the face</td>
<td>—</td>
</tr>
<tr>
<td>Mouthcoating</td>
<td>Gives the impression of a coating film that adheres to mouth surfaces and which falls from the mouth surfaces with time</td>
<td>Canola oil (Wesson brand)</td>
</tr>
<tr>
<td>Salty</td>
<td>Fundamental taste sensation elicited by salts</td>
<td>2.5 g/L NaCl in DI water</td>
</tr>
<tr>
<td>Sweet</td>
<td>Fundamental taste sensation elicited by sugars</td>
<td>30 g/L sucrose in DI water</td>
</tr>
<tr>
<td>Bitter</td>
<td>Fundamental taste sensation elicited by caffeine, quinine</td>
<td>1.0 g/L caffeine (Sigma-Aldrich, FC) (in DI water)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5 g/L theobromine (MP Biomedical) (in canola oil)</td>
</tr>
<tr>
<td>Umami</td>
<td>Chemical feeling factor elicited by certain peptides and nucleotides</td>
<td>5 g/L monosodium glutamate (B&amp;G Foods) (in DI water)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 g/L monosodium glutamate (B&amp;G Foods) (in canola oil)</td>
</tr>
<tr>
<td>Sour</td>
<td>Fundamental taste sensation elicited by acids</td>
<td>1.5 g/L citric acid (Sigma-Aldrich) (in DI water)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0 g/L citric acid (Sigma-Aldrich) (in canola oil)</td>
</tr>
<tr>
<td>Cocoa flavor</td>
<td>Common flavor/aroma notes characteristic of chocolate and other cocoa products</td>
<td>—</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>—</td>
</tr>
</tbody>
</table>
illustrate the use of the gLMS (Hayes, Allen, & Bennett, 2013).

During training, participants were also introduced to the gLMS, which they used to rate the perceived intensity of the attributes. A brief explanation of scale usage and examples was given. It was emphasized to participants that the scale is used for intensity ratings, not liking. Examples such as “brightness of a dimly lit room < brightness of a well-lit room < brightest light you have ever seen” and “loudness of a whisper < loudness of a conversation” were used to illustrate the use of the gLMS (Hayes, Allen, & Bennett, 2013).

2.4.3 | Attribute rating/testing

On the first day, participants rated the three samples made from NCP varying only in fat content (42–46%). On the second day, participants rated the two samples made from DFCP and AECP with 42% fat content. Samples were presented monadically and the order of presentation was counterbalanced across the participants so that within a testing day each sample was seen at each position about the same number of times. Participants were instructed to rate the perceived intensity of the attributes with the samples in their mouth and spit samples after rating. To clear their palate in between samples, they were instructed to eat a cracker and rinse with water during a 3-min break.

2.5 | Experiment 2

2.5.1 | Sample formulation/preparation

Samples were prepared using NCP and adjusted to final fat contents of 46, 51, and 56% using canola oil. NCP was mixed with an appropriate amount of canola oil using a spoon, until no visible dry powder was observed. Samples were portioned out as 0.5 g samples and served with 6.35-cm makeup spatulas (Pana Brand, Beauticom Inc., Arcadia, CA) in uncovered 37-ml plastic soufflé cups (Dart Container Corp., Mason, MI).

2.6 | Sensory testing

2.6.1 | Participants

Participants (n = 100, 57 females; 20–65 years old; median age = 42 years old) were recruited from the Pennsylvania State University campus and the surrounding State College, PA area. Criteria for eligibility were the same as for experiment 1. A total of 53 participants in experiment 2 also participated in experiment 1, while the remaining 47 were new to the study. Participants provided informed consent and were compensated for their time in accordance with the procedures approved by the Pennsylvania State University Institutional Review Board (Protocol No. 33164).

2.6.2 | Training

Participants were given a brief 15-min training session prior to testing, similar to experiment 1. Training was conducted in the same manner as experiment 1, starting with presentation of attribute references and definitions, followed by introduction and explanation of the gLMS. The same references were used, as in experiment 1; however, liquid samples were presented in oil, rather than water and participants were given 5 ml instead of 10 ml of the references. Prior to tasting liquid references, participants were instructed to shake and/or stir samples to ensure a homogeneous sample. As in experiment 1, written definitions were presented and provided within the test, in a drop-down menu.

