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Edited by Teodora Emilia Coldea

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Meet the editor

Teodora Emilia Coldea was born in 1984. She graduated in Food Engineering from the University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca Romania in 2008, worked in industry for four years, and then returned to university. She completed her PhD in Biotechnology in 2011 and her postdoctoral studies in 2012. She joined the Faculty of Food Science and Technology in 2013 and is presently a lecturer teaching fermentation technology at the university. Since 2011, she has collaborated on projects in biotechnology, food engineering, product development, consumer preferences, and data analysis. She and her coauthors have presented more than 20 papers and posters at international conferences, and published over 30 papers in peer-reviewed journals and three international book chapters. Her past five years' research have focused the quality assessment (spectrometry, gas chromatography mass spectrometry, gas chromatography coupled with flame ionization detector, Fourier transform infrared spectrometry, high performance liquid chromatography) of spirit drinks, beer, and traditional fermented beverages, and the valorizing of fermentation industry by-products to obtain value-added products such as functionalized beverages. Her published papers consist of the application of advanced methods for the study of volatile compounds, phenolic compounds, and risk chemicals (organochlorine pesticides, methanol, furfural, and heavy metals content) present in beverages.

Contents

Preface

Nowadays, there is a difference between food technology and food engineering. The first treats the application of methods of food preservation and food processing, while food engineering is a more complex area focusing on a combination of food and applied sciences such as microbiology, physical sciences, chemistry, and engineering.

Achieving food quality with respect to its flavor and stability is a complex process, especially when considering the large variety of flavor compounds and diversity of food accepted by consumers. Knowledge of all mechanisms involved in the change of food flavor during processing and storage and identifying the techniques for its constant quality assurance is essential. The desire for food producers to succeed in the global food market involves lengthy periods until the product reaches the consumer. Innovative cost-effective technologies are being introduced capable of satisfying consumers' quality demands.

Advanced processing methods tend to preserve the characteristic properties of food better, including its sensory and nutritional qualities, when compared with conventional food processing methods. Additionally, there is a clear rise in those suffering from food allergies. This fact is widely attributed to the changing livelihoods of populations in both developed and developing nations. The return to ancient food recipes by the industrial reinterpretation of food could be a successful alternative to a healthier lifestyle and a rising consumer trust in industrialized food.

In this book a selection of novel technologies applied to food preservation, sugar replacement, and food fortification with various bioactive compounds is presented in a series of original research and review chapters. Given the rapid growth of engineering fields, namely the food industry with novel food process technologies, novel ingredients, advanced enzyme production and applications, and other complementary technologies, this book will disclose the latest trends in food engineering. This text is a compilation of selected research articles and reviews covering current efforts in research in and application of emerging technologies in the food industry. The chapters in this book are divided into three broad sections. Section 1 deals with introductory information about enzyme application, preserving treatments (such as thermal treatment, active packaging concepts) in a sustainable, cost-effective manner, inclusion in food processing of wild edible plants as a part of cultural and generic heritage, and the upscaling of extraction techniques to increase the bioavailability of bioactive compounds. Section 2 provides data concerning the food industry's emerging technologies. Section 3 reveals the latest trends in food fortification. Overall, this book serves as an inspiring source for both scientific and industrial actors or anyone involved in any aspect related to the food industry.

I am most appreciative to Ms. Romina Skomersic, the Author Service Manager, who supervised and organized the publishing of all materials, assisted me and the authors in the completion of our work in an easy, timely manner, and provided helpful advice and guidance throughout this project. I thank the authors for their wonderful contributions. I also thank the technical editors who prepared these

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Section 1

Introductory Chapter

Chapter

Alternatives for Sugar Replacement in Food Technology: Formulating and Processing Key Aspects

Marko Petković

Abstract

The physical, chemical, thermal, rheological, and sensory characteristics of spreads with noncarbohydrate nutritive sweeteners (such as polyols), produced on ball mill, could be predicted. Spreads with 70 and 100% maltitol, as a sweetener, produced on different temperatures (30, 35, 40°C) and mixer speed rotations (60, 80, 100 r/min), give the spreads with very good or excellent sensory characteristics, characteristic spreadability without sandiness (gritty texture), good melting behavior, and pleasant taste. Both process parameters are very important and have the dual effect on spread quality. The best spread quality, considering all characteristics, has the spread with 100% maltitol, produced on the highest process parameters (40°C, 100 r/min).

Keywords: polyols, sugar, confectionery, spread, chocolate

1. Introduction

Low-energy foods, or products with reduced energy value, are very popular among the consumers. There is a need for developing the new and enriched existing products nowadays. The consumers' awareness is raised. They want to primarily satisfy the need for the sweet taste, as well as for maintaining or reducing your body weight, without any consequences for your health [1].

Replacement of nutritive sweeteners with other low-energy sweeteners (such as polyols) can change the sensory characteristics of the basic product. Proper selection of raw materials, as well as proper management of the technological process, can obtain the products with optimal sensory properties [2].

