

ORIGINAL ARTICLE

The effect of fat content on sensory perception and consumer acceptability of 70% cacao dark chocolate made from reconstituted cocoa liquor

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Abstract

Dark chocolate is a complex food defined by its unique flavor, taste, mouthfeel, and melting properties. The craft chocolate market is a new segment of the US confectionery industry that highlights cocoa bean origin by making two-ingredient dark chocolate composed of cocoa liquor and sugar. To study the impact of natural variance in fat levels inherent to unblended cocoa liquor in two-ingredient chocolate, we made 70% cacao dark chocolate from cocoa liquor reconstituted from cocoa powder and cocoa butter at total fat contents of 30%, 35%, and 40% (w/w), and collected sensory and acceptability data from 108 regular chocolate consumers. Increasing fat content did not significantly affect liking ($p > .05$). However, with increasing fat levels, perceived intensities of bitter taste, cocoa flavor, and drying mouthfeel significantly decreased, and sweet taste perception significantly increased ($p < .05$). Consumer chocolate preference (milk vs. dark) significantly affected perceived intensity of drying mouthfeel.

Practical Applications: Our research suggests that liking of astringent stimuli may result in decreased perception of astringency in highly astringent foods. Further research is recommended to understand this mechanism as well as the physical and chemical underpinnings by which fat content impacts sensory perception of dark chocolate.

1 | INTRODUCTION

Dark chocolate is a unique food; it is solid at room temperature and melts at body temperature to become a semi-solid suspension of fine solid particles of sugar and cocoa in a continuous fat phase (Ziegler, 2017). Dark chocolate is the predominant type of chocolate produced by the US craft chocolate market, which has experienced abundant growth in the past twenty-plus years (Fine Chocolate Industry Association, 2018; Giller, 2017). The craft chocolate movement

started in 1996, with Scharffen Berger Chocolate Maker, and today there are over 300 craft chocolate makers (Cadby et al., 2021; Giller, 2017; Mishra & Pontikes, 2015). A craft chocolate company (a) makes chocolate from cocoa beans into chocolate bars (i.e., “bean to bar”); (b) is not owned by one of the “Big Five” multinationals (Allen, 2009); and (c) was established after 1997, during the recent wave of innovation (Leissle, 2017).

Recent research has identified that dried bean quality, ethical sourcing, cultivation methods, and cocoa bean origin are the most

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important considerations for craft chocolate makers when purchasing cocoa beans (Cadby et al., 2021). One of the ways that craft chocolate makers emphasize bean origin is by producing two-ingredient chocolate using only cocoa liquor and sugar (Engeseth & Ac Pangan, 2018; Giller, 2017; Masonis, 2017a). Cocoa liquor is defined as “a solid or semiplastic food prepared by finely grinding cacao nibs...[that] contains not less than 50 percent nor more than 60 percent by weight of cacao fat” (Chocolate Liquor, 21 CFR§163.11, 2023). Thus, cocoa liquor is a combination of cocoa solids and cocoa butter that when mixed and ground with sugar produces two-ingredient chocolate.

1.1 | Sensory perception of chemical compounds in cocoa liquor

Two-ingredient chocolate highlights the chemical properties of cocoa liquor that influence sensory perception. These include the flavor and aroma of volatile chemical compounds, the bitterness and astringency of nonvolatile chemical compounds, and the mouthfeel and melt of cocoa butter (Afoakwa et al., 2008; Ziegler, 2017).

Over 600 volatile aromatic compounds have been identified that when combined are perceived as quintessential “chocolate flavor” (Ziegler, 2017). Volatile compounds are derived from so-called flavor precursors that are formed during cacao fermentation and drying when yeast and bacteria act upon peptides and reducing sugars (Aprotosoaie et al., 2016; Rohan, 1963, 1964; Rohan & Connell, 1964). Several literature reviews have laid out the chemical compounds that contribute to chocolate flavor, which include alcohols, aldehydes and ketones, esters, pyrazines, acids, and phenols (Afoakwa et al., 2008; Aprotosoaie et al., 2016; Counet et al., 2002; de Vuyst & Weckx, 2016; Engeseth & Ac Pangan, 2018; Kongor et al., 2016; Lemarcq et al., 2021; Lima et al., 2011). Volatile chemical compounds are taken in by the nose and perceived in the olfactory pathway in the brain, along with the pathways for taste, touch, sound, vision, and active sensing, all of which combine to form the perception of chocolate flavor (Shepherd, 2006).

Nonvolatile compounds in cocoa and chocolate have been studied extensively to understand which compounds contribute to bitterness and astringency. Bitterness in cocoa is thought to be driven by 2,5-diketopiperazines and methylxanthines (i.e., theobromine and caffeine); astringency is driven by acid amides and polyphenol glycosides; and flavan-3-ols are responsible for both bitter and astringent sensory perception (Kauz et al., 2021; Stark et al., 2005, 2006; Stark & Hofmann, 2005b). Bitter is a prototypical taste perceived by receptors on the tongue (Belitz & Wieser, 1985), whereas astringency is an oral sensation that has multiple sub-qualities, including drying, puckering, and roughing (Bajec & Pickering, 2008). There are several theories for the mechanisms of astringency that are thought to occur simultaneously in the mouth (Gibbins & Carpenter, 2013). The theory of de-lubrication suggests that astringent compounds strip the oral cavity of epithelial and mucosal proteins through precipitation, resulting in increased friction between the surfaces of the oral cavity, and thus astringency perception (Bajec & Pickering, 2008; Lyman &

Green, 1990). This theory posits that relubrication can occur with the presence of fat (des Gachons et al., 2012), however, cocoa liquor contains astringent compounds, is composed of roughly 50% fat, and is still perceived as astringent, contrary to the theory of de-lubrication (Fleming et al., 2016). A second theory proposes that astringency is a receptor-based mechanism, like prototypical tastes (Schöbel et al., 2014). Gibbins and Carpenter (2013) suggest that astringent compounds bind with proteins (e.g., Mucin 5 and cystatin) in the mucosal pellicle to form aggregates, exposing the pellicle, thereby reducing its ability to lubricate the epithelium, or by exposing receptors. The most recent hypothesis posits that Mucin 1, an oral mucosa protein, binds with astringent compounds, leading to a cascade of reactions that ultimately cause the astringent sensation (Canon et al., 2021).