2.6.3 | Testing

Samples were presented monadically and counterbalanced across participants, so each sample was seen at each position about the same number of times. As in experiment 1, participants were instructed to rate the perceived intensity of the attributes while the sample was in their mouth and spit the sample out after rating. Instructions to consume a cracker and rinse with water were also presented during a 3-min break between each sample.

2.7 | Data analysis

Data were collected using the Compusense Cloud software (Compusense Inc., Guelph, Ontario, Canada). Statistical analyses were performed using R Studio (v. 3.4.4, Boston, MA) and R (v. 3.4.4) with the additional package “agricolae.” Phenolic comparison data were analyzed using MANOVA with Wilks’ lambda and paired t-tests, while the remaining datasets were analyzed using MANOVA with Wilks’ lambda, ANOVA, and post hoc comparisons with Tukey’s honest significant difference (following significant ANOVA). Significance was set at $p < .05$ for all tests.

3 | RESULTS AND DISCUSSION

3.1 | Experiment 1

3.1.1 | The effect of free versus bound phenolics on astringency

To test the hypotheses that both free and bound polyphenols contribute to perception of Astringency and associated subqualities or side tastes, samples were made using DFCP that contained all polyphenols and cocoa powder from which free polyphenols and other acetone-water soluble compounds had been extracted (AECP). We hypothesized that stripping the cocoa matrix of the free polyphenols and other acetone–water solubles would result in a decrease in the attributes Astringency, Bitterness, Sourness, Drying/Roughing, and Puckering. Polyphenols are implicated in the currently accepted delubrication mechanism underlying the astringency of many foods, such as chocolate. By
removing the free or readily extractable polyphenols, a reduction in astringency is expected due to lower availability of polyphenols to precipitate salivary proteins, resulting in delubrication of the oral cavity. The DFCP sample differed significantly from the AECP sample as determined by MANOVA ($\lambda = 0.5466$, $1/200$ df, $F = 14.326$, $11/190$ df, and $p < .05$).

Analysis of the individual attributes using ANOVA found that there were significant differences in the rating of the following attributes: Bitter, Sour, Drying/roughing, Cocoa flavor, Salty, and Sweet ($p < .05$). As expected, sample AECP—the sample that was stripped of fat, free phenolics, and other acetone-water solubles—had significantly lower intensity ratings for astringent side tastes (Bitter and Sour) and Cocoa flavor (Figure 1), likely due to the extraction of theobromine and caffeine (Bitter), organic acids (Sour), and aromatics (Cocoa flavor). However, an increase was seen in the intensity ratings for Drying/Roughing, which may be attributed to particle size differences, as AECP had visibly larger particles prior to processing. Although the results do not provide conclusive evidence about the mechanism of astringency, it does suggest that both free and bound polyphenols contribute to its perceptions, since Astringency is still perceptible after extraction of acetone-water solubles. Our data also suggest that the subqualities and side tastes may be distinct phenomena as we see that Drying/Roughing increased after extraction of the free polyphenols and acetone-water solubles, while Bitter and Sour decreased, and Astringency and Puckering did not change significantly.

In addition, we were also able to compare samples from cocoa powder that had been defatted (DFCP) with samples from cocoa powder that had not been defatted (NCP) at equivalent fat content of 42%. NCP contained 5–6% wt. cocoa butter with 36–37% wt. canola oil, while DFCP contained no cocoa butter and 42% wt. canola oil. The results of MANOVA revealed no overall differences in any of the attributes ($\lambda = 0.9182$, $1/203$ df, $F = 1.563$, $11/193$ df, and $p > .1$), indicating that the substitution of canola oil for cocoa butter in the pseudo-cocoa liquor model did not affect sensory results and can be used for sensory testing.

![FIGURE 1](image)

**FIGURE 1** Mean attribute intensity ratings of defatted cocoa powder (DFCP) and acetone extracted cocoa powder (AECP). Attributes that are significantly different by t test are marked with *; $p < .05$

3.2 | **Experiment 2**

3.2.1 | **Fat content**

The second objective of this study was to determine the effect of fat content on Astringency and its associated subqualities and side tastes. We hypothesized that as fat content increased, there would be a decrease in perceived intensity ratings of Astringency, Drying/Roughing, and Puckering since with a higher fat content there would be more lubricity to counteract the delubrication caused by astringent stimuli. Furthermore, we predicted that there would be minimal changes in perception of side tastes due to changes in viscosity and mass transport to taste receptors.