This chapter should explain the possibility of native sugar substitution with sugar alternatives, such as polyols (maltitol, mannitol, sorbitol, xylitol, isomalt, lactitol, erythritol).

Polyols are the most suitable nutritive sugar substitute for confectionery products, such as chocolate, chocolate desserts/bars, spreads and cocoa cream products, hard/soft candies or chewing gums, bakery products, and nonalcoholic beverages. Choosing an adequate polyol, as a sugar (sucrose) nutritive substitute, gives the possibility for a product that has almost unchanged sensory properties and that has maintained a sweet taste. This information is of crucial importance for industrial production. It provides important technological parameters and information for changing the process parameters and the need for new equipment:

1. Polyols are very stable at high temperatures and do not react with amino acids. Generally, polyols [3] have about 40–50% less energy value than sucrose that has significantly more stability than monosaccharides from which they are produced because they do not have a carbonyl group.

2. Do not participate in caramelization and Maillard reactions.

3. Do not ferment in the oral cavity and therefore do not cause caries having a pleasant and neutral taste.

4. Give the feeling of cooling, especially sorbitol and xylitol.

Polyols are normally present in little amounts in organic products and in addition to specific sorts of vegetables or mushrooms. They are additionally recognized as safe food additives [4, 5].

In addition, polyols are used as emulsifiers, stabilizing agents, flavor enhancer humectant, moisture binding, controlling crystallization, anticaking agent, bulking agent, cryoprotectors, etc. According to the European Union regulation, polyols are nutritive food additives and identified by E number, i.e., sorbitol (E420), mannitol (E421), isomalt (E953), maltitol (E965), lactitol (E966), xylitol (E967), and erythritol (E968). Polyols must be always listed in the ingredient lists on the food package, and its use in food products is defined by the Regulation (EC) 1333/2008 on food additives [6].

The acceptable daily intake (ADI) dose of polyols has not been defined. Polyols are marked to be *quantum satis* level for all purposes [6]. But polyols have a few side effects when overeaten, such as laxative effect, gastrointestinal symptoms, bloating, diarrhea, and abdominal pain. Therefore, if any food product containing more than 10% added polyols must include the statement “excessive consumption may produce laxative effects” [7, 8]. So, polyols are helpful in weight control, diabetes, and tooth decay [9, 10].

2. The basic physical and chemical properties of polyols

Polyols (sugar alcohols) are nutritive sweeteners obtained by the catalytic hydrogenation of the oxo-group of natural sugars, i.e., by substituting an aldehyde or keto group with hydroxyl [11].

The sweetness of sugar alcohols (polyols) is shown in **Table 1** [3–7].

The sweetness of polyols is lower than sucrose. Therefore, polyols might be used as a bulk sweetener. The desired level of sweetness and flavor of food products are achieved by the combination of polyols and non-nutritive, usually artificial, sweeteners. Polyols are responsible for texture, preservation, filling, moisture capture, and cooling effect in the mouth [5, 11–14]. Polyol sweetness, such as maltitol, is up to 90% of the sucrose sweetness [8].

In addition, consumption of products containing polyols does not increase the glucose level in blood or insulin secretion, and thus food products with polyol are recommended for people with diabetes. Polyols are alike prebiotics and can normalize, as fibers, intestine function [4, 7, 8]. Polyols, such as maltitol, are able to increase mineral bioavailability in humans and rats [15].

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Polyol	Energy value (kJ/g)			Glycemic index	Sweetness	Hygroscopicity	Heat of solution (kJ/kg)	Cooling effect (kcal/g)	Melting point (°C)	Solubility (g/100 g H_2O (25° C))	Heat stability (°C)	Acid stability	Molecular weight (g/mol)	Molecular formula
	EU*	USA**	Japan											
Xylitol	10.0	10.0	16.7	13	1.0	High	−153	Very cool (−36.6)	94	63	>160	2–10	152.2	$C_5H_{12}O_5$
Maltitol	10.0	8.8	8.4	35	0.9	Median	−79	/(−18.9)	150	60–65	>160	2–10	344.3	$C_{12}H_{26}O_{12}$
Sorbitol	10.0	10.8	12.5	9	0.6	Median	−111	Cool (−26.5)	97	70–75	>160	2–10	180.2	$C_6H_{14}O_6$
Erythritol	0***	0***	0***	0	0.6	Very low	−180	Cool (− 18.9)	126	37–43	>160	2–10	122.1	$C_4H_{10}O_4$
Mannitol	10.0	6.7	8.4	0	0.6	Low	−121	Cool (−28.9)	165	18–22	>160	2–10	182.2	$C_6H_{14}O_6$
Isomalt	10.0	8.4	8.4	9	0.5	Low	−39	/(−9.4)	145–150	25–28	>160	2–10	344.3	$C_{12}H_{26}O_{12}$
Lactitol	10.0	8.4	8.4	6	0.4	Median	−53	Slightly cool (−13.9)	122	55–57	>160	2–10	344.3	$C_{12}H_{26}O_{12}$ $C_{12}H_{26}O_{12} \cdot H_2O$
Sucrose	16.7	16.7	16.7	68	1.0	Median	−18	/(−4.3)	190	67	160–186	>3	342.3	$C_{12}H_{22}O_{11}$

*-European Union.
**-United States of America.
***-0–0.8368 kJ/g.

