The effect of sugar substitution on model confectionary systems

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Abstract

In modern diet sugar gives high percentage of the recommended daily calorie intake. Excessive consumption of added sugar is associated with many health problems, for example obesity, type 2 diabetes, etc. Hence there is an urgent need for the product reformulation by total replacement or partial reduction of sugar in food industry. The aim of this research was to study the effect of sugar substitution (by stevia and xylitol) on model confectionary systems. We investigated differences in the texture properties, the viscosity and thermal properties of the blends. Based on our results the sugar substitution affects the physical properties of the measured samples. The apparent viscosity and the texture properties were changed due to the different dry matter content in the samples. In the DSC curves the different melting of the samples were expressed according to the changes in sugar content. Further work is needed in this field to follow up discovered changes in the thermal behaviour of these mixtures.

Keywords: thermal behaviour, sugar replacement, sugar-lipid system

Introduction

In the world around 30 % (2,1 billion) inhabitants are overweight or obese. (Dobbs et al, 2014; Miele et al, 2017). According to the mortality rate the death associated with excessive weight gain is more prevalent than those arising from underweight (WHO, 2016a; Miele et al, 2017). Excessive sugar intake is generally considered to contribute to excessive caloric intake, lower diet quality and adverse health affect such as dental carries, obesity, type 2 diabetes, cardiovascular disease and some cancer (Luo et al, 2019). In modern diet, sugar gives around 25% of the 2000 kJ recommended daily calorie intake (Lustig et al, 2012), which is far more than the maximum 10 % recommended by the WHO (Miele et al, 2017). Approximately 80 % of youth (Wang et al, 2008) and 63 % of adults (Bleich et al, 2009) consume sugar-sweetened beverages every day.

Hence the above mentioned there is an urgent need for sugar reduction and/or substitution in food products. The key tool for sugar replacing is the use of alternative sweetening agents that provide less energy per gram then sugar (Buttriss, 2017). However, delivering the same texture and sugar-like sweetness with partial or full sugar reduction is challenging task as sweeteners typically display an unusual sensory characteristic and different texture (Moraes & Bolini, 2010).

Use of alternative sweeteners is almost inevitably requires trade-offs and the best choice will probably depend on the matrix and recipe of the food, the legal restrictions on certain food categories, and the expectations and preferences of consumers (Buttriss, 2017).

In confectionary products the main ingredients are fats and sugars. Generally, in creams and fillings palm oil is used due to its wide applicability.

Palm oil has a balanced fatty acid composition in which the saturated fatty acids and the unsaturated fatty acids content is almost equal. Palmitic acid (P, 44–45%) and oleic acid (O, 39–40%) are the major fatty acid components along with linoleic acid (Ln, 10–11%) and stearic acid (St, 4-5%) (Gunstone, 2002). Palm oil consist of three main types of triacylglycerols (TAGs), trisaturated-PPP, disaturated – POP and monosaturated –POO (Gee, 2007; West & Rousseau, 2016).

Studying the crystallization phenomenon of fats (e.g palm oil) is essential for food products. However, fats and oils are rarely present as a bulk material in processed foods. Rather, they often act as a continuous matrix that incorporates non-fat ingredients for example sugar. The dispersed ingredients may alter the crystallization pathway and rigidity (Walstra, 2003; Fernandes et al., 2013), with potential consequences on techno-functional and sensory properties of the products. (Beckett, 2000; West & Rousseau, 2019)

The aim of this research was to study the effect of sugar substitution (by stevia and xylitol) on model confectionary systems. Here, we investigated differences in the texture properties, the viscosity and thermal properties of the blends.

Materials and Methods

Commercial sugar (saccharose), stevia and xylitol were used in this the study. Palm oil was purchased from Palmfood Kft. The oil was creamed with an equal mass fraction (50 wt.%) of sugar manually. The different sweeteners were added according their sweetening power, thus xylitiol was used in the same proportion as saccharose (50% fat+ 50% sugar/xylitol), where stevia was added in smaller ratio (80% fat + 20% stevia).

Apparent viscosity

The apparent viscosity of the samples was analyzed with Brookfield DV-E rotation viscometer. The tests were made at 30°C with increasing speed from 0 to 20 RPM with LV4 cylindrical spindle.

Thermal properties

Thermal properties were analysed by differential scanning calorimeter (DSC) (NETZSCH DSC 3500) previously calibrated with indium. The samples (14.0 ± 1 mg) were hermetically closed in concave aluminium pans and heated in a calorimeter from 25 to 80 °C, cooled to -20 °C and heated again to 200 °C at constant rate 5 °C min^{-1}. An empty aluminium pan was used as reference. Temperatures (T_o - onset, T_p - peak, T_e - end) and enthalpy of thermal transitions (ΔH-Area, J g^{-1}) were determined with the use of the instrument's software Proteus Analysis.