Cocoa butter is the fat phase of cocoa liquor. It is composed of triglycerides made up of four main fatty acids, including palmitic acid, stearic acid, oleic acid, and linoleic acid. Cocoa butter is a unique fat in that it is solid at room temperature and then melts sharply between 25 and 30°C (Talbot, 2017). This unique melting profile allows the aforementioned chemicals in chocolate to be released slowly in the mouth (Guichard, 2002).

1.2 | Variation in chemical compounds of cocoa liquor

Cacao variety classification (e.g., as “fine” or “flavor” or “bulk”) and origin (e.g., soil type, altitude, sun exposure, latitude, temperature, etc.) determine most of the quantities and qualities of chemical properties inherent to the bean (da Veiga Moreira et al., 2016; ICCO, 2018; Rottiers et al., 2019; Tuenter et al., 2020). Counet et al. (2004) found significantly different levels of volatile compounds (e.g., methylpyrazine, 2,5-dimethylpyrazine, etc.) attributable to different cacao origins (e.g., New Guinea, Ghana, Ivory Coast, Ecuador, etc.). Luna et al. (2002) demonstrated a wide breadth of types and levels of nonvolatile compounds in several trees of the cultivated variety (i.e., cultivar) EET95 of Ecuadorian cacao; while research by McClure et al. (2021) has shown differences in nonvolatile compounds may be attributable to different cacao origins (i.e., Peru, Madagascar, and Ghana). Varied roasting conditions influence the quantities and qualities of both volatile and nonvolatile compounds, (McClure et al., 2021, 2022; Reineccius, 2006; Rocha et al., 2017), which are further modified by processes such as conching, thus impacting sensory perception and consumer acceptability of resultant cocoa liquor and chocolates (Afoakwa et al., 2008).

Cocoa liquor is typically 53.5% total fat but has been shown to vary between 48% and 57% depending on the cacao origin, variety, maturity when picked, and degree of drying and roasting (Chaiseri & Dimick, 1989; Fowler & Coutel, 2017; Tuenter et al., 2020). McClure et al. (2021) observed that liquor produced from Ghanaian cacao ranged in fat percentage from 52.8% to 56.8%; while cocoa liquor from Peru ranged from 55.4% to 58.3%; and Madagascan liquor ranged from 48.5% to 55.5%. Cocoa liquor produced from cacao beans



sourced from different regions of Vietnam had a total fat content ranging from 48.3% to 55.1% (Tran et al., 2016), while total fat content ranged from 47.2% to 54.1% in cocoa liquor produced from 24 individual trees of cultivar EET95 in Ecuador (Luna et al., 2002). Fermentation heap variation on a single farm in Ghana was found to result in a range of 53.02% to 56.37% total fat content (Camu et al., 2008).

Previous research performed by our lab group determined total fat content to range from 47% to 57% in cocoa liquor produced from eleven different cultivars of cacao grown in Honduras. When tasted by a trained descriptive analysis panel, total fat content had a significant negative correlation with astringency, viscosity, and mouthcoating (Brown et al., 2019). Hamada et al. (2019) replicated this effect in a model or “pseudo-cocoa liquor” system by mixing natural cocoa powder and canola oil with varying fat contents of 46%, 51%, and 56%. Of the several attributes rated by consumers, drying/roughing, mouthcoating, and puckering were found to have a significant negative correlation with total fat content.

Because cocoa liquor properties vary from harvest to harvest, US law allows chocolate manufacturers to standardize cocoa liquor by using cocoa butter or cocoa powder to maintain consistency in their product formulations over time (*Chocolate Liquor*, 21 CFR§163.11, 2023). However, many craft chocolate makers do not standardize their cocoa liquor and instead use it unblended to express the bean origin in two-ingredient chocolate (Cadby et al., 2021; Giller, 2017).

1.3 | The impact of formulation on chocolate sensory perception

Chocolate formulation literature using sensory analysis provides insight into how total fat content variance might influence perception of two-ingredient chocolate. The majority of these studies have focused on methods to decrease or replace fat (i.e., cocoa butter) and sugar in an effort to reduce cost or lower calorie content while maintaining sensory qualities (Belščak-Cvitanović et al., 2015; Deou et al., 2022; Ewens et al., 2021; Joseph et al., 2022; Melo et al., 2013; St. John et al., 1995), however, there are four relevant studies.

Guinard and Mazzucchelli (1999) used descriptive analysis to investigate formulation changes in sugar content (ranging from 28% to 36%) and total fat content (ranging from 40% to 55%) in milk chocolate. They found significant differences in several sensory attributes and concluded that while fat content was primarily responsible for textural changes, such as melt rate and mouthcoating, sugar content drove most sensory differences (i.e., changes in sugar content accounted for 82% of the variance in the PCA of the data) (Guinard & Mazzucchelli, 1999). In another milk chocolate study, Daget and Vallis (1994) investigated differences in total fat content using time-intensity. They found no significant differences in sensory attributes that were attributable to total fat content, however, a solid fat content of 50% versus 70% had a significant difference.

Puchol-Miquel et al. (2021) used 40 untrained consumers to evaluate two sets of 70% and 95% cacao dark chocolates (i.e., one set

was made using cocoa liquor, while the other was made with cocoa liquor reconstituted from cocoa powder and cocoa butter) for aroma, taste, and acceptability. While the study is underpowered in terms of total number of participants, the researchers concluded that the most significant effect on perception and liking was cacao percentage rather than cocoa liquor makeup (Puchol-Miquel et al., 2021). Ober-rauter et al. (2018) compared “origin” (e.g., Brazil, Madagascar, Ecuador, etc.) and “nonorigin” (i.e., mainly from West Africa) chocolates varying in cacao content by 66.8%–80.1% and 54.5%–80%, respectively, using temporal dominance of sensation. This study did not provide formulation specifics in terms of total fat content yet concluded that chocolates made with lower cacao percentages and origin cacao were significantly lower in bitterness and higher in sweetness.

