Sugar and Cocoa: Sweet Synergy or Bitter Antagonisms. Formulating Cocoa and Chocolate Products for Health: A Narrative Review

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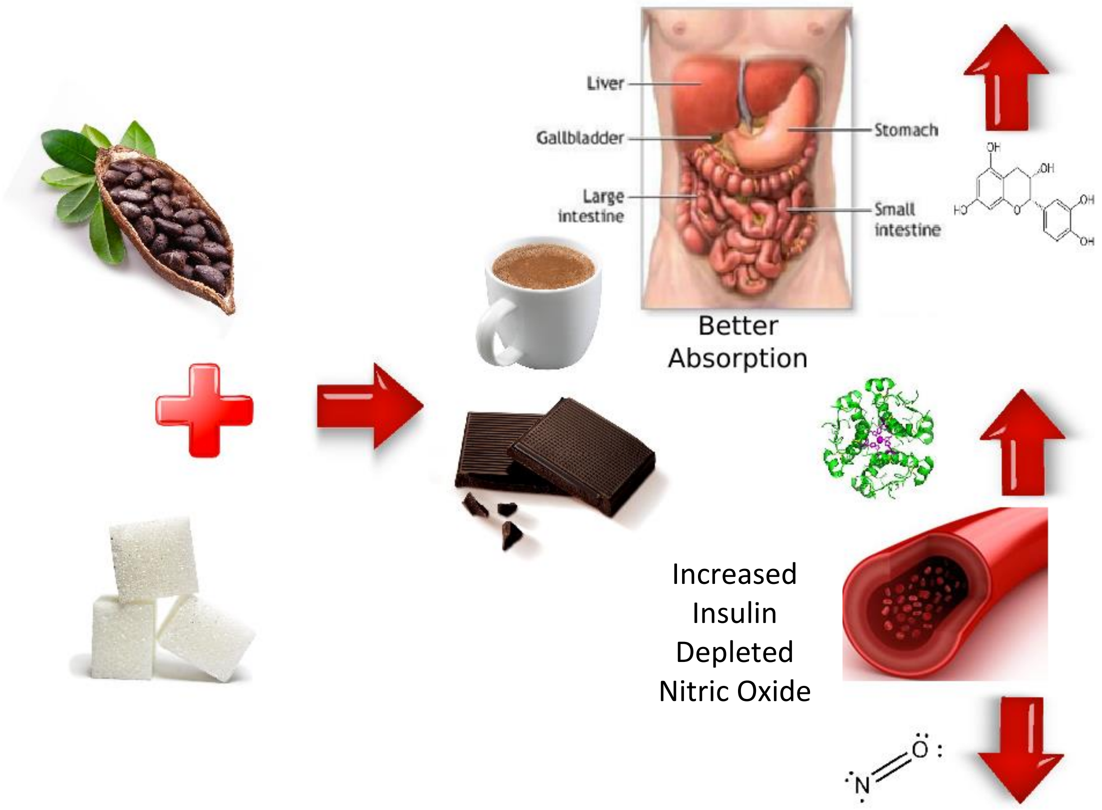
Graphical abstract



Abstract

The potential health effects of cocoa flavanols are well described. Ranging from reducing risk of developing type 2 diabetes and cardiovascular disease at population levels, moderating disease risk factors including endothelial function and lipid metabolism in clinical trials and mechanistic studies in laboratory studies highlighting target tissues and pathways. However, translating these benefits into public health messages is problematic, due to the high energy and sugar content of many cocoa products, including chocolate. This review considered the role of sugar in cocoa products, what are its physiological effects on bioavailability and bioactivity? Considering, then how cocoa products can be reformulated to reduce sugar intake, and the likely effects on beneficial effects of cocoa flavanols and consumer preferences. Ultimately, although interesting physiological effects are seen with cocoa flavanols, their use as a disease-modifying commodities may be limited the effect such products may have within an individual’s and populations overall dietary patterns.

Key Words:

Polyphenols, Cocoa, Sugar, Bioavailability, Reformulation, Prebiotics

Introduction

There is a considerable emerging interest over the past two decades around the potential role of cocoa in enhancing human health. This has a deep routed history, with cocoa having cultural along with a role in traditional medicine dating back to the Aztecs and Mayans in Central America. Historical benefits include an association with increased endurance, with the Codex of the time recording that Emperor Montezuma II claimed that a soldier could march for a whole day on a single cup of cocoa (Dillinger et al., 2000, Mellor and Naumovski, 2016, Ellam and Williamson, 2013).