Texture Analyses

Hardness, Work of penetration and Adhesiveness were measured using a texture analyzer (TA.XT2i, Stable Micro Systems) calibrated with a 2kg load cell. Plastic cups were filled with the samples (~10g). For analysis, a 45° steel cone was calibrated to a 10mm height above the sample surface and programmed for approach at $2mm \cdot s^{-1}$. Upon contact with its surface, the cone penetrated the sample at $1mm \cdot s^{-1}$ for 80% of the original height, at which point the measured force value was recorded as hardness. The area under the positive curve was determined as work of penetration, which is the energy required to deform the samples to the defined distance. Withdrawal of the cone probe from the sample provides information about adhesive characteristics of the samples.

Statistics

Data were analyzed by one-way analysis of variance (one-way ANOVA) to test the variations in different samples, $p < 0.05$ was considered statistically significant. If there were significant difference in variance, paired-samples t-test was used.

All measurements were done at least triplicate.

Result and Discussion

Apparent viscosity

In the literature one of the commonly used rheological model is Casson model (Barbosa et al, 2016). This used to describe the flow behaviour of high sugar and fat content matrixes such as e.g. the molten chocolate.

$$\sqrt{\tau} = \sqrt{\tau_0} + \sqrt{\eta * \gamma}$$

where τ – shear stress [Pa]; τ_0 – yield stress [Pa]; η- viscosity [Pas]; γ- shear rate [1/s]

In our case from the measured apparent viscosity and speed values the parameters in the Casson equation were calculated. The correlations between shear rate and shear stress for all investigated mixtures are shown in Figure 1.

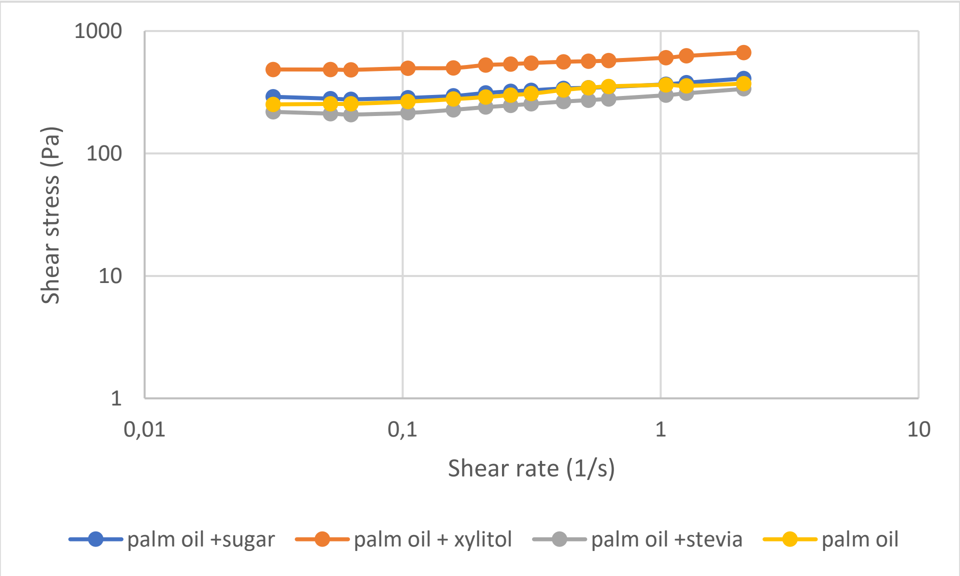

Figure 1: Correlation of shear stress and shear rate calculated by the Casson model

In every case the shear stress value increased with increasing the shear rate. The addition of stevia decreased the shear stress values, while saccharose and xylitol increased it compared to the pure fat. The observed reduction of the viscosity in stevia sample was due to the lower dry matter content of the mixtures. The results of the saccharose and xylitol samples were influenced by the water content of the ingredients which is related to the hygroscopic behaviour of the materials.

Texture analysis

The presence of dispersed phase influenced the texture properties of the sample (Figure 2). Hardness and the work of penetration values increased with the addition of saccharose and xylitol compared to the pure fat. However, in the case of stevia these values reduced, due to the lower dry matter content of the samples. In every case the adhesiveness of the mixtures decreased compared to the pure fat. This effect can be related to the mixing ratios. From the statistical analyses we found that, in work of penetration only stevia, in adhesiveness only palm oil was significantly different compared to the other samples. However, in hardness values the mixtures were mostly different, only between palm oil and stevia were no difference.