The results of ANOVA revealed significant differences in perceived intensity of the attributes Mouthcoating, Drying/Roughing, and Puckering (Figure 2). All other attributes were found to be not significantly different ($p < .05$). As fat content increased, perceived intensity of each of these attributes decreased. Post hoc regression analysis showed a significant linear effect ($p = .001$) of fat content on perceived intensity of all three attributes. For the astringent subqualities Drying/Roughing and Puckering, this was consistent with our hypothesis based on the delubrication mechanism. However, Mouthcoating was expected to increase with more oil to coat the surfaces of the mouth. We suspect that this reversal was observed due to misunderstanding in the definition for this attribute. Related pilot studies on cocoa liquor in our lab revealed this same dissonance between what we were attempting to measure and the participants’ interpretation of Mouthcoating. By using canola oil as the reference material for this attribute, we intended for participants to rate the intensity of the oiliness of the oral surfaces, such as tongue, cheeks, and gums, and expected to see an increase with higher fat content, as there would be more oil to coat the insides of the mouth. In contrast, participants may have rated the perception of how easy it was to clear their mouth; with increasing fat content, it was easier for them to clear their mouth of the cocoa-liquor because with increasing fat content the cocoa-liquors were less sticky or adhesive. A potential alternative word choice might be Sticky (Pascua, Koç, & Foegeding, 2013) or use...
of a modified definition or reference, such as peanut butter may be helpful in future studies.

### 3.2.2 Training comparison

The final objective of this study was to compare the results of the 46% fat sample between Experiments 1 and 2. In doing so, it was hypothesized that differences in training, that is, the reference matrix, would lead to differences in the ratings of the 46% fat sample that was otherwise the same in both experiments. Since references suspended in canola oil would be more similar to the sample testing matrix than references dissolved in water, we expected that ratings after presentation of oil references in the training (Experiment 2) would yield a significant difference between attribute intensity ratings using the different training sets.

When comparisons were made between Experiments 1 and 2, including all participants, no significant differences in intensity ratings between the samples were observed using MANOVA ($\lambda = 0.9679$, 1/203 df, $F = 0.5817$, 11/193 df, and $p = .8365$). However, when participants were split into groups based on whether they were trained with both sets of references, that is, those who participated in both Experiments 1 and 2 (Group 1, $n = 53$) versus one or the other, that is, those who participated in either Experiment 1 or 2, but not both (Group 2, $n = 48$ oil, 51 water), a significant difference was seen in the perceived intensity rating for Bitter between the two groups ($\lambda = 0.8688$, 1/203 df, $F = 2.6499$, 11/193 df, and $p = .0035$). The average rating for Bitter was higher for participants who only received 1 of the trainings compared with those who received both (Group 2 > Group1) ($p < .0001$), but there was no significant difference based on whether the training references were oil based or water based ($p > .05$). For attributes Astringency and Drying/Roughing, ANOVA showed a significant sample-by-group interaction ($p < .05$), which means that samples are rated differently by the two groups, with Group 1 rating both attributes lower than Group 2 (Figure 3).

Most of the reference materials (Table 1) were insoluble in oil. Therefore, the oil-based references were presented as dispersions, and it was difficult to keep the particles dispersed during testing. Participants were instructed to shake these references prior to tasting them. However, since there were no significant differences observed between ratings of participants trained with oil-based references vis-à-vis those trained with water-based references (Figure 3), we suggest the use of water-based references as they are easier to prepare and sample. These results suggest that further studies in the area may yield useful information about the utility of different sample reference matrices in the testing of sensory panelists.

The results of this study have shown that there are significant differences in some taste and mouthfeel attributes as a result of polyphenolic extraction and fat content modification. Data from Experiment 1 show that extraction of free polyphenols and other acetone–water extractables results in a decrease in Cocoa flavor, Bitter, and Sour, while an increase was observed in Drying/Roughing. It was also observed in Experiment 1 that no significant differences in attribute ratings resulted from the defatting procedure and replacement of cocoa butter with canola oil in the samples. Therefore, our use of canola oil as a base for a pseudo-cocoa liquor is validated.

Experiment 2 showed that there were significant decreases in Drying/Roughing, Puckering, and Mouthcoating with increasing fat content. In general, these results provide support for the hypothesis that astringency is a weighted sum or average of the subqualities and side tastes, given that Bitter and Sour decreased while Drying/Roughing increased with no change in Astringency, but that these subqualities may be separate phenomena independent of each other. This also provides support for further research into the role that bound phenolics play in taste, flavor, and mouthfeel.

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