However, the historically cocoa was not consumed sweetened or processed as it is today and as these claims of soldier's endurance could not be ascribed to its sugar content. Modern cocoa drinks and chocolate developed alongside the industrialisation of food sector in the 19th and 20th century. Historically, cocoa was consumed as a bitter, unstable grit containing drink, initially as a part of the religious ritual of the the elite of Aztec society well before its arrival in the chocolate houses of Europe of the 17th and 18th centuries. At the time, rapid advances in food technology, including the development of dried milk and effective ways to separate cocoa butter from cocoa solids before recombining to form a stable solid end product have allowed modern chocolate to be developed. These innovations occurred at the same time as sugar becoming more widely available, allowing for the sweet, smooth and melt in the mouth chocolate products that are familiar to consumers today (Dillinger et al., 2000).

In order to critically considering the potential effects of adding sugar to cocoa in products, it is vital to consider the end form the product will take; primarily if it is a solid (chocolate) or liquid product (beverage). Main reason for this is that manufacturing process requires a consideration of a number of different variables in the development and formulation of the required products. The way in which the cocoa itself if process will impact on its polyphenol content, even before it is being incorporated into a product (Bordiga et al., 2015). This is before considering the potentially, large variations in bioavailability and bioactivity between solubilised cocoa or chocolate as delivery vehicles for cocoa flavanols (Mellor, 2013, Davison and Howe, 2017). Beyond their food chemistry, there are nutritional considerations linked to the high energy content of cocoa and chocolate products, including significant levels of fat (especially saturated fatty acids) and sugar, which could have the potential to reverse any advantageous effects of the cocoa flavanols. Attempts have been undertaken to replace sugar with sweeteners such as stevia (Azevedo et al., 2017), add fibre to reduce the overall energy content of the product (Aidoo et al., 2017) or even both approaches (Rezende et al., 2015) however the effect of these approaches on the bioactive effects of chocolate is largely unknown. Although these points are potentially academic as the quality of the research data counts for nothing, if the resultant food product is unpalatable to the consumer. During the formulation or use of any functional food product (in this case cocoa products) the commercial goal of the product development is to devise a method of delivery for '*active*' ingredients to the maximal absorption site of the gastrointestinal tract. Therefore, it is empirical to consider the bioavailability and biological activity of the cocoa flavanols and how this may relate to the food product formulation and *vice versa*, before finally considering the place of the product in the context of whole diet patterns from a public health perspective.

One challenge is the relatively poor bioavailability of cocoa flavanols, even epicatechin which is reported to have the best bioavailability still is has limited absorption of around 25% (Baba et al., 2000). This has led to questions being raised about the effect of cocoa and chocolate as a functional food (Rein et al. 2013), this is despite the large number of clinical trials supporting a beneficial effect (Mellor and Georgouspoulou, 2017). It is plausible to consider that even with optimal product formulation the net amount of epicatechin available and any effect it might product could be negated by the negative nutritional impact of the energy, fat and sugar content of the end product.

Modern cocoa and chocolate products being highly palatable and energy dense, leads to its consumption being at controversy with public health messages. It appears that the potential of cocoa flavanols to enhance health are at odds with its high sugar and fat content resulting in a product with a high energy density that is desirable and easily over-consumed. Despite this, a growing body of data has emerged suggesting that cocoa and chocolate consumption may be associated with lower risk or chronic disease, especially cardiovascular disease and its associated risk factors (Ried et al., 2017, Larsson et al., 2016, Yuan et al., 2017). With these potential conflicting interests of high energy content and public health concerns about sugar, it is important to consider the role of sugar and other carbohydrates in cocoa and chocolate products and what effects might be expected if formulation changes are made to products, both with respect to consumer's preferences and perceptions as well as influences on bioavailability and bioactivity.

Mechanisms of Cocoa Flavanols: Potential interaction with sugar

A number of mechanisms have been proposed in attempt to explain how cocoa flavanols may improve human health. Perhaps the most pertinent mechanisms explaining how cocoa flavanols may reduce blood pressure and reduce risk of chronic disease, is via its effect on nitric oxide (NO) (Fraga et al., 2011). With cocoa flavanols, having potential to induce endothelial nitric oxide synthase (eNOS) and therefore increase the available pool of NO, with additional influences of insulin mediated pathways being another potential mechanism (Grassi et al., 2005). It is thought that the sugar content of chocolate could potentially negate any impact of the cocoa flavanols. The potential mechanism for this is seen via the depletion of the pool of available NO which is not a direct action of sugar, but rather the result of its potential to increase insulin levels, as the resulting hyperinsulinaemia could deplete the NO pool (Dworakowski et al., 2008, Munzel et al., 2008). This may be of importance as the effects of NO depletion and endothelial function are implicated in obesity and related metabolic diseases including type 2 diabetes and cardiovascular disease (Sansbury and Hill, 2014).