Table 1.
The basic important physical and chemical parameters of different polyols.

The energy value of polyols and glycemic index, in relation to sucrose, are shown in **Table 1** [3–7].

Polyols have a lower nutritional value (10 kJ/g) than sugars (16.7 kJ/g, **Table 1**), due to slower and incomplete absorption from the intestine. The results of polyol fermentative degradation by the intestinal flora are fatty acids and gases [7, 10]. Due to their incomplete absorption, polyols produce a lower glycemic response than carbohydrates (**Table 1**) and therefore might be useful in diabetic diets, causing smaller increases in blood glucose and insulin levels as compared to sugar and other carbohydrates [8].

Molecular weight and melting point (**Table 1**) are good to investigate when initially screening ingredients for applications. Maltitol is, for example, suitable as a bulking agent, without an additional agent to be needed. The solubility of a polyol can lead to recrystallization in a product. It is important to adapt the polyol to the specific application and monitor throughout shelf life of the final product (e.g., to predict the shelf life).

The primary application of polyols in foods is shown in **Table 2** [2, 16–18].

When the first formulas for sweet products were developed, several facts of sweetener choice had to be taken into account (**Table 2**). Obviously, the choice between crystalline polyol and liquid polyol (polyol syrup) will depend on the type of product and the ability to mix them or on the type of carbohydrate sweetener to be replaced. When we compare the physical and chemical properties of sucrose with polyols, and we talk about chocolate or spread, the most optimal choice of sucrose substitute is maltitol [2, 16–18].

Polyols, such as maltitol, affect seeding technique (β_V stable cocoa butter crystal) and rheological, textural, and thermal characteristics of dark chocolates [19]. Temper index value (TIV) gives information about tempering degree of the chocolates. TIV values of dark chocolate with sucrose were as TIV values of dark chocolate with maltitol. Dark chocolate with maltitol should satisfy the required terms of demoulding process, sensory characteristics (color, appearance, texture), thermal behavior (melting demands), and shelf life stability [20]. Particle size distribution and texture of dark chocolate with maltitol did not change strongly. Thermal characteristics, such as melting, were determined by DSC method (differential scanning calorimeter). The sweetener concentration, as well as seeding, didn't change melting characteristics at all [19]. Rheological properties are described by the flow curves where the shear stress of the sugar-free chocolates is a function of shear rate. The shear rate versus viscosity indicates the shear behavior of the sugar-free dark chocolate. This variation between the flow behaviors can be generally affected by

Polyol	Food application
Xylitol	Jellies, chewing gums, coatings for gum, mint-flavore candies
Maltitol	Chocolate, spread, hard candies, chewing gums, coating for gums
Sorbitol	Chewing gums, tablets, candies, humectants, plasticizers, hard candies, baked goods
Erythritol	Hard/soft candies, chocolate, beverages, bakery products, chewing gums
Mannitol	Dusting power, chewing gums, effervescent products
Isomalt	Chewing gum, dusting powder
Lactitol	Candies, frozen desserts, jams and jellies, chocolate, dusting powder, bulking agent, baked products

Table 2.
The primary application of different polyols.

ingredients (type and concentration of fat, sweetener, emulsifier) and process parameters (refining process, such as refining time, temperature, mixer speed rotation, etc.) [19–22].

The use of maltitol, as the only sweetener in the production of chocolate and spread products, does not require the use of other non-nutritive artificial sweeteners. Non-nutritive artificial sweeteners are calorie less. Only aspartame provides 4 kcal/g but is consumed in small amounts (about 200 times sweeter than sucrose) and contributes negligible energy [14].

Application of polyols in confectionery products, such as cookies, shows that maltitol has a similar effect due to their comparable molecular weights. Cookie characteristics with maltitol are similar to the cookies with sucrose, with a crumb structure, comparable rise and greater diameter increase, higher hardness, and brittleness [23, 24]. The crust lightness for maltitol cookies was decreased by 25% because Maillard reactions were not occurred [25]. Cookies with maltitol have a significantly softer texture too. When we analyze the relative sweetness of cookies, maltitol cookies were comparable to cookies with sucrose, and general acceptance of cookies with maltitol was significantly higher [24].