These studies are helpful, yet their implications are limited because they used milk chocolate, are underpowered, do not disclose exact formulations, and use additional ingredients such as emulsifiers, which are uncommon in craft chocolate. To further understanding of the impact of fat content variation on dark chocolate perception, we asked the following research questions: (1) How does total fat content affect the perception of bitterness, sweetness, cocoa flavor, drying mouthfeel, and liking of 70% cacao dark chocolate as evaluated by regular chocolate consumers? (2) How does consumer preference for milk or dark chocolate affect perception of bitterness, sweetness, cocoa flavor, drying mouthfeel, and liking in 70% cacao dark chocolate?

2 | MATERIALS AND METHODS

2.1 | Dark chocolate formulation and preparation

To answer these research questions, 70% cacao dark chocolate samples were formulated with three different reconstituted “cocoa liquors” composed of varying levels of cocoa butter and natural cocoa powder. Dark chocolate at 70% cacao content was selected due to its frequent occurrence in craft chocolate (M. Clark, 2020; Giller, 2017) and its broader usage in premium categories of dark chocolate since gaining popularity in craft chocolate (Wohlmuth, 2017; Ziegler, 2017). While not legally defined by the US Food and Drug Administration (FDA) “cacao,” when named on the front of a chocolate package, and how it will be used in this manuscript, is widely understood to be the sum of ingredients derived from the cacao bean, which include cocoa liquor, cocoa powder, and cocoa butter (Miller et al., 2006). We will refer to the samples as dark chocolate for the remainder of this manuscript; however, we note that the US legal standard of identity for chocolate requires the use of cocoa liquor (rather than cocoa powder and cocoa butter) and does not explicitly define dark chocolate, instead naming semisweet or bittersweet chocolate which must contain a minimum of 35% cocoa liquor (Sweet Chocolate, 21 CFR§163.123, 2023).

Reconstituted cocoa liquors were formulated to replicate the fat content of cocoa liquors previously described in the literature and ranged from 43% to 57%. Natural cocoa powder (10%–12% cocoa butter

by mass; Gerkens Cacao, Cargill, Minneapolis, MN) was selected rather than alkalized to provide a realistic cocoa flavor. Total fat content analysis, as described below, revealed an actual cocoa butter content of 9.4% in the powder. This value was used to calculate the percentage of cocoa butter and cocoa powder necessary to produce dark chocolates with total fat contents of 30%, 35%, and 40%, which reflect total fat contents found in commercially available dark chocolates (Wohlmuth, 2017).

Dark chocolate pastes were produced by mixing varying amounts of natural cocoa powder and deodorized cocoa butter (Blommer Chocolate, Chicago, IL) with constant amounts of extra fine granulated cane sugar (Good Food Inc., Honey Brook, PA) to create 1500 g batches (Table 1). The ingredients were mixed and ground for 24 h in a wet grinder equipped with stone wheels (Premier, Diamond Trading Inc, Hillsborough, NJ) per the directions for dark chocolate production provided in the grinder manual (Indian Kitchen, 2021). While other methods of grinding and conching exist (Ziegler & Hogg, 2017), stone grinders are commonly used in craft chocolate production and thus this method was selected to emulate this production style (Giller, 2017; Masonis, 2017b). Dark chocolate pastes were later tempered using a Chocovision Revolution Delta tempering unit (Chocovision Corporation, Poughkeepsie, NY) and chocolate temper was verified using a temper meter (model 404A Automatic Temper Meter, Tricor Systems, Elgin, IL). Chocolates were molded into 0.60 g cup-shaped pieces ($10 \times 5 \times 13 \text{ mm}^3$) (Harwood et al., 2012) and stored until evaluation.

2.2 | Total fat content analysis

Total fat content was determined using low resolution Time Domain-Nuclear Magnetic Resonance (TD-NMR). Chocolate pieces were melted and weighed ($1.54 \pm 0.04 \text{ g}$) into glass NMR tubes ($180 \times 17.75 \times 0.6 \text{ mm}^3$; Bruker, Billerica, MA, USA) and preheated at 40°C for 2 h in a forced-air laboratory oven (Model no. FED 56UL, Binder, Tuttlingen, Germany). For analysis, the preheated tube was removed from the oven and immediately placed in the NMR (minispec mq20, Bruker, Billerica, MA, USA), following the pre-set method as described by Todt et al. (2006). Total fat content was expressed as grams of fat per 100 g and ultimately as a percentage. Prior to analysis, the instrument was calibrated using vegetable oil. Each chocolate

was measured in triplicate. Total fat content of finished chocolate was confirmed to be within $\pm 0.7\%$ of the target fat content (Table 1).

2.3 | Sensory characterization

For sensory analysis of the chocolate samples, we used consumers to rate both sensory attribute intensity and sample acceptability. Previous research by Ares et al. (2011) found that consumers show similar discriminability and reproducibility as a trained descriptive analysis panel, while Popper et al. (2004) and Vickers et al. (1993) demonstrated that consumers provide accurate and reproducible data for both perceived attribute intensity and acceptability. Studies conducted previously in our group have successfully used a brief qualitative reference attribute orientation followed by the collection of sensory attribute intensity with or without affective data (Fleming et al., 2016; Hamada et al., 2019; McClure et al., 2022; Tenney et al., 2017).