Health Policy and the Drive to Reduce Sugar Content of Foods

Although, sugar in cocoa and chocolate products may negate the effect of cocoa flavanols, it is a nutrient of wider concern from a public health perspective. Relatively recently, there has been increased public health and political interest on the impact of sugar consumption on human health. Following systematic reviews showing a link between consumption of free sugar and obesity (Te Morenga et al., 2014) and further evidence of its negative effects on dental health (Moynihan and Kelly, 2014), the World Health Organisation (World Health Organization., 2015) adjusted its recommendation to an absolute maximum of 10% of total energy from free sugar, with an aim to reduce intake to 5% of total energy coming from free sugars. The term 'Free sugar' is a recently added definition used to cover all sugars added to foods as well as that found in fruit juices and smoothies (World Health Organization., 2015). This view to recommend a more aggressive reduction in free sugar intake has been taken further in the UK with the Scientific Advisory Committee on Nutrition (SACN) which set the upper limit of 5% of total energy from free sugars for the UK population (Scientific Advisory Committee on Nutrition., 2015). The rationale for this stricter target is the evidence linking free sugar intake to obesity, with the lower intake level being justified as it could be associated with a 100kcal/day (418kJ/day) decrease in energy intake, that could at a population level reduce average Body Mass Index (BMI), and moderate population obesity levels. However, SACN suggested this energy reduction from sugar could be replaced with wholegrain, so not reducing overall energy intake and therefore not likely to impact population obesity levels (Scientific Advisory Committee on Nutrition., 2015). The relationship between free sugar intake and other diseases is emerging including associations with type 2 diabetes (Basu et al., 2013) and other chronic disease (Yang et al., 2014) however, this evidence was deemed not strong enough to inform current guidelines (Scientific Advisory Committee on Nutrition., 2015, World Health Organization., 2015).

The increasing evidence regarding the negative implications of free sugar on human health, particularly related to sugar sweetened beverages, which would include based cocoa drinks has also led to legal changes to bring in taxation on sugar in drinks in countries as diverse as Mexico, France and the UK. This has led to further calls from public health, political and clinician groups to implement sugar taxes along with debates about the associated challenges in other countries including Australia. With cocoa products however, these legislations could further complicate the markets potentially leading to cocoa drinks being taxed and chocolate not being subject to any additional levies, highlighting the challenges of health related taxation being applied to food and beverage products. In addition to taxation, in the UK a long term strategy of voluntary reformulation by the food industry which has reduced energy intake along with amounts of fat, sugar and salt. Together these changes potentially impact on cocoa and chocolate products and their development. Sugar has key roles in chocolate and cocoa products including flavour, a key aspect being the masking of the bitter flavours and clawing mouth feel associated with the flavanols in these products (Thamke et al., 2009). The move to reduce energy and fat too has added pressure to reduce serving size, which in turn has the effect of making a product with an effective *'dose'* of flavanols increasingly challenging.

It is therefore vital to understand the characteristics of the optimal formulation of cocoa and chocolate products with respect to sugar content and sweetness when delivering flavanols to maximise bioavailability and bioactivity. If food products are to be developed, it is key to devise formulations of food products aimed at optimising health whilst minimising any potential adverse effects. This approach is following the norms (and standards) of the pharmaceutical industry where the central theme is balance of benefit over potential harm. However, functional foods, tend to be judged primarily for hygiene, safety and contribution to nutritional adequacy of diets, and as such are not subject to such critical analysis. It is important to note, that adding a new active ingredient in the particular food product, does not and should not lead to it being classified automatically as a functional food. The new ingredients can form very complex *'interactions'* and *'degradations'* within the food matrices and as such be potentially completely inactive.

Effect of Sugar on Absorption and Metabolism

The absorption and metabolism of polyphenols and flavanols is very complex cascade of events that is tightly regulated by changes in pH, gut microbiota and overall health status of the gastrointestinal tract (Crozier et al., 2009). In foods these compounds exist as monomeric catechins (mainly epicatechins) and oligomeric flavanols, typically varying from dimers to decamers. In cocoa the ratio of these compounds depends on a range of factors; from the country of origin through to the method of processing (mainly fermentation and roasting) (Hurst et al., 2011). Typically, 34-37% of the flavanols in cocoa are monomeric and as such have a greater potential to be more bioavailable (Langer et al., 2011, Wollgast and Anklam, 2000). The stability of these compounds in post-harvest foods is also an important consideration. In chocolate and cocoa the flavanols (especially flavano-3-ol) content has been reported as being stable for at least two years (Hurst et al., 2009), whereas in beverages stability of the product is significantly shorter, partly related to high water activity, risk of spoilage and their oxidative stability. Therefore, the potential increased stability of the flavanols in chocolate may be at least in part related to its composition including its sugar content, which contributes to its low water activity. Consequently, chocolate was described as an ideal matrix for the preservation and potentially the delivery of flavanols (McShea et al., 2008). Nevertheless, these delivery property is largely dependant on the other components of the chocolate formulation.

