1. INTRODUCTION

1.1. Background

A survey conducted by Nielsen in 2014 indicated that confectionary products (including sugary sweets like chocolate) make up the biggest sales contribution to the overall snack category. Across the regions, chocolate comes 2nd as the snack of choice. From this survey, it was discovered that half of the global respondents had consumed chocolate within the last 30 days. Chocolate are categorized as dark, milk, and white chocolate and the difference lies within their cocoa solid, milk fat, and cocoa butter content (Afoakwa et al., 2007). Milk chocolate is predominant as the chocolate product produced worldwide, with an estimated 51% market share, followed by dark chocolate (31%) and white chocolate (18%) respectively (Afoakwa, 2016). A market survey about chocolate confectionery was launched by Euromonitor in 2019 and reported that sales of chocolate in the UK in 2020 is estimated to be about £6.7 billion, having increased £200 million compared to the previous year (Ewens et al., 2021).

In recent years, health has become a major trend in the consideration of the food industry. Much of the focus has centered upon sugar consumption and sugar contents in food products. WHO (2015) also stated that excessive free sugars intake is associated with poor diet that leads to obesity and the risk of noncommunicable diseases (NCDs). Therefore, much of the concerns in the food industry have shifted into developing less-sugar or sugar-free products (Nielsen, 2018).

However, De Melo (2009) reported that despite the health claims, consumers are reluctant in consuming a product if the ingredients or formulation caused noticeable off-flavors. Simultaneously, this situation exerts a new challenge for the manufacturers to reformulate the recipe in order to develop a product possessing beneficial characteristics of sugar replacers without compromising its final quality.

Previous review studies reported that sugar alcohols have a great potential as sugar replacer in chocolate manufacturing. It is able to provide sweetness, whilst having much less caloric value than sucrose. Sugar alcohols are also believed to possess a sucrose-like taste and texture (Aidoo et al., 2013; Sharma et al., 2016). Some existing developments of sugar alcohols application in chocolate manufacturing will be displayed in the next subchapter. However, comprehensive review studies relating to the effect of sugar substitution with sugar alcohol in chocolate manufacturing, especially to its rheological properties, are still very scarce. Therefore, novel studies regarding this particular topic, especially to the chocolate quality, are further needed to be studied.

1.2. Previous Review Studies

Previous existing studies regarding chocolate and its development, especially with sugar alcohols as sugar replacer, are listed in Table 1.

Table 1. Existing Reviews about Low Calorie Chocolate

No.	References	Key Points
1	Nazir & Azad, (2017)	Preference in fewer calories in chocolate but with no change in sensory attributes.
2	Afoakwa et al., (2007)	Replacement of sucrose components with sugar alcohols affects the rheological properties and thus the final quality of chocolate. Chocolate rheology is greatly influenced by ingredients composition, processing technique, and particle size distribution (PSD).
3	Aidoo et al., (2013)	Sucrose composes about 40-50% in chocolate formulation and has a huge impact on the chocolate rheology. Chocolate rheology directly impacts the final texture and melting characteristics of chocolate. Alternative sweetener of chocolate is deemed as successful if it can closely match the taste quality and physical attributes of sucrose.
4	Barišić et al., (2019)	Sugar alcohols vary in sweetness, from less to almost as sweet as sucrose, whilst providing much less caloric value of sugar per weight basis. Sugar alcohols give a sucrose-like texture and taste.
5	Selvasekaran & Chidambaram, (2021)	Although it is possible to develop low calorie chocolate, there will be dissimilarities to that of conventional chocolates in terms of physicochemical and sensory aspects.

As illustrated from the table above, sugar alcohols have a great potential as a sugar substitute in chocolate manufacturing. In the review, Afoakwa et al. (2007) concluded that the physical, rheological, and sensory properties of chocolate are greatly modified by PSD, however the underlying mechanism of how PSD influences the change of flow behavior in chocolate is still unspecified. In the review by Aidoo et al. (2013), it was concluded that sugar substitution in chocolate manufacturing requires deeper understanding of the ingredients and their impacts on the end product quality. Meanwhile, Selvasekaran & Chidambaram (2021) discussed many of the advances in formulation of alternatively healthier (lower in fat and sugar) chocolate. In this review, it was concluded that although replacing sugar in the chocolate manufacturing is possible, there would still be some slight difference in terms of rheological, physical, and sensory properties.