In the present research, participants were recruited from The Pennsylvania State University campus and the surrounding State College, PA, area for a single sensory evaluation session in January of 2020. Screening criteria included no known 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; willingness to taste chocolate; and regular consumption of chocolate (at least once a month). Participants provided implied informed consent and were compensated for their time according to procedures reviewed and deemed exempt by the Penn State Institutional Review Board (protocol number 33164).

Sample evaluation occurred at the Sensory Evaluation Center at Penn State. Each participant was seated in an individual testing booth under white light, with constant temperature and air flow control. Compusense Cloud software (Academic Consortium, Guelph, ONT, Canada) was used to collect data. Similar to prior work (Hamada et al., 2019; McClure et al., 2022; Tenney et al., 2017), evaluation began with a brief attribute orientation followed by data collection.

First, participants were familiarized with the different sensory attributes: bitter, drying, cocoa flavor, and sweet. Importantly, the term *drying* was used in place of astringency in the test. While we recognize that astringency includes distinct subqualities, including drying, roughing, and puckering (Bajec & Pickering, 2008; Lee & Lawless, 1991), we presumed that drying was the most consumer-friendly language to be used in place of astringency. Once in the sensory booth, participants were presented with four aqueous qualitative attribute reference samples in 5–7 mL volumes in 12 mL souffle cups (Dart Container Corporation, Mason, MI). The qualitative attribute references were as follows: (a) *bitter* (1 g/L caffeine [FCC grade; Sigma-Aldrich, St. Louis, MO, USA] in reverse osmosis (RO) water) (Hamada et al., 2019), (b) *drying* (1.5 g/L alum [potassium aluminum sulfate; McCormick, Hunt Valley MD, USA] in RO water) (Fleming et al., 2016), (c) *cocoa flavor* (1:1 (w/w) natural cocoa powder [10%–12% cocoa butter by mass; Gerkens Cacao, Cargill, Minneapolis, MN] in vegetable shortening [Crisco, B&G Foods, Parsippany, NJ, USA])

TABLE 1 Formulas for the three different 70% dark chocolate samples in weight percent (g/100 g); and measured total fat content in finished products.

	30% fat	35% fat	40% fat
Sucrose (%)	30	30	30
Cocoa powder (%)	44	39	33
Cocoa butter (%)	26	31	37
Total fat content (%) ^a	30.1	34.7	40.1

^aTotal fat content as determined by TD-NMR.



(Hamada et al., 2019), and (d) *sweet* (30 g/L granulated cane sugar [Good Food Inc., Honey Brook, PA] in RO water) (Hamada et al., 2019). For the orientation portion, participants were instructed to swish the sample for 5 s in their mouth, then expectorate, and pay attention to the sensation they experienced. In between each reference sample participants were asked to cleanse their palates with room temperature water.

Participants then proceeded to evaluate each of the three samples, which were presented in sequential monadic order that was counter-balanced to account for first-order effects (Wakeling & MacFie, 1995). For sample evaluation, participants were instructed to use their tongue to press the sample to the roof of their mouth and rub it until completely molten before rating the perceived intensities of the four attributes (i.e., bitter, drying, cocoa flavor, and sweet) on a 0–1000-line scale, anchored with “none” on the left and “a lot” on the right end of the scale. A fifth “other flavor or texture” attribute was included to avoid potential “dumping” and halo effects (C. C. Clark & Lawless, 1994). After rating perceived intensities, participants were asked to indicate how much they liked the sample on a 9-point hedonic scale (Peryam & Pilgrim, 1957). During an enforced two-minute break in-between samples, participants were instructed to cleanse their palate with room temperature water. After evaluation of all three samples, chocolate preference type (Dark Chocolate, Milk Chocolate, White Chocolate, Other), consumption frequency of products from different chocolate segments (milk, dark, candy bar, truffles, premium chocolate, craft chocolate (Brown et al., 2020), and basic demographical information (gender, age, race/ethnicity) were collected from all participants.

2.4 | Data analysis

All data analysis was carried out in RStudio (version 2022.07.0) running R (version 4.2.1) with the additional packages *lmerTest*, *ggplot2*, *emmeans*, *multcomp* (Hothorn et al., 2008; Kuznetsova et al., 2017; Lenth, 2021; Wickham, 2016). For all sensory attributes and the liking data, generalized mixed-effects regression models were created using fat content as a continuous and fixed effect predictor, consumer chocolate preference (dark chocolate consumer vs. milk chocolate consumer) as a categorical and fixed effect predictor (coded as -1 for dark chocolate consumer and $+1$ for milk chocolate consumer), and participant as a categorical and random effect predictor (Næs & Langsrud, 1998). For each model, marginal R^2 and conditional R^2 were calculated to represent the variance explained by the fixed effects, and the entire model, respectively.

3 | RESULTS

3.1 | Participant characteristics

A total of 108 regular chocolate consumers were recruited and completed the sensory evaluation (84 women, 24 men; 18–65 years of age with a mean age of 41.2 years; 81% White, 6% Asian, 5% Black,

3% Hispanic, 3% Mixed, 3% Other). Nearly two-thirds ($n = 66$) indicated a preference for dark and unsweetened chocolate (i.e., dark chocolate consumer) while the remaining 42 preferred milk or white chocolate (i.e., milk chocolate consumer). Over two-thirds of participants indicated consumption of milk or dark chocolate bars at least once a week, with the rest eating dark and milk chocolate bars at least once a month. Consumption of premium and craft chocolate (Brown et al., 2020) was least frequent, with nearly 50% consuming craft chocolate only once every 6 months and more than 20% indicating they had never consumed craft chocolate.

3.2 | Fat content and preference for chocolate type affect sensory perception of chocolate

Regression models fit to the data indicate that fat content of dark chocolate, varying between 30 and 40% (w/w), significantly affects perceived intensities of bitter taste, sweet taste, cocoa flavor, and drying intensity, but not chocolate liking (Table 2). Chocolate preference (i.e., Dark vs. Milk) was only a significant term ($p < .05$) in the model for drying mouthfeel but not the bitter, sweet, and cocoa flavor models ($p > .05$; Table 2).