Effects of Sugar in the Upper Gastrointestinal Tract

To date; the effect of food ingredients other than cocoa has concentrated on the effects on the effect of adding milk to either beverages or solid chocolate. The rationale for this was related to the effect of the milk proteins binding to flavanols and the hypothesised reduction in their bioavailability with studies providing less definitive information (Roura et al., 2007, Rashidinejad et al., 2017). Additionally, the primary focus on the protein component of the milk has potentially overlooked any effect of other components including fat and lactose.

The beneficial effects in humans of cocoa flavanols in chocolate or beverages were suggested to be reduced due to the sugar content (Faridi et al., 2008, Njike et al., 2011). Typically, the added sugar in cocoa and chocolate products is sucrose, which along with other carbohydrate content may be of interest with respect to how it may influence bioavailability. In human clinical trials where cocoa was administered with or without sugar (sucrose), it appears that sucrose might actually enhance the flavanols absorption (Schramm et al., 2003). The same group continued this work to investigate the effects of other carbohydrate-rich foods with cocoa, which produced a similar enhancing effect on flavanols absorption. Although this was not necessary a representative of how it is typically consumed as bread and sugar were included as part of a meal containing cocoa, rather than formulated in a real food matrix of a typical of a chocolate or cocoa product. In addition, different types of sugars are not compared using a standardised flavanol intake.

A review of how a range of individual macronutrients effects generally on polyphenol bioavailability and action was undertaken by (Jakobek, 2015). This highlighted that there were a number of factors of how carbohydrates may influence polyphenol and potentially cocoa flavanol bioavailability, not all of which would be applicable to a cocoa beverage or chocolate matrix such as;

a. *Polyphenol structure;* cocoa and chocolate predominantly contain catechins and proanthocyanidins, although their proportion and quantity is reduced by fermentation and other processing procedures (Wollgast and Anklam, 2000). Cocoa products tend to have higher levels of the lower molecular weight catechins, particularly epicatechin which has been shown to have greater bioavailability and stability in comparison to other catechins (Manach et al., 2005).
b. *Complexity of polyphenol-carbohydrate structure*, which in cocoa products, due to effects of processing is likely to be less complex than other sources. This can also add to the enhanced bioavailability of the polyphenols in the food product
c. Enzymatic breakdown of the carbohydrate may be a factor that could most plausibly contribute to inter-individual variability. Both directly from the individual's expression of enzymes and the effect of the gut microbiota.

Effect of Carbohydrate in the Large Intestine, the Influence of Microbiome.

The potential beneficial effects of combinations of polyphenols and carbohydrate in the large intestine have also been reviewed by Jakobek (2015) suggesting that the occurance of polyphenols in conjunction with carbohydrates can both help the delivery of polyphenols to the lower GI tract and provide benefits in the colon itself. The environment of the lower GI tract and the increased diversity of enzymes preventable to metabolise polyphenols and carbohydrates resistant to digestion, provided by the gut microbiome means this provides an additional site where important interactions may take place. However, unlike in the small intestine, unless sugars are conjugated to the flavanol molecule the carbohydrates associated with polyphenols in the colon are likely to be more complex having potentially escaped hydrolysis.

It has become generally accepted that the gut microbiota is considered to play roles in health and disease (Clemente et al., 2012), and can be modulated by certain dietary components, especially prebiotics which are non-digestible compounds that are selectively metabolised by beneficial microbiota (Bindels et al., 2015). These can include various dietary polyphenols (Duenas et al. 2015) and Cocoa flavanols have been proposed as a potential candidate for a prebiotic (Strat et al., 2016, Tzounis et al., 2011), exhibiting at least some of their biological effects in the colon. In a study by Tzounis et al. (2011), cocoa flavanol intake resulted in significantly increased growth of beneficial *Bifidobacterium* spp. and *Lactobacillus* spp. in human volunteers. It was even postulated that as many of the metabolites observed in plasma have been attributed to microbial activity on cocoa polyphenols, owing to the plasma compounds not being found in the original cocoa, suggesting the key role of gut microbiota in cocoa flavanols activity. Nevertheless, the interactions of cocoa flavanols with carbohydrate and sugar in this process is yet to be determined.