Semidried jerky made by polyols enhanced the quality attributes, especially xylitol, which is very appropriate in meat composition. The increase in the level of polyols causes a slight reduction in the pH values, regardless of the polyol type. The water activity of semidried meat jerky with polyols led to lower water activity and depends on the molecular size of polyols. As the molecular weight of polyols is larger, its solution has a greater osmotic pressure than the same amount of sucrose solution [26]. Sugar alcohols, such as sorbitol and xylitol, make the metal-chelating ability and cell reinforcement movement, reducing the oxidation of meat products. Kim et al. demonstrated that sorbitol increased the textural characteristics of pork meat jerky [27].

Flavor release in chewing gum depends of the type and particle size of polyol. Particle size distribution of polyols was determined by modern laser diffraction technique using a Malvern Mastersizer. As the particle size of the polyols is decreased, the surface area for flavor release is increased. The distribution of highly polar flavor compounds, such as the high-intensity sweeteners (HIS), is higher too because the high-intensity sweeteners are less entrapped by the gum base during manufacture. But, some flavor compounds had a higher flavor release when formulated with a larger particle size of polyols, specifically limonene [28]. Optimal dimensions of polyol particles in the production of chewing gum are sorbitol 200 μm, mannitol 60 μm, xylitol 90 μm, and maltitol 35 μm [11].

Replacement of nutritive sweeteners with other low-energy sweeteners can change the textural and sensory characteristics of the basic confectionery product, such as spreads or chocolate. Proper selection of raw materials, as well as proper management of the technological process, can obtain the final products of optimal sensory properties.

2.1 The physical and chemical properties of maltitol

Maltitol (E 965, 4-O-α-d-glucopyranosyl-d-glucitol) is a white crystalline powder, odorless, and not enzyme-resistant. It is produced from starch, by hydrogenating maltose or a very high maltose glucose syrup and crystallization from the maltose syrup [29, 30]. Maltitol is a disaccharide (equal parts of glucose and sorbitol) which causes a mild cooling effect, with physicochemical characteristics similar to sucrose. As a sucrose substitute, the technological parameters of chocolate and spread production do not need to be changed. As well as the other polyols, maltitol is able to change the rheological characteristics of spread and chocolate [6, 8]. Its use is like a bulking agent, sweetener, emulsifier, humectants, stabilizer, and thickener. As a fat substitute, maltitol gives a creamy texture to food [30–32].

Maltitol is very soluble in water (66 g/100 g at 25°C) and has a higher solubility than sucrose at temperatures >40°C. Due to its low hygroscopicity and high-temperature stability, it is used in many baked products as a bulk sweetener and energy reducer [10]. The ADI value of maltitol is not specified and depends of consumer organism condition, its age, sex, etc. The minimum amount exceeding 25–30 g/kg body weight per day can reveal laxative effect; thus, the maximum amount should not exceed 50 g total [13, 33, 34]. Maltitol is enzyme-sensitive and slowly digested in the small intestine (absorption range is from 5 to 80%) to glucose and sorbitol, where the nonabsorbed part passes to the colon where it undergoes fermentation by bacteria. It does not undergo Maillard reactions (browning process) and caramelization, with negligible cooling effect with other polyols [30–32, 35]. Maltitol has a low glycemic index, increases the mineral bioactivity in humans, and reduces postprandial glycemic responses with short-chain fructo-oligosaccharides [15, 30–32, 36, 37].

3. The basic spread-/chocolate-making process in laboratory

The basic spread/chocolate-making process in laboratory is outlined in **Figure 1**.

Spreads, unlike chocolate, do not contain cocoa butter (which requires a conching and tempering phase, **Figure 1**) but special vegetable fats, so spread production is cheaper and less demanding. Special vegetable fats have emphasized plastic properties, such as palm fat. At the conventional method, chocolate needs a special tempering procedure to satisfy texture, quality, and appearance [38–40].

In laboratory conditions, laboratory ball mill is most often used for spread refining (particle size reduction, the largest particles should be below 30 μm, optimum size is 20–22 μm). The process parameters are the temperature, the mixer speed rotation, the diameter/number of balls, the speed of spread recirculation, the

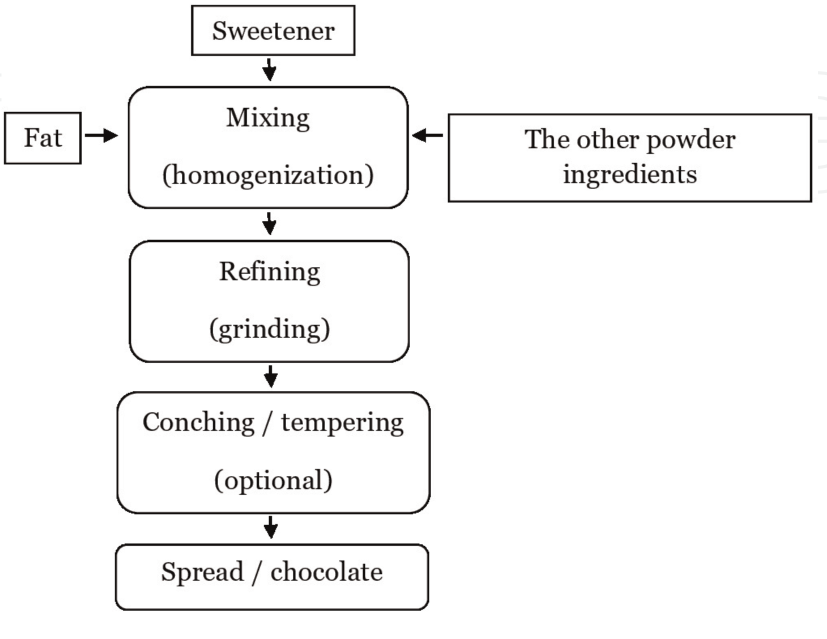

Figure 1.
The basic spread-/chocolate-making process in laboratory.