The three chocolate samples were similar in acceptability, and neither fat ($F(2,212) = 0.977$, $p = .378$) nor chocolate preference ($F(1,106) = 0.477$, $p = .491$) were significant predictors of overall liking. Mean liking scores were just below “*Like Moderately*” and ranged from 6.7 for the 30% fat sample to 6.8 for the 35% and 40% fat samples on a 9-point hedonic scale.

When comparing regression coefficient estimates for the fat variable between sensory attributes (Table 2), it becomes apparent that bitter and sweet taste intensities change at a similar rate with increasing fat content (-7.41 for bitter taste vs. $+7.89$ for sweet taste), albeit in the opposite direction. Cocoa flavor intensity ratings also decrease with increasing fat content, however, at a slower rate, at about 50% of the rate of bitter taste (-3.60 vs. -7.41).

Figure 1 shows the regression lines for the four sensory attributes: drying, bitter, sweet, and cocoa flavor. With increasing fat content, the perception of drying, bitter, and cocoa flavor all decrease, while sweet intensity increases. In fact, the former three attributes show a significant positive association to each other when evaluated by Kendall's rank correlation: bitter and drying ($\tau = 0.52$, $p < .001$), bitter and cocoa flavor ($\tau = 0.13$, $p < .001$), drying and cocoa flavor ($\tau = 0.16$, $p < .001$). For sweet taste, only cocoa flavor ($\tau = 0.26$, $p < .001$) shows a strong significant association, and while changes in drying intensity were significantly associated with changes in sweet taste intensity, the effect was small ($\tau = 0.08$, $p = .031$). Changes in bitter taste intensities as a function of fat content were not associated with changes in sweet taste intensities as a function of fat content changes ($\tau = 0.04$, $p = .317$).

Interestingly, for drying mouthfeel intensity, both fat content and chocolate preference (Dark vs. Milk) as well as the interaction between fat content and chocolate preference were significant predictors in the regression model. This indicates that dark chocolate preferring participants perceived the intensity of the drying

TABLE 2 Regression model results for the perceived intensities of the sensory attributes and sample liking.

	R^2_{marg}	R^2_{cond}	Intercept	Fat (F)	Chocolate Pref. (CP)	F × CP
Drying	0.029	0.578	476 ± 69.0; $p < .0001$	−6.96 ± 1.91; $p = .0003$	200 ± 69.0; $p = .004$	−5.21 ± 1.91; $p = .007$
Bitter	0.036	0.530	470 ± 67.5; $p < .0001$	−7.41 ± 1.88; $p = .0001$	84.9 ± 67.5; $p = .201$	−1.76 ± 1.88; $p = .350$
Sweet	0.017	0.680	162 ± 70.1; $p = .022$	7.89 ± 1.91; $p < .0001$	−65.5 ± 70.1; $p = .351$	1.75 ± 1.91; $p = .360$
Cocoa Flavor	0.032	0.735	647 ± 63.3; $p < .0001$	−3.60 ± 1.71; $p = .0359$	−16.3 ± 63.3; $p = .797$	1.61 ± 1.71; $p = .348$
Liking	0.006	0.580	6.41 ± 0.439; $p < .0001$	0.010 ± 0.012; $p = .408$	−0.487 ± 0.439; $p = .268$	0.016 ± 0.012; $p = .185$

Note: For all models, the random participant term was a significant source of variation ($p < .05$). Reported are marginal and conditional R^2 values for the model, nonstandardized coefficients ± standard error and the corresponding p -value for each model term. All sensory attributes were rated by 108 participants on an unstructured 0–1000-point line scale, while liking was rated on a standard 9-point hedonic scale. Bolded regression coefficients are significant ($p < .05$).

sensation differently from participants who prefer milk chocolate. When plotting the regression lines for both consumer groups separately (Figure 1a), it becomes clear that participants who prefer milk over dark chocolate perceive a larger decrease in drying intensity with increasing fat content compared to those who prefer dark chocolate. Indeed, milk chocolate consumers rate the drying intensity of the 40% fat sample significantly lower than both the 35% and 30% sample, using planned contrasts: 30% versus 40%: $t(212) = 4.04$, $p = .0002$, $r = .27$; 35% versus 40%: $t(212) = 2.46$, $p = .0389$, $r = .17$; 30% versus 35%: $t(212) = 1.58$, $p = .256$, $r = .11$. This was not the case for dark chocolate consumers who did not perceive drying significantly different between the three samples: 30% versus 40%: $t(212) = 0.729$, $p = .747$, $r = .05$; 35% versus 40%: $t(212) = 0.597$, $p = .822$, $r = .04$; 30% versus 35%: $t(212) = 0.131$, $p = .991$, $r = .009$.

4 | DISCUSSION

All four sensory attributes studied were significantly affected by fat content; with increasing fat content, the perceived intensities of bitter taste, cocoa flavor, and drying mouthfeel all decreased, while sweetness increased. These results will be interpreted under the lens of varying fat content; however, it is important to note that the levels of cocoa powder have also been changed to maintain 70% cacao, which is an inherent limitation to formulation studies.

We expect fat content to have an impact on rheological properties, such as yield stress and viscosity, and that these may result in a change in residence time in the mouth and therefore, sensory perception (Beckett, 2008). However, Puchol-Miquel et al. (2021) found that chocolate made with cocoa liquor was more viscous instrumentally than chocolate made with cocoa powder and cocoa butter, yet this difference was not significantly reflected in the sensory evaluation of mouthfeel. Therefore, it is possible that while there may be instrumental differences in the samples, those differences may not be perceptible.

4.1 | Consumer preference for dark chocolate impacts perceived drying intensity

For drying mouthfeel, consumer preference for either dark or milk chocolate was a significant predictor for perceived intensity. Participants who preferred milk chocolate showed a stronger and significant decrease in perceived drying intensity as fat content increased, while participants with a preference for dark chocolate did not perceive significant differences in drying mouthfeel between the three different fat contents. In addition, as can be seen in Figure 1a, the dark chocolate consumers perceived drying mouthfeel at a lower level than the milk chocolate consumers: for 30% fat, the lowest fat sample, this difference was statistically significant.