The predominant cocoa flavanol monomers, catechin and epicatechin appear to be more readily absorbed than more complex polyphenols in the small intestine, although uptake is still only around 25-30% of that in the product consumed (Baba et al., 2000). The larger molecular weight oligomers (procyanidins) travel undigested to the large intestine, to be metabolised by the gut microbiota (Rein et al., 2013, Strat et al., 2016), suggesting molecular weight could be a key factor in reaching the lower GI tract. In order for the higher molecular weight polyphenols to become bioavailable, it appears that fermentable carbohydrates are required. It has been proposed that the fermentation of prebiotic oligosaccharides may contribute to the absorption of polyphenols in the large intestine by suppressing bacterial degradation of polyphenols in the caecum and stimulating mucosal blood flow (Zhang et al. 2014). More insight is needed into the role of the lower GI tract in polyphenol metabolism and its role in health, especially the potential of a synergistic relationship between fermentable carbohydrate, polyphenols and gut microbiota.

The Role of Sugar in Cocoa and Chocolate Products

Majority of the commercially available products containing cocoa have a high energy density; derived from the cocoa butter component (along with some added fats depending on the product and the jurisdiction of manufacture) and added sugar. The sugar is added mostly for sensory properties, as many of the proposed health promoting bioactives are associated with strong bitter flavours and a usually unpleasant mouth feel (Thamke et al., 2009). With lower concentrations of the fat free cocoa mass (which are rich in flavanols compared to cocoa butter) and more sugar and cocoa butter being associated with a creamy flavour and better mouth-feel (Thamke et al., 2009), results in many commercially available products that are formulated for flavour containing very modest levels of these potentially beneficial compounds.

One of the relatively unexplored areas is the effects of sugar content in cocoa and chocolate products and their influence on the health effects of these commercial products, these have been summarised in table 1, and discussed in detail in this review. There appears to be an initial thought suggesting that sugar may reduce the effect of any bioactives, however the differences in bioavailability of maybe related to if they are conjugated (glycone) or not (aglycone) to a sugar moiety (Bohn, 2014). This, also requires to be moderated by the negative effects of excess sugar intake, beyond its calorific load which is its potential to raise insulin levels which can mitigate some of the beneficial effects from the flavanols and other components, including the depletion of the NO pool which would be enhanced by supplementation.

Post-absorption Effects of Sugar on Cocoa Bioactivity

To date, there is a limited data about the effect of both different sugars on the behaviour of cocoa flavanols including bioavailability and overall efficacy in humans. A small number of studies have investigated the different effects of sugar sweetened products compared to those sweetened with sugar alcohols (Rodriguez-Mateos et al., 2012) on bioavailability along with comparing non-nutritive sweeteners (sugar-free) cocoa to sugar sweetened cocoa on endothelial function (Njike et al., 2011, Faridi et al., 2008).

Couple of clinical trials investigated the effects of feeding cocoa products rich in flavanols with and without sugar on endothelial function both acutely (Faridi et al., 2008) and then over a 6 week period (Njike et al., 2011). The findings of these studies indicated that flavanol rich cocoa improves endothelial function, it appeared that in cocoa given as a beverage the addition of sugar resulted in a reduced improvement compared to the non-nutrient sweetener beverage. Where the cocoa flavanols were given as an equivalent dose in the form of chocolate, the effects appeared to be rather different, suggesting that there could be a synergistic interaction between the lipid content of the cocoa butter, flavanols and potentially sugar in a solid product. No statistical analysis was reported comparing the cocoa beverage to the chocolate, therefore there is a lack of data to support whether sugar behaves differently in cocoa beverages than in solid chocolate. This is definitely an area warranting further study, as consuming cocoa flavanols in solid chocolate may lead to better bioavailability (Davison and Howe, 2017). Additionally, human studies with variable sugar content are required as the optimal sugar content in either a cocoa beverage or chocolate is yet to be determined.