fat/solid content, the water content, the type/amount of emulsifiers, and the particle size distribution [18, 41].

Spreads were produced by a nonconventional producing method, in laboratory ball mill (capacity 5 kg). Laboratory ball mill is a horizontal or vertical cylinder, with a double wall and a bottom. Hot water circulates through the wall and bottom. In the central part of the cylinder, there is a shaft with a mixer and blades. The interior of the laboratory ball mill (60–80%) is filled with stainless steel balls (9.1 mm diameter, 30 kg weight). The speed of spread recirculation is 10 kg/h. The refining (grinding) time is 150 minutes. Experimental spread samples (50 g) were sealed in plastic glasses and stored at a temperature of 25°C [17].

The basic ingredients for spreads are sweetener 47.4%, palm fat 36%, cocoa powder 7%, whole milk powder 7%, soy flour 2%, lecithin 0.5%, and flavor 0.1%. The used sweeteners are maltitol (100%), sucrose (100%), and a combination of maltitol and sucrose (70/30% and 30/70% ratio). Spreads were produced at different temperatures (30, 35, 40°C) and mixer speed rotations (clockwise—60, 80, 100 r/min). Spread with 100% maltitol, produced at temperature 30°C and 60 r/min, is labeled as "M–30–60" [17]. The fat content is over 32%; there are a few changes in yield value with any further additions [20, 42]. The temperature ratio was chosen because the solid palm fat content on temperatures over 30°C is less than 1%. Higher-temperature range causes higher energy costs too.

The refining time (150 minutes) was purposely chosen. It provides the absence of sandiness (particles >30 μm).

4. The basic physical and chemical characteristics of spreads

4.1 The chemical composition of spreads

The chemical composition of spreads was determined by methods [12]: total carbohydrates (polarimetry), total fat (Soxhlet), total proteins (Kjeldahl), total moisture (thermogravimetry), total sucrose (polarimetry), and total maltitol (HPLC).

Spreads with 100% maltitol have the lowest energy value (20.37 kJ/g—100% maltitol; 21.42—70% maltitol; 24.29—100% sucrose; 23.28—70% sucrose) [17]. This result is expected [17, 18, 20]. Spreads with sucrose have slightly increased moisture content (1.06%, the moisture content of spreads with maltitol is 0.73–0.78) because sucrose has pronounced hygroscopic properties compared to maltitol, which is in acceptable limit [17, 42].

4.2 Particle size distribution of spreads

Particle size distribution was determined by the microscopic method [17].

Spreads with 100% maltitol have lower parameters of medium dimension of largest particles (61.67–70.58 μm—100% maltitol; 62.76–64.5 μm—70% maltitol; 73.12–88.55 μm—100% sucrose; 69.16–72.43 μm—100% sucrose). Sucrose is more hygroscopic and partly recrystallizes and forms the agglomerates. The mixer speed rotation is more dominant; the higher speed rotations affect the stronger frictional forces and smaller dimensions of the largest particles. Spreads, produced on maximum speed rotation (100 r/min), have the lowest average values of the largest particles [17]. Chocolate with a high percentage of particles above 30 μm has a gritty or coarse perception in the mouth [17, 43, 44].

4.3 Textural characteristics of spreads

Textural characteristics of spreads were determined on the Texture Analyzer TE32 by the manufacturer's specified method TA Chocolate spread_SPRD2_SR [10, 12]. The experimental results define the following parameters: the firmness (the maximum force at the curve of the force dependence of time) and the work of shear (determined by the area under the curve, which defines the spreadability of spreads). The firmness and the work of shear are outlined in **Figure 2**.

Spreads with maltitol (70, 100%) have harder crystals (the maximum penetration force 1093–1351 g, **Figure 2**) because of higher crystalline strength [2, 10]. The hardness of solid tempered chocolate is correlated with the type of fat and its content, the particle size distribution, the type of sweetener, and the tempering process [17, 43–45]. But, replacement of maltitol as a bulking agent in the study of Konar had no substantial effect on chocolate hardness [46].

When the process parameters are increased, the firmness is slightly increased, while the spreadability is decreased, regardless of the sweetener type. So, these parameters are in high correlation (R^2 = 0.927, 0.953, 0.989, 0.961). The mixer speed rotation is a dominant. Combination of sucrose and maltitol results in parameter variation.