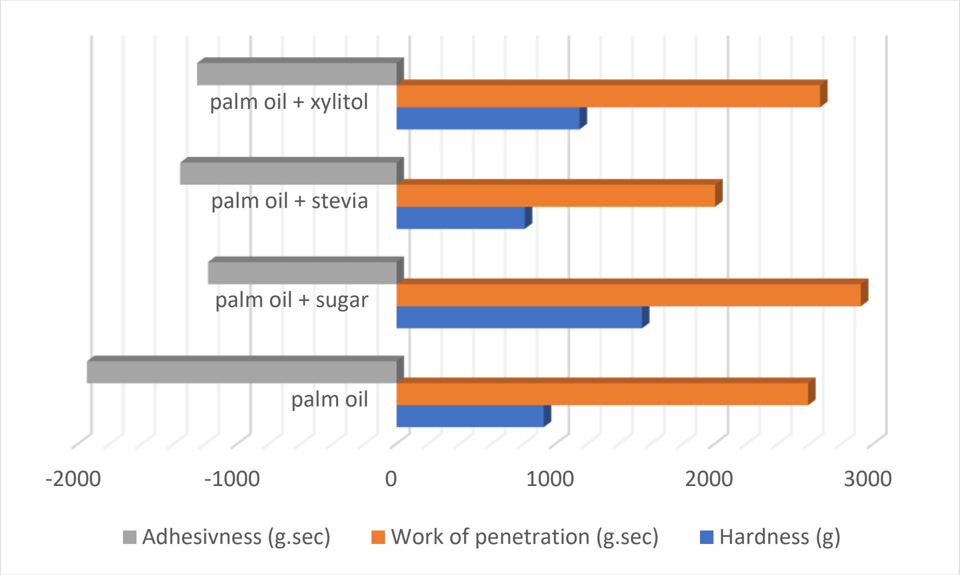

Figure 2 Results of the penetration tests done by texture analyser

Thermal Properties

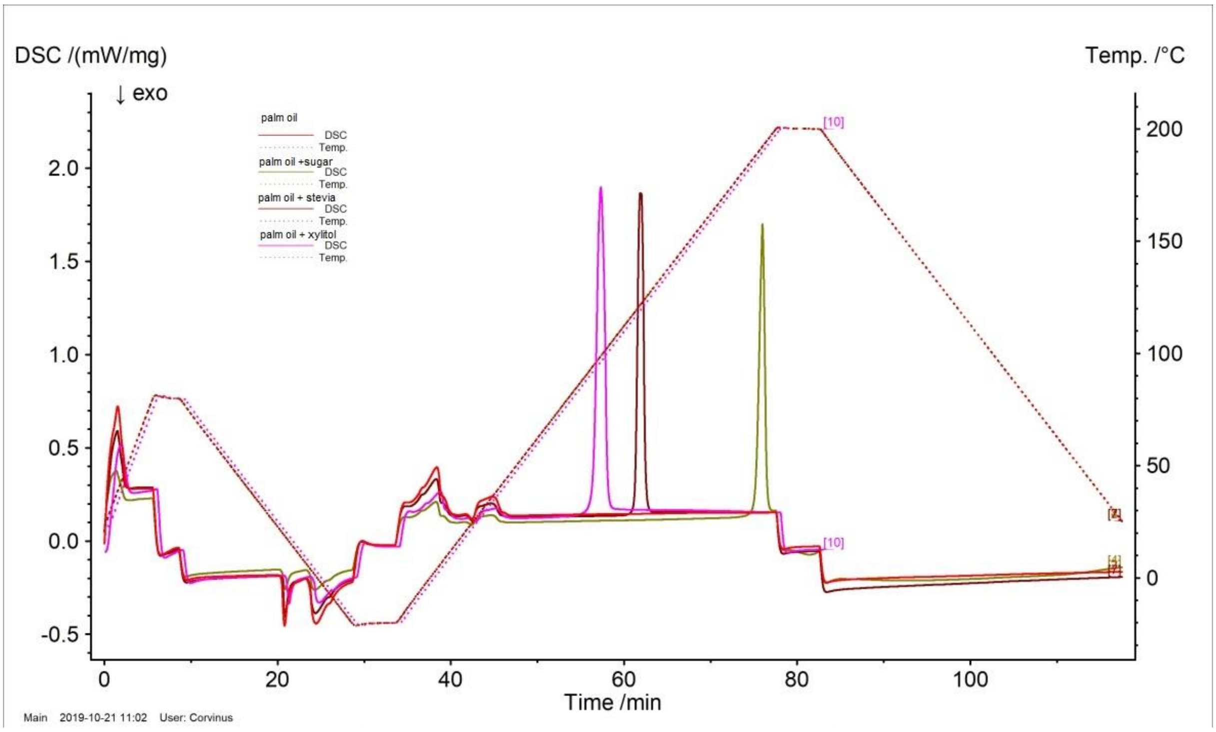

Figure 3: DSC curves of the mixtures

The crystallization and the melting behaviour of the samples were analysed with DSC (Figure 3). In Table 1 the Onset, Peak, Area and the End temperature values of melting are showed. Generally, the addition of sugar resulted in a high peak on the melting temperature curves of the sugar or sweetener, unlike the fat-connected peaks, which were negligible small in these cases. The Onset, Peak and End temperature of the samples were shifted according to the melting characteristic of the samples. Xylitol melted first, than stevia and the saccharose at the highest temperature around 190 °C. However, the enthalpy of the mixtures showed revers result, with the increasing temperature values the enthalpy values decreased. All the measured parameters were significantly different among the three samples.

Table 1: Melting characteristics of the mixtures

	Onset (°C)	Peak (°C)	Area (J/g)	End (°C)
Palm oil+xylitol	92,3 ± 0,23	96,5 ± 0,06	115,9 ± 4,02	100,7 ± 0,1
Palm oil+stevia	118,7 ± 0,06	121,5 ± 0,06	80,5 ± 4,15	124,2 ± 0,32
Palm oil +sugar	188,5 ± 0,07	192,0 ± 0,35	59,1 ± 8,14	194,3 ± 0,64

In Table 2 the Onset, Peak, Area and End temperature values of the crystallization are showed. In every case 2 peaks can be seen in the curves. According to our results the main crystallization temperatures were almost the same in every samples, which is related to the crystallization characteristic of the fat crystals. These values were not affected by the dispersed sugar or sweeteners particles. The first Onset temperature was slightly influenced by the presence of saccharose or xylitol. However, the enthalpy values showed bigger differences. According to the statistical analyses in the first enthalpy values only between sugar and xylitol were no significant difference. In the second enthalpy values palm oil showed significant difference to the other samples and xylitol and stevia were also different. In every case a reduction in enthalpy can be seen compared to the pure fat. This can be due to the palm oil content of the samples, which is influenced by the mixing ratios. Therefore it is possible that the sugar and xylitol gave almost the same results, because they were mixed with 50 % solid matter ratio. The stevia was added in lower amount because of its higher sweetening power, it resulted in a higher enthalpy value.