To attempt to explore the difference between beverages and solid chocolate a post hoc *t*-test based on the published data of (Faridi et al., 2008) suggested that for endothelial dysfunction there was significantly greater improvement in flow mediated dilation for the dark chocolate compared to the sugared cocoa ($p=0.0076$, standard error of difference (SED) = 0.82) with no significant difference between the dark chocolate and the sugar-free cocoa ($p=0.1325$, SED =0.913) (Mellor, 2013). The principle difference between the sugared cocoa and the chocolate was that the dark chocolate contained approximately two-thirds less carbohydrate (sucrose) than the cocoa (39 compared to 104g). The difference in carbohydrate content, only resulted in a 30% reduction in the energy content (327 compared to 460 kcal (1370 compared to 1920kJ)); a reflection of the significantly greater fat content of the chocolate (27 compared to 2g) for the cocoa (Mellor, 2013). Therefore, it was clear that the cocoa product had far more sugar, and it is plausible the excess of sugar could have been the issue with the cocoa drink compared to the chocolate, or there could be effects of the combination of sugar together with fat in a chocolate matrix. Thus, this limited data could suggest that an optimal sugar content may exist for cocoa and chocolate products, that enhances absorption without impeding bioactivity.

Evidence of the effect of varying the type of sugar, to a sugar alcohol provides data on with respect to any beneficial effect of sugar on the absorption of cocoa flavanols. A study by Rodriguez-Mateos et al. (2012), aimed to reduce the energy density and improve the glycaemic profile of the product itself. The substitution of sucrose by maltitol, although not quite the same as varying the sugar intake gives insight into potential effects, in this case it appeared to reduce the absorption of flavanols, which was seen both as area under the curve and at with a delay, with significantly less flavanol in plasma at one and two hours following ingestion (Rodriguez-Mateos et al., 2012). This finding supports the notion that sugar may provide a function in enhancing cocoa flavanols absorption, although there was no assessment of bioactivity such as endothelial function (Njike et al., 2011).

There appears a lack of studies that have attempted to compare chocolate and cocoa which has been matched for not only epicatchins and carbohydrate along other potentially biologically active compounds (e.g. caffeine and theobromine). To our knowledge, only one to date study by Baba et al. (2000) was identified. This being a very small crossover study reporting data from only five healthy males, which, unfortunately was not powered adequately to determine a difference in absorption between the cocoa and chocolate. It claimed that the only difference between the cocoa and the chocolate was the contribution of cocoa butter to the fat and energy content of the chocolate. It could be proposed that there is a potential role for both carbohydrate and fat together in enhancing cocoa flavanol absorption. This study of the effect of the form of the cocoa product suggested that there were no significant differences in uptake from the gut between cocoa and chocolate, although the clearance of epicatechin metabolites in the chocolate group was 29.8±5.3% of the ingested epicatechins, compared with 25.3±8.1% (p=0.329) for the cocoa. However, the levels of free epicatechins appeared to be higher with cocoa at the one and two hour points following ingestion (0.10±0.03 compared to 0.22±0.06μmol/l and 0.15±0.04 compared to 0.22±0.02 μmol/l respectively) (Baba et al., 2000). However, due to its underpowered nature claiming no significant effect as it risks a type 1 statistical error.

A logical deduction from the limited data could be that it is suggesting that interactions could be occurring in the two different products, which could relate to differences in product formulation and composition. This single study presents a mixed picture of the effects of cocoa and chocolate on the bioavailability of epicatechin. Based on this study which utilised urinary recovery as its measure of bioavailability, was a study with a sample size of 21 would have an 80% power to detect a significant difference between chocolate and cocoa at the 0.05 level estimated using G*Power 3 (Faul et al., 2007). However, this does not directly measure bioavailability, along only partially reflecting the retention of epicatechins and their metabolites in the body, it does not assess extent and effect of de novo metabolism or the activity of metabolites. Therefore, further work is needed to address, including assessments of serum epicatechin concentrations, along with data on their metabolites and their biological effects. This more forensic approach, is vital to be able to detect any difference in the absorption of epicatechins from a macronutrient and other bioactive matched chocolate and cocoa.

There are a number of mechanisms to explain why flavanols administered in the form of chocolate may have enhanced absorption compared with flavanols administered in a cocoa drink. These include a combination of physical and chemical properties of the cocoa or chocolate, along with the nutrient and non-nutrient effects on gastrointestinal physiology (Mellor, 2013). It is also plausible as most studies are include a comparator, the level of participant self-disclosure and adequacy of blinding procedures could influence the study outcomes.

A common feature of dietary polyphenols including flavanols, is their need to be hydrolysed acidic or enzymatic), as in the plant, they mostly exist in a glycoside form. The length of time and amount of hydrochloric acid secreted in the stomach as well as the combination of foods ingested will influence the acid hydrolysis. Additionally, the enzymatic hydrolysis will be influenced by the levels of enzymes such as lactase phloridzin hydrolase and cytosolic β-glucosidase in the intestine (Crozier et al., 2009). Initially, based on data from *in vitro* studies, it was considered that increased time in the stomach might hydrolyse a greater proportion of procyanidins and thus increase the pool of epicatechin and other monomeric flavanols available for absorption (Spencer et al., 2000). These data were somewhat refuted by (Rios et al., 2002) who suggested that in humans fed via a nasogastric tube there were no differences seen with respect to degradation of procyanadins after a gastric transit of up to 60min.