The application of higher values of process parameters makes it possible to obtain more fine solid particles, a homogenous mass with a wider specific surface area. This area contributes better suspension of continuous fat phase.

4.4 Rheological characteristics of spreads

Rheological characteristics of spreads were determined on the HAAKE RheoStress 600 rotary viscometer (temperature 40 ± 0.1°C, the shear rate 0–60/s, the shear stress 0.1–10 Pa, frequency 1 Hz (ω = 6.28 rad/s)) [17]. Dynamic oscillatory measurements are applied to monitor the modulus of elasticity G' and the modulus of viscosity G," which are determined in the linear viscoelastic regime (LVE).

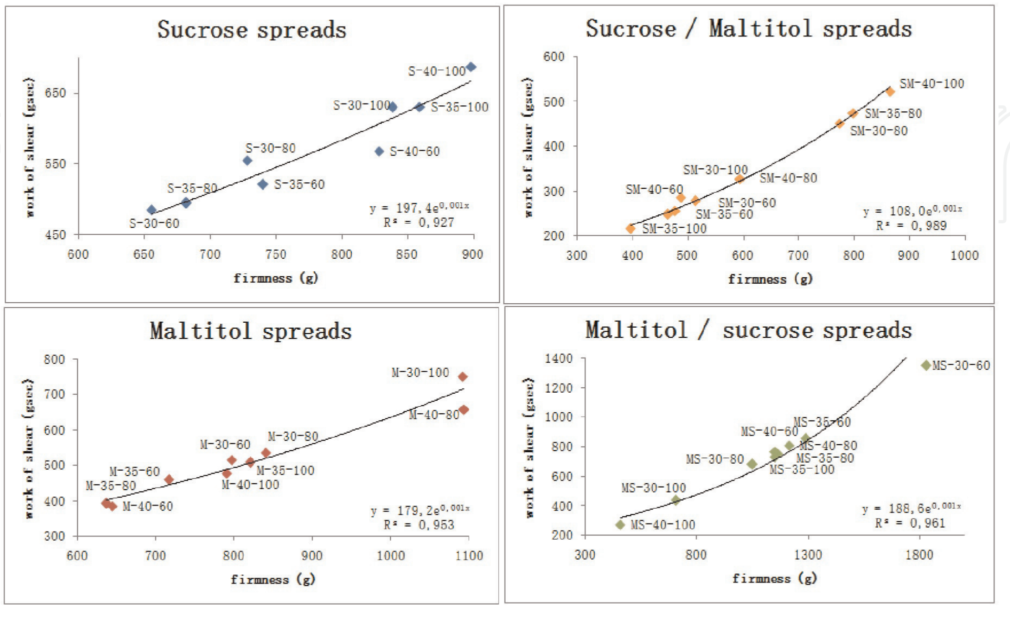

Figure 2.
The firmness and the work of shear of spreads.

Spreads are classified into pseudoplastic systems in which the solid particles (sucrose, maltitol, cocoa particles, whole milk powder, etc.) are wrapped into a fat continuous phase and fitted in it. The thixotropic loop, which occurs on behalf of viscous and elastic areas, is described by the yield stress t (Pa), Casson plastic viscosity η (Pas), and thixotropic area P (Pa/s). The parameters of viscosity are outlined in **Table 3**. Flow curves were produced by standard procedure and graphically outlined in **Figure 3**. Casson plastic viscosity range of spreads with maltitol is variable and between 1.218 and 558.3 Pa/s, as a result of maltitol and sucrose combination. Different hygroscopicity of polyols causes different Casson viscosity of chocolate; chocolate with high levels of polyols has higher Casson plastic viscosity [42].

The plastic viscosity of spreads with maltitol is larger than with sucrose (**Table 3**, [2, 16–18]). Casson plastic viscosity for chocolate is between 2.1 and 3.9 Pas [20, 42]. The viscosity of spreads with maltitol in our study is in this range and Casson yield values too. The sweetener type is more dominant than the mixer speed rotation; maltitol makes the yield stress decrease, and viscosity and thixotropic area are increased. The higher plastic viscosity of spreads with maltitol might be in a correlation with its slightly lower density (1.60 g/cm^3) than sucrose (1.63 g/cm^3) [34]. Temperature is more dominant than the mixer speed rotation; increasing the temperature, viscosity, yield stress, and thixotropic area become