Table 2: Crystallisation characteristics of the mixtures

	Onset1 (°C)	Onset2 (°C)	Peak1 (°C)	Peak2 (°C)	Area1 (J/g)	Area2 (J/g)	End1 (°C)	End2 (°C)
Palm oil+xylitol	-8,7 ± 0,55	16,1 ±0,06	1,2 ± 0,06	18,7 ± 0,06	-17,5 ±0,56	-6,4 ±0,2	4,4 ± 0,0	20,3 ± 0,06
Palm oil+stevia	-10,5 ± 0,46	16,1 ± 0,06	1,0 ± 0,0	18,6 ± 0,06	-24,7 ± 0,17	-8,8 ± 0,04	4,4 ± 0,12	20,0 ± 0,1
Palm oil +sugar	-9,5 ± 0,98	16,0 ± 0,21	1,3 ± 0,23	18,7 ± 0,38	-17,6 ± 4,28	-6,3 ± 1,55	4,4 ± 0,06	20,5 ± 0,61
Palm oil	-10,6 ± 1,7	16,1 ± 0,0	0,7 ± 0,14	18,8 ± 0,07	-31,7 ± 0,09	-11,6 ± 0,88	4,5 ± 0,14	20,5 ± 0,07

Conclusion

The effect of sugar and sugar substitution on model confectionary system was examined. The objective of this study was achieved through the measurement of apparent viscosity, texture and thermal properties of the samples. The different parameters were influenced by the addition of saccharose, stevia or xylitol to the pure palm oil. Shear stress of palm oil with xylitol and with saccharose increased compared to the pure fat. Adhesiveness of the mixtures decreased independently form the type of sweetener. Hardness of mixtures increased thanks to their increased solid matter contents. The work of penetration was significantly smaller in the case of xylitol compared to sugar, which could be related to its smaller particle size; however this was not verified in this research. In the melting of the samples sugar or sweetener resulted in high peak in their melting temperature, the pure fat peak was negligible small in every case. In crystallization all the enthalpy values decreased compared to the palm oil due to the mixing ratios of the blends. Most of the changes was due to the different dry matter content of the samples, which was defined by the sweetening power of the different ingredients. However, the sweetening power of the samples weren't tested organoleptically. Hence this work is will continue towards sensory experiments and more complex rheological modelling.

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