The potential for acid hydrolysis in the stomach of both the glycosides and the procyanadins to increase bioavailability of the polyphenols from chocolate or cocoa, could be of considerable importance. It has been widely described that stomach emptying is quicker for liquids than solids, which could infer that the increased viscosity of chocolate compared to cocoa drinks might slow gut transit time. The difference in the fat but not sugar content can potentially lead to an increase in the time the food is in the stomach. Gut peptides, including cholecystokinin produced by the duodenal mucosa under the influence of fat are known to supress gastric emptying (Liddle et al., 1986). This highlights two potential mechanisms on how chocolate might act to slow gastric emptying when compared to cocoa. However, to our knowledge there is no published work that has tested this.

The product formulation or food matrix also has a number of physical effects that could affect bioavailability. A study in much larger molecular weight green tea polyphenol epigallocatechin gallate has identified that its systemic absorption was reduced when this catechin ingested with food or if it is imbedded in the food matrix if compared to the pure product (Naumovski et al., 2015). From the studies reported, the quality and concentrations of the cocoa powder constituents used was not always reported including its ability to be dispersed in the medium (typically water) (Fogliano et al., 2011). Cocoa is not very water soluble even in hot water and this property might be a barrier to bioavailability, with the hydrophobic cocoa particles being less readily digested, preventing the procyanadins and monomeric flavanols from being hydrolysed to more bioavailable forms (Fogliano et al., 2011). However, in chocolate, these physical characteristics are very different; the cocoa tends to be evenly distributed within the product, the effect of which is to increase surface area available for hydrolysis and digestion, resulting in increased bioavailability. Therefore, it is plausible that the high fat content can provide a hydrophobic matrix, but the particle size is likely to be much smaller and as such it is not clear which of these two factors is more important in influencing bioavailability.

The effect of food ingredients other than cocoa has to date largely concentrated on the effects of adding milk or altering the sugar (usually sucrose) component of the end product. The sucrose or other carbohydrate content may be of interest in terms of its biological activity, in addition to its potential effects on bioavailability. In human studies, where cocoa was administered with or without sugar (sucrose), it appears that sugar might enhance flavanols absorption (Schramm et al., 2003).

When considering the effect of sugar on bioavailability of cocoa flavanols, it is important to consider the potential effects of the form, it appears from post-hoc analysis of data by Faridi et al. (2008) reported earlier; that being in the form of chocolate may increase bioavailability compared to cocoa and more specifically being associated with greater physiological changes following consumption (Davison and Howe, 2017, Davison and Howe, 2015). Although there may be a role for sugar in synergy with fat found in chocolate, there could be relationships in the differences in delivery and bolus formation in the upper gastrointestinal tract. An alternative mechanism could be that a combination of fat and sugar is needed, in that the fat may help to alter gastric emptying and protect the flavanols from degradation, and then the sugar may facilitate absorption in the small intestine. This view is further supported by the earlier observations of (Neilson et al., 2009) which appeared to show an influence, which did not reaching significance of sucrose on flavanol absorption.

Reformulation and Potential Future Products

One of the main problems associated with the available reviewed studies to date is that the actual concentrations of included flavanols were not clearly reported and as such the effects of flavanols related to the binding with sucrose or fat could not be entirely validated. Nevertheless, even at with unknown flavanol concentrations it is evident that a relationship is still present and existent. Given the negative health effects associated with the high sugar consumption, the use of different sweeteners has clear merits based on preferences and the needs of the current food market. However, it appears that these sweeteners can potentially reduce flavanol absorption. Therefore, sugar appears to have two roles in chocolate products aiming to achieve health benefit, one enhancing uptake and the second masking the bitter flavour notes of the flavanols.

The latter challenge of masking bitter flavours when designing 'healthy chocolate products' could be addressed perhaps by abandoning the reliance of bitter cocoa flavanols as their bioactive. This could take the form of milder tasting white chocolate, with different sources of potential bioactives, such as berries, then at the same time as reducing sugar content (Morais Ferreira et al. 2016). However, the consumer acceptability and functionality in humans of such products is yet to be elucidated.