1.3. Chocolate Manufacturing

Chocolate is a food or beverage product made from cocoa/cacao beans of *Theobroma cacao* plants. Cacao beans are fermented, dried, and shelled from cacao nibs. They are then roasted, ground, and mixed with other ingredients into chocolate products that we know today (Katz et al., 2011). Generally, commercial chocolate manufacturing begins after roasted and de-shelled cocoa nibs are obtained.

Processing stage for chocolate manufacturing is illustrated in Figure 1 below:

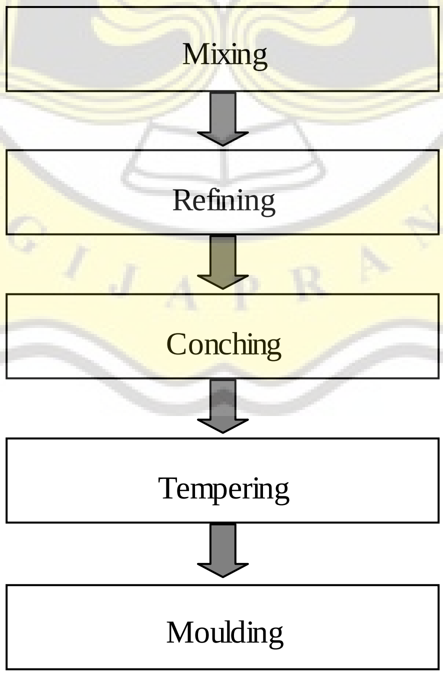

Figure 1. Processing Steps for Chocolate

On the mixing stage, ingredients like sugar, cocoa liquor, cocoa butter, and milk powder are added and mixed altogether until they become a thick paste. Afterward, the paste will proceed to the refining process, which is to apply particle size reduction by means of running the paste through roll refiners. Chocolate paste is flattened by these rollers, traveling up to the refiner until removed by a knife blade. In this stage, roller shearing crushes the solid particles, at the same time coating the new surfaces with lipids. Refined mixtures are then moved into the conching process (Afoakwa et al., 2007).

Conching means to agitate the chocolate mixture in a large tank over an extended period of time. Normally, this stage is executed by agitating the chocolate at temperature above 50^{o}C for 4-6 hours at minimum (Aidoo et al., 2014). This process is essential for developing the final flavor and texture of chocolate. In this process, residual volatile acids and excess moisture are removed, particle sizes are reduced thus resulting in the modified viscosity, and color transformation due to emulsification and tannins oxidation. Conching is generally a two-stage process: converting solids into paste by friction, then converting the thick paste into a free flowing liquid with the help of cocoa butter and lecithin (Afoakwa et al., 2008[a]; Taylor et al., 2009). Conching makes sure to thoroughly coat the new surfaces with fat, developing the flow properties of molten chocolate. This continuous mixing process combined with some heating and ventilation, aids the modifying flavor formation of chocolate by releasing undesirable volatile compounds This process also functions as particle size reduction and maintaining the fluidity of the chocolate mass. The outcome would be a smoother mass with an exquisite taste of chocolate. This well-dispersed chocolate mass then undergoes the tempering process (Afoakwa et al., 2007).

During tempering, chocolate mass is treated thermally, cooled down then heated up again for a couple of times, to obtain homogeneously dispersed, highly stable fat crystals of the correct type and size. Form β_V is the preferred polymorph structure as it obstructs the migration of fat crystals to the surface, thus delays blooming, and gives the glossy appearance of chocolate. At the same time, this polymorphic form has the desirable melting point of 32-34^{o}C, which is much above the ambient temperature yet slightly below the body temperature, so that it melts in the mouth and ‘snap’ when it is broken (Svanberg et al., 2011; Ewens et al., 2021). Well-tempered chocolate is demonstrated in the final solidified product possessing glossy surface, good color, good snap, smooth and fast melting at oral temperature, also stable to heat and blooming (Ramsey, 2016; Beckett et al., 2017).

1.4. Sugar and Sugar Replacer in Chocolate Manufacturing

Generally, sugar makes up about 30-55% of the composition of chocolate. Its existence has massive impacts to the overall chocolate sweetness, mouthfeel texture, and more importantly the rheological properties of chocolate (Beckett et al., 2017). Sucrose is widely used as a primary sweetener in the chocolate industry. It has caloric value of 4kcal/g and is mainly accounted for providing sweetness to the product, also offering other important functional properties such as bulking agent, texture and mouthfeel modifier, flavor enhancer, and as preservatives (Aidoo et al., 2013; Afoakwa, 2016). Although sugar holds such importance on the overall chocolate products, its high caloric value has become a major drawback.