The trend observed for milk chocolate consumers is likely a result of the decrease in cocoa powder content as fat content increases. Cocoa powder, which contains astringent chemical compounds (e.g., flavan-3-ols, polyphenol glycosides, and hydroxycinnamic acid amides), decreased in quantity to accommodate more cocoa butter to maintain the cacao percentage (Kauz et al., 2021; Stark & Hofmann, 2005a, 2006). Hamada et al. (2019) observed the same trend in pseudo-cocoa liquor varied in fat content from 46%, 51%, and 56%; drying/roughing and puckering were found to be significantly and negatively correlated with total fat content. However, Hamada et al. (2019) did not find significant differences in cocoa flavor, bitterness, or sweet taste intensities between the pseudo cocoa liquor samples. Des Gachons and others (2012) compared consumption of astringent green tea with and without fatty dried meat. They found that when sips of tea were interspersed with bites of dried meat, astringency perception was significantly decreased, even after 30 sips and bites compared to the green tea sipped without meat, for which astringency perception and intensity increased exponentially. Our results for milk chocolate consumers reinforce the opponency of astringency and fat sensations as described by Hamada et al. (2019) and des Gachons et al. (2012).

The observed differences in the decrease of drying intensity (i.e., slope) with increasing fat content for the “dark chocolate

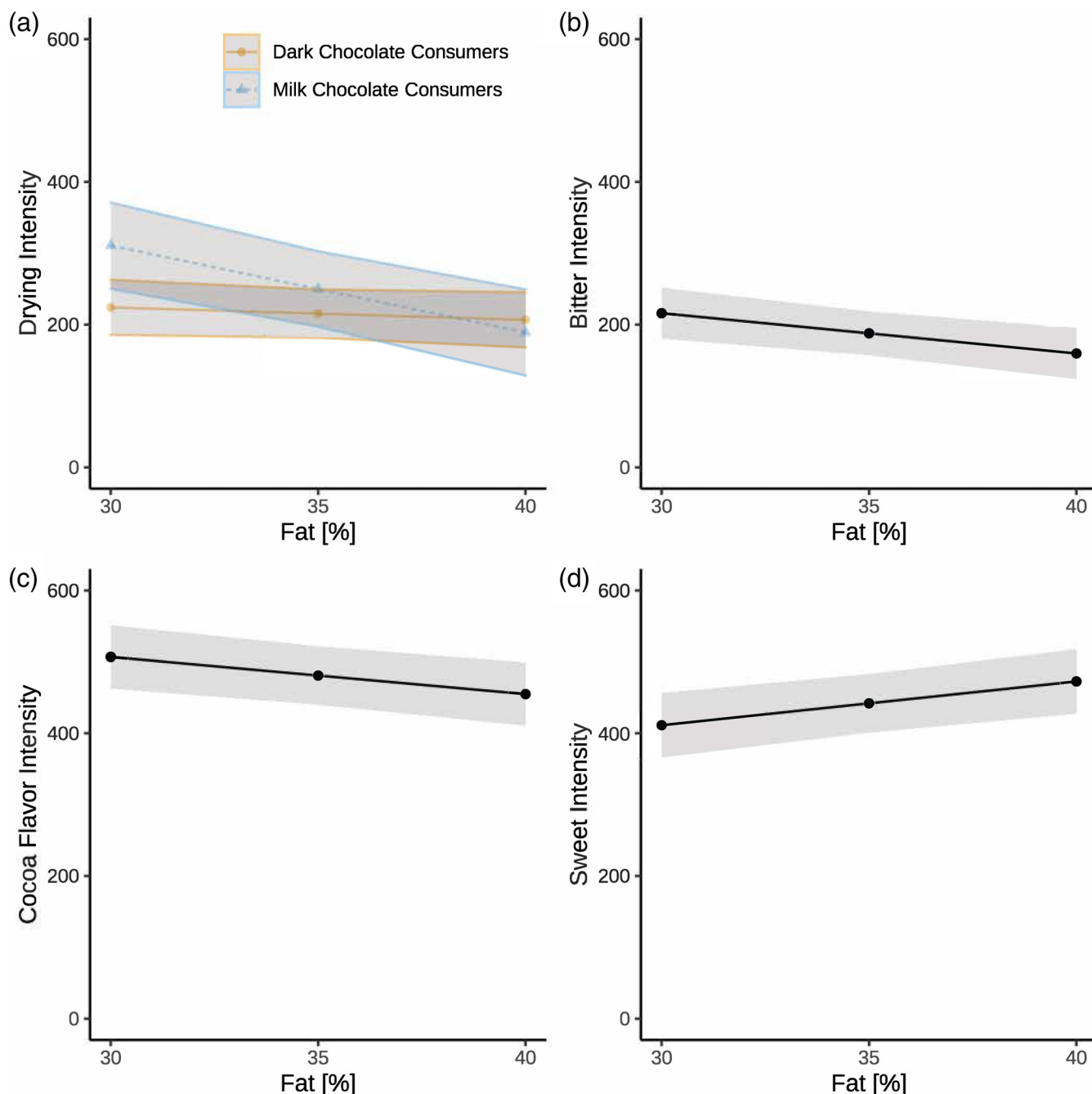


FIGURE 1 Mixed effects regression models with 95% confidence interval for the perceived intensities of (a) Drying Mouthfeel, (b) Bitter Taste, (c) Cocoa Flavor, and (d) Sweet Taste as a function of fat content in dark chocolate. Regular chocolate consumers ($N = 108$; consuming chocolate at least once a month) rated each attribute on a 0–1000 unlabeled line scale. For drying (a), regression lines were separated by chocolate preference into dark chocolate consumers ($n = 66$; yellow filled circles and solid lines) and milk chocolate consumers ($n = 42$; blue filled triangles and dashed lines).

consumer” versus “milk chocolate consumer” segment, but not for any of the other sensory attributes, nor liking, point toward an interaction between perception and the fundamental mechanism(s) of astringency perception. Consumers who like dark chocolate and are presumably regularly exposed to dark chocolate (which tends to be higher in astringency, bitterness, and cocoa flavor) perceived less drying from the three chocolate samples.