With the potential scope for many candidate products with different sensory and physical characteristics, new approaches to processing and evaluating products will be needed. With respect to processing, reducing sugar and other changes in ingredients are likely to alter physical properties of chocolate through the various stages of production. This is an area warranting further investigation, with adaptations in processing needing to be considered to obtain the optimal particle size and viscosity to produce the optimal texture and sensory characteristics in the end product (Toker et al., 2017). Alongside adapting processing methods, new approaches to sensory evaluation of products during development will be required to make this feasible. The use of traditional sensory panels is unlikely to be practicalicable when assessing a potential large volume of new formulations prior to pilot production. Therefore, novel approaches such as gas chromatography-mass spectrometry (Waehrens et al., 2016) could be use to assess candidate products, before taking a feasible number of potential products forward to the next stages of product development.

The combinations of different sugar and sweetener concentration ranges need to be definitely further investigated as well as the relationships with the fat content. Although it is well established that the mouthfeel of food is in general ascribed to the fat content it is important to include the different concentrations and potentially different types of fat in the formulation of these products, this will have impacts throughout the product development and processing stages of any potential product aiming to have health benefits .

REGULATION

A major challenge of the use of sugar in cocoa and chocolate products is related to the cocoa health claims. If cocoa containing food products are to be marketed as health foods and hold approved health claims is not limited to just the physiological and food formulation effects. Public health policy in some jurisdictions has led to the development of nutrient profiling rules for products, linked to their legislative framework for making health claims on foods. Perhaps the most clearly articulated of these is perhaps the Food Standards Australia New Zealand code, which prior to approving any disease related health related claim a food must meet standards regarding levels of other nutrients (FSANZ, 2017). Similar guidance developed from the FAO codex exist in European union (EU) and in United States. These systems score products based on factors including energy, fat and sugar content, this could discourage a cocoa or chocolate manufacturer from either pursuing a health claim or look at ways to improve the nutrient profile, which is likely to have palatability and structural impacts on the end product. Ultimately impacting on consumer acceptability, shelf life and product cost.

Conclusions and Future Research

The available data suggests a role for digestible carbohydrate, with sugar or starch in enhancing the bioavailability of cocoa flavanols. It is not however clear if this effect is seen in both solid chocolate and cocoa beverages. The differences observed between the enhancement of absorption and bioactivity seen from solid chocolate compared to cocoa drinks could suggest that the effect could be due to a combination of energy dense fat and sugar are required to maximise the bioavailability of cocoa flavanols. The data currently available is hard to interpret, as there are limited studies and to date they have not reported both absorbed metabolites of cocoa flavanols and their biological action.

The potential of a functional need to combine cocoa flavanols with sugar and fat is not an ideal solution with respect to overall public health, as the associated excess of energy could result in weight gain. Based on the observations of combining cocoa flavanols with bread and sucrose (Schramm et al., 2003) and substituting sucrose with maltitol (Rodriguez-Mateos et al., 2012) supports the view that optimised flavanol bioavailability appears to occur when they are co-consumed with carbohydrate. With respect to bioactivity, the picture is different, with artificially sweetened cocoa beverages being more effective than sugar sweetened beverages (Njike et al., 2011), although chocolate appeared superior to cocoa beverages. What is apparent is that further work is required to gain a further understanding of the ratio of flavanols to carbohydrate and the preferred type of carbohydrate to meet the competing needs of palatability, enhanced bioavailability and cost. With this in mind, the golden trio of a successful functional food; being acceptable to customers, have good bioavailability of the active ingredient and functionality of the food product overall will all be achieved.

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Table 1: Summary of the positive and negative effects of carbohydrate and especially sugar on cocoa polyphenol availability and bioactivity.

Site of effect	Effect of Sugar/ Carbohydrate	Evidence	Reference
Upper GI Tract (small intestine)	Apparent enhanced absorption	Sugar and carbohydrate rich foods appear to increase absorption. Possibly through conjugation of aglycone forms of flavanols Sugar alcohol decreases absorption relative to sucrose	Schramm et al., 2003 Rodriguez-Mateos et al., 2012
Low GI Tract (colon)	Interaction between the fermentation of complex polyphenols and fermentable carbohydrate especially oligosaccharides	Potential effect, of the oligosaccarhides suppressing the degradation of polyphenols by bacteria and stimulating mucosal blood flow. This synergistic effect may have prebiotic potential	Zhang et al. 2014
Post-absorption in vivo circulation	The effect of sugar on glycaemia and in turn insulin may deplete nitric oxide (NO) pool. The synthesis of which may have been induced by epicatechin	No added sugar (artificially sweetened) cocoa improved endothelial function (which is linked to NO availability) compared to sugar sweetened cocoa	Njike et al., 2011, Faridi et al., 2008