Sugar substitutes are defined as food additives that duplicate the effect of sugar in taste, but with lower caloric value. Depending on their relative sweetener potency, sweeteners are divided into two categories, i.e. intense and bulk sweeteners. Intense sweeteners are also called artificial sweeteners as most of them are obtained by chemical synthesis, whilst other sugars naturally presented in plants are considered as natural (Mortensen, 2006).

Sweetener potency is defined as how many times that a sweetener is sweeter than sucrose. High intensity sweeteners include aspartame, saccharin, acesulfame-K, neotame, sucralose, and advantame are regulated as food additives. These sweeteners have sweetening power much higher than sucrose and are considerably used in a lot of food and beverage products (Mérillon & Ramawat, 2018). Despite much controversy over their carcinogenic potential, these substances are generally considered as safe to use (GRAS) in food products (Das & Chakraborty, 2016). However, their low bulking properties makes high intensity sweeteners unsuitable as sugar replacers in chocolate.

Caloric sugar substitutes are able to substitute for both the physical bulk and sweetness of sugar, hence also known as "bulk sweeteners". Alternative ingredients to replace sucrose are mainly polysaccharides and sugar alcohols. Sugar alcohols (polyols) generally used as sucrose substitutes in chocolate manufacturing are sorbitol, maltitol, xylitol, isomalt, mannitol, and lactitol (Sharma et al., 2016; Konar et al., 2018). Properties of these sugar alcohols are listed in Table 2.

According to Chattopadhyay et al. (2011), sugar alcohols are generally highly soluble and non-hygroscopic. They are non-reducing, temperature stable, and more resistant to browning reaction than sucrose. Sugar alcohols are also able to retain much of sugar's structure, bulk, and function, making it ideal for one-on-one bulk sugar replacement. It also provides almost zero to half of the calories of sucrose per weight basis (Aidoo et al., 2013). In theory, this makes sugar alcohols a perfect fit for replacing sucrose in chocolate manufacture. Selecting the correct polyols gives the possibility of reformulating the product with lower caloric value and other advantages of polyols, but with only minimum change to the sensory properties (Pirouzian et al., 2017; Petkovic, 2019).

However, replacing sugar with sugar alcohol or reformulating traditional chocolate formulation may not seem as simple as it is. Chocolate is a complex food product possessing a set of sensory and rheological parameters that needs to be met in order for a chocolate product to be perceived as "tasty". The substitution of sucrose with sugar alcohol is believed to still impose some problematic challenges in chocolate manufacturing (Ewens et al., 2021; Wal et al., 2019). To our knowledge, a specific review on how sugar alcohols affect the rheological properties of chocolate is still scarce. Presumably, rheological properties of molten chocolate are a good indicator of the end-product quality. Therefore, a review focusing on the effect of sugar alcohols to the rheological properties of molten chocolate is deemed as necessary.

Table 2. Properties of Sugar Alcohols

Sweetener	Relative Sweetness	Calories/g	Glycaemic Index	Melting Point (^oC)	Solubility (g/100g H_2O at 25^oC)	Source
Sucrose	1.0	4.0	61 - 65	190	67	Cane and beet
Xylitol	1.0	3.0	7 – 13	94	64	Hydrogenated xylose
Maltitol	0.5 – 0.9	3.0	35 - 52	152	60	Catalytic hydrogenation of high maltose corn syrup
Erythritol	0.7	0.2	0	121	37	Fermentation of glucose by Moniliella pollinis
Sorbitol	0.6	2.6	9	99	70	Hydrogenated glucose
Mannitol	0.5 – 0.72	1.6	0	167	20	Hydrogenation of invert sugar or fructose
Isomalt	0.45 – 0.65	2.0	2	96-145	25	Hydrogenated isomaltulose
Lactitol	0.35 – 0.4	2.4	6	92-124	92-124	Hydrogenated lactose

(Chattopadhyay et al., 2011; Nabors, 2012)

The need to understand the difference of sugar alcohols' characteristics and their impact on the chocolate quality called for a more extensive study, especially relating to the rheological and sensory properties. This review will analyze the effect of sugar alcohols as sugar substitutes on the rheological properties of molten chocolate.

1.5. Objective of Review

The aims of this review are to describe the chocolate quality and to analyze the effect of sugar alcohols as sugar substitutes on the rheological properties of molten chocolate.