This difference in perception could be explained by inherent individual differences in saliva, such as higher levels of total salivary protein content (Fleming et al., 2016), the ability to maintain salivary protein content (Dinnella et al., 2011), a higher salivary flow rate (Fischer et al., 1994), or salivary protein composition that has adapted to regular intake of astringent foods (Crawford & Running, 2020).

A body of research has been devoted to understanding how consumer perception of astringency and bitterness influences liking and consumption of foods high in these perceptions, including alcohol, coffee, and tea. Some studies have found that an increased perception of bitterness leads to increased liking and consumption of bitter foods (e.g., India Pale Ale-style beer) (Higgins et al., 2020), while other studies have shown that increased perception results in decreased consumption of bitter foods (e.g., red wine, beer) (Pickering & Thibodeau, 2021). A study by Ong et al. (2018), showed that a higher perceived intensity of specific bitterants (propylthiouracil [PROP] and quinine) decreased coffee consumption, while a higher perceived intensity of caffeine increased coffee consumption; meanwhile opposite relationships were found for tea consumption. Because bitter and astringent compounds have been found to overlap, especially in chocolate (i.e., flavan-3-ols) it is possible that a similar trend exists for astringent foods. Our findings support the possibility of a perception/acceptability trend in that decreased perception of drying mouthfeel in dark chocolate may lead to increased liking and consumption of dark chocolate, or vice versa. Further chocolate-focused studies are required to confirm this and investigate the possible biological underpinnings.

4.2 | Fat content impacts bitter and sweet taste; cocoa flavor

Bitterness intensity was found to negatively correlate with increasing fat content and decreasing cocoa powder content, while sweetness had the opposite relationship. This result is expected because cocoa powder contains bitter compounds such as methylxanthines (i.e., theobromine and caffeine), diketopiperazines, and polyphenols (Kauz et al., 2021; Stark et al., 2005, 2006; Stark & Hofmann, 2005b). Thus, as cocoa powder decreases there is likely a dilution effect in samples as the fat content increases.

Although the sugar content for all samples was kept constant at 30% (w/w), sweet taste intensity increased with increasing fat content and decreasing cocoa powder. This is likely an effect of the decreasing level of cocoa powder, which contributes the aforementioned bitter-tasting chemical compounds to the system. Similar results were found in the milk chocolate study by Guinard and Mazzucchelli (1999) where nine samples were produced that varied in total fat content from 28.1% to 36.1%. The samples lowest in fat content, highest in cocoa liquor, and lowest in sugar, displayed the lowest level of sweetness of 3.78 on a 0–10 scale versus the sample highest in fat content, lowest in cocoa liquor, and highest in sugar, which also displayed the highest level of sweetness, an average of 8.22 on a 0–10 scale (Guinard & Mazzucchelli, 1999).

At the 30% fat content level, bitter-sweet taste suppression (Kroeze & Bartoshuk, 1985; Lawless, 1979) likely occurs, where a reduction in bitter taste perception goes hand in hand with an increase in perceived sweet taste intensity. As fat content increases and cocoa powder content decreases, there is an absence of bitter compounds, and the sugar is available to be perceived by the tongue.

Similar bitter-sweet taste suppression was reported in 100% cacao chocolate, where sweetness increased as bitterness decreased, even in the absence of added sugar (McClure et al., 2022).

Cocoa flavor intensity decreased as fat content increased. Because we used deodorized cocoa butter, we do not expect any cocoa aroma or flavor to come from the cocoa butter and instead expect that cocoa powder is wholly responsible for cocoa flavor (Kamphuis & Fowler, 2017). Overall, our finding confirms previous descriptive analysis results, in which milk chocolate was perceived as having an increase in cocoa flavor as cocoa liquor content increased from 6% to 21.2% (Guinard & Mazzucchelli, 1999).

4.3 | Total fat content does not have a significant effect on consumer acceptability

All three 70% cacao dark chocolate samples made from reconstituted cocoa liquor were rated acceptable with mean liking scores of around 6.75 or “Like Moderately” on a 9-point hedonic scale. Thus, fat content had no significant effect on acceptability. This is surprising, given that higher fat chocolates are associated with higher quality (Beckett, 2008). In addition, in an informed consumer study comparing milk chocolate and reduced-fat milk chocolate, expected liking was significantly lower for milk chocolate labeled “reduced-fat” (although actual liking after tasting was not significantly different from the milk chocolate product) (Norton et al., 2013).

However, our findings align with Rolon et al. (2017), who found no significant differences in consumer acceptability of vanilla ice cream ranging in fat content from 6% to 14% fat when standardized with maltodextrin for viscosity changes. In addition, Harwood et al. (2013) investigated rejection thresholds of 73% cacao chocolate compound in which the cacao was a combination of natural cocoa powder and an astringent high flavanol cocoa powder. They determined a group rejection threshold at a level of 80% of the highly astringent cocoa powder in the blend and there was no difference when participants were divided by their milk or dark chocolate preferences. While rejection threshold is not the same as liking, this result demonstrates that both milk and dark chocolate consumers tolerant to chocolate compound made with highly astringent cocoa powder used at a level of 80%.

4.4 | Industry implications, study limitations, and future directions

For the craft chocolate industry, our findings are two-fold. We demonstrated that if total fat content in cocoa liquor differs based upon harvest or cocoa bean origin, when used in a two-ingredient chocolate, there will likely be significant effects on drying, bitterness, sweetness, and cocoa flavor perception. However, total fat content within the range of 30%–40% may not impact consumer acceptability of the chocolate.