Spread	Yield stress (τ) (Pa)	Thixotropic area (P) (Pa/s)	Casson plastic viscosity η (Pas)	Spread	Yield stress (τ) (Pa)	Thixotropic area (P) (Pa/s)	Casson plastic viscosity η (Pas)
S-30-60	7.38	575.8	0.912	SM-30-60	2.76	479.40	2.73
S-30-80	8.56	447.7	1.806	SM-30-80	4.08	542.10	2.68
S-30-100	8.53	374.0	1.216	SM-30-100	4.07	263.40	1.218
S-35-60	7.57	401.9	1.216	SM-35-60	3.46	499.00	3.099
S-35-80	6.34	220.0	1.597	SM-35-80	6.42	497.00	3.018
S-35-100	8.72	401.3	172.800	SM-35-100	2.87	23302.00	1.425
S-40-60	8.25	364.6	1.794	SM-40-60	43.32	451.70	2.693
S-40-80	7.29	241.0	1.430	SM-40-80	6.13	481.70	3.001
S-40-100	9.32	361.8	150.600	SM-40-100	5.56	669.30	4.493
M-30-60	5.56	2099.00	7.137	MS-30-60	11.68	2229.00	14.094
M-30-80	7.85	1181.00	4.717	MS-30-80	7.17	837.90	4.907
M-30-100	9.49	2436.00	4.061	MS-30-100	6.18	643.10	5.166
M-35-60	3.29	1547.00	558.300	MS-35-60	9.15	1570.00	8.614
M-35-80	8.13	1469.00	6.030	MS-35-80	5.99	682.20	4.73
M-35-100	6.40	1715.00	5.748	MS-35-100	9.03	1049.00	7.004
M-40-60	2.96	1177.00	449.000	MS-40-60	8.18	818.80	4.795
M-40-80	11.68	2342.00	13.636	MS-40-80	34.30	999.50	6.015
M-40-100	5.53	1613.00	5.672	MS-40-100	8.09	549.20	1.821

Table 3.
The parameters of viscosity of spreads.

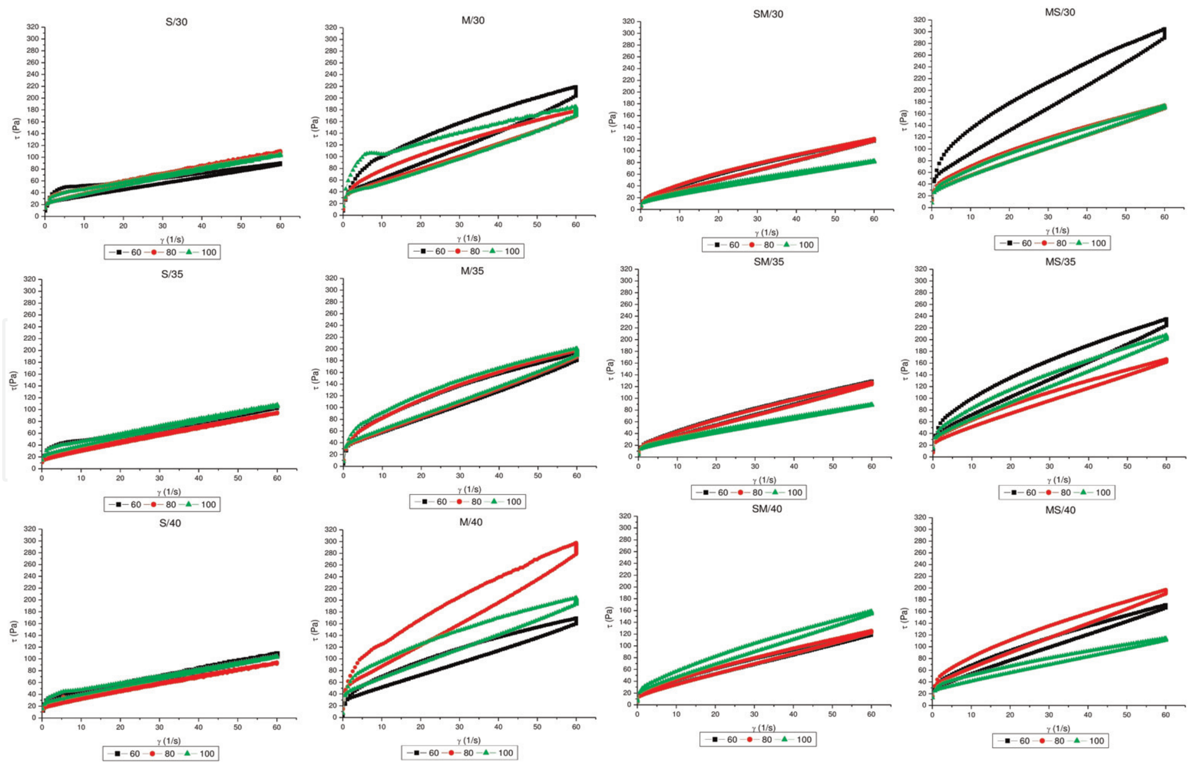

Figure 3.
Flow curves of spreads.

lower. High values of plastic viscosity can be explained with a theory that particle size distribution becomes wider with a heterogeneous specific surface area. Smaller particles fill spaces between larger and reduce the viscosity [17, 20, 42]. Casson yield values for spreads with maltitol are within the limits of the parameters for milk chocolate and have been reported to be between 2 and 18 Pas [13]. In general, chocolate with a high level of maltitol (75%) has a very similar flow index as chocolate with sucrose [45].