To our knowledge, this is the first study of its kind to use good sensory practices to study the impact of variance in fat and cocoa



solids content on sensory properties and consumer liking of dark chocolate (Lawless & Heymann, 2010). The main strength of our study is that it used a large number of regular chocolate consumers who underwent a brief orientation session with qualitative attribute references and provided both attribute intensity ratings and liking information for 70% cacao dark chocolate made from reconstituted cocoa liquor. While a consumer panel may not be able to differentiate small differences between samples (Ares et al., 2011) or provide a comprehensive sensory profile beyond easy-to-rate attributes, this approach provides ecologically valid data on consumer perception and links consumer perception to consumer acceptability without changing consumers' ability to provide affective responses (Popper et al., 2004).

The main limitation of this study is consistent with limitations of other chocolate formulation studies: when fat percentage is changed in the formula, the percentage of natural cocoa powder must also be changed to satisfy the 70% cacao requirement. This makes it difficult to determine whether the change in sensory perception was a result of the fat or cocoa powder content. In their study to understand varying levels of sugar and fat in milk chocolate on sensory perception, Guinard and Mazzucchelli (1999) also remarked on the difficulty of chocolate formulation studies in that when one ingredient increases in proportion, the other must decrease. Thus, this is an inherent limitation of formulation studies, and suggests the use of mixture designs in the future.

Additionally, with the wet grinder method, we expect the difference in fat content to impact grinding and therefore physical properties of the chocolates. For example, with less fat in the wet grinder, there is more friction between the stones and the particle size distribution may have higher levels of fine particles than the samples produced with more fat (and less friction between the stones) (Bolenz & Manske, 2013). The result would be an increase in particle-particle interactions and therefore an increase in viscosity, which may have impacted sensory perception (Bolenz & Manske, 2013). For this study, we did not perform physical characterization of the samples, such as particle size distribution or rheology (e.g., yield stress and viscosity). Physical characterization techniques have been shown to correlate well with sensory analysis and are well-established measurements in the chocolate industry (Bolenz & Manske, 2013; Guinard & Mazzucchelli, 1999; Ziegler et al., 2001). Particle size distribution of milk chocolate has been shown to influence rheological properties (Mongia & Ziegler, 2000) thereby having a significant effect on sensory properties (Ziegler et al., 2001). Measurement of these physical properties could indicate whether the formulation changes in total fat content resulted in changes in physical properties, which may underpin the differences in sensory perception.

A further limitation of this study was the use of cocoa powder produced from bulk cocoa rather than "fine" or "flavor" cocoa or "origin" cocoa. Oberrauter et al. (2018) demonstrated that "origin" chocolates had significantly different temporal dominance profiles in terms of sweetness, astringency, and bitterness, when compared to chocolates of West African origin. To increase relevance to craft chocolate, future studies should use "fine" or "flavor" or "origin" cocoa powder. In addition, future studies should use more samples to understand

whether the relationships demonstrated are indeed linear. To test suggested astringency mechanisms in high-fat, low-water foods such as chocolate, salivary characteristics of participants could be collected and analyzed.

5 | CONCLUSION

The present study reports on the effect of fat content on sensory perception and acceptability of 70% cacao dark chocolate made with reconstituted cocoa liquor using regular chocolate consumers ($n = 108$). Three 70% cacao dark chocolate samples were created from reconstituted cocoa liquor composed of varying levels of natural cocoa powder and cocoa butter such that total fat content was varied between 30% and 40%. We found that with increasing fat content, the perceived intensities of bitter taste, cocoa flavor, and drying mouthfeel all decreased, while sweetness increased. Interestingly, consumer chocolate preference (milk chocolate vs. dark chocolate) significantly affected perceived intensity of drying mouthfeel such that dark chocolate consumers perceived all three samples at relatively the same intensity. Additionally, the chocolates were found acceptable to all chocolate consumers, independent of fat content, with mean liking scores of around 6.75 on a 9-point hedonic scale.

AUTHOR CONTRIBUTIONS

Allison L. Brown: Conceptualization (equal); funding acquisition (lead); investigation (lead); methodology (equal); project administration (equal); software (equal); writing—original draft (equal); writing—review and editing (equal). **Ezekiel R. Warren:** Investigation (supporting); methodology (supporting); software (equal); writing—review and editing (supporting). **Bradley W. Ingraham:** Investigation (supporting); methodology (supporting); software (supporting); writing—original draft (supporting); writing—review and editing (supporting). **Gregory R. Ziegler:** Conceptualization (equal); funding acquisition (supporting); methodology (equal); project administration (equal); resources (equal); supervision (equal); writing—review and editing (equal). **Helene Hopper:** Conceptualization (equal); data curation (lead); formal analysis (lead); funding acquisition (supporting); methodology (equal); project administration (equal); resources (equal); software (equal); supervision (equal); visualization (lead); writing—original draft (equal); writing—review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

Allison L. Brown currently works in the confectionary industry; however, this work was conducted at Penn State with Allison L. Brown's current employer having no role in the work presented here, including study design or interpretation, funding, or the decision to publish. Authors Ezekiel R. Warren, Bradley W. Ingraham, Gregory R. Ziegler have no financial relationships relevant to this article to disclose. Helene Hopfer has received speaker honoraria, consulting fees, and/or travel expenses from numerous organizations, including federal agencies, universities, nonprofit organizations, trade groups, and for-profit corporations, to present data on perception, flavor and food chemistry, and consumer behavior. Additionally, the Sensory Evaluation Center at Penn State routinely conducts product tests for industrial clients to facilitate experiential learning for undergraduate and graduate students. Helene Hopfer is the Associate Director of this facility. None of these entities have had any role in the work presented here, including study design or interpretation, or the decision to publish these data.

DATA AVAILABILITY STATEMENT

Data collected in this study is not publicly available due to human research protection reasons.

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