Spreads with 100% maltitol have a higher thixotropic area (**Figure 3**). This behavior can be mainly connected with the high molecular mass of maltitol [42]. Maltitol crystals, after refining, are coarse and have heterogeneous distribution of particle size with a large specific surface area. The high Casson yield value of maltitol products is a consequence of agglomeration in mass. The high molecular mass of maltitol increases the nonpolar intermolecular interactions. As a result, the mass becomes firmer and agglomerated, and thus more energy is required to start the flowing process [45]. The sucrose/maltitol combination spreads cause a huge variation in rheology results.

The parameters of loss coefficient (tanδ, tanδ = G″/G′) are shown in **Table 4** [2, 16–18].

The area of the elastic component is for tanδ > 1, while the viscous area is for tanδ < 1 (**Table 4**). Spreads belong to viscoelastic systems, in which the elastic component of the system is dominant. This characteristic is very important in process design and quality assessment for food such as butter or spreads [47]. For spreads with a point of intersection, the viscous area is dominant on frequencies below 2 Hz, up to the point of intersection, where the elastic area becomes more dominant in the system [2, 16–18].

The dominant process parameter is the mixer speed rotation. The Casson plastic viscosity decreases with an increase of shear rate (mixer speed rotation). Chocolate with 100% maltitol was found to be very similar to the control (chocolate with sucrose) in the tested plastic viscosity [45].

Spread	tanδ	Spread	tanδ
S-30-30	0.833880	SM-30-30	0.499218
S-30-40	0.855628	SM-30-40	0.533216
S-30-50	0.884045	SM-30-50	0.551405
S-35-30	1.002739	SM-35-30	0.865578
S-35-40	0.837005	SM-35-40	0.795029
S-35-50	1.022986	SM-35-50	0.697446
S-40-30	0.870694	SM-40-30	0.916253
S-40-40	0.961491	SM-40-40	0.781274
S-40-50	1.027589	SM-40-50	0.678345
M-30-30	0.492289	MS-30-30	0.540614
M-30-40	1.019242	MS-30-40	0.786911
M-30-50	1.359460	MS-30-50	0.750791
M-35-30	1.162145	MS-35-30	0.460028
M-35-40	1.079023	MS-35-40	0.793502
M-35-50	1.072265	MS-35-50	0.778090
M-40-30	0.942098	MS-40-30	0.754004
M-40-40	1.164598	MS-40-40	0.814258
M-40-50	0.949932	MS-40-50	0.826978

Table 4.
The loss coefficient parameters of spreads.

4.5 Thermal characteristics of spreads

Thermal characteristics of ingredients and spreads are analyzed by TG analysis device "LECO TG701." The thermal decomposition of spreads is monitored in the air stream (3.5 dm^3 min^{-1}), with the heating rate of 5°C min^{-1} in the temperature range of 25–800°C [2, 10, 16–18]. The peak of DTG curves gives the temperature corresponding to maximum degradation (T_{max}). The characteristic peaks of sweeteners and spreads are outlined in **Table 5**. Thermal decomposition of sucrose, maltitol, and palm fat is outlined in **Figure 4**.

Thermal decomposition of maltitol and sucrose is two-phase (**Figure 4**). The initial thermal decomposition of maltitol starts at 269.79°C with the distinguished peak at 340.39°C (**Table 6**). The mass loss in the first thermal decomposition phase occurs rapidly without complex biopolymer and is about 80%. The second decomposition phase occurs slower. The second peak of maltitol decomposition is 481.317°C (the residual mass at 600°C is 0.9%). The peaks of maltitol are sharper and with more expressed the inflection point.

Thermal decomposition of spreads is outlined in **Figures 5** and **6**. Spreads with 100% maltitol have the initial peak of maltitol decomposition, which is lower and between 335 and 356°C (**Table 6**), as a result of the presence and similar initial temperature decomposition of palm fat. The peak of palm fat decomposition is between 387 and 406°C. This peak similarity disables the mass loss determination. The mixer speed rotation is dominant; higher mixer speed rotation parameter makes the peak formation on higher temperatures.

	Sucrose peak, T_{max}/°C	Maltitol peak, T_{max}/°C	Palm fat peak, T_{max}/°C		Sucrose peak, T_{max}/°C	Maltitol peak, T_{max}/°C	Palm fat peak, T_{max}/°C
Sucrose ($T1_{max}$/°C)	240.793			Sucrose ($T2_{max}$/°C)	493.023		
Maltitol ($T1_{max}$/°C)		340.391		Maltitol ($T2_{max}$/°C)		481.317	
Palm fat ($T1_{max}$/°C)			402.784	Palm fat ($T2_{max}$/°C)			/
S-30-60	231.74		354.27	MS-30-60	219.61	326.40	395.56
S-30-80	233.97		378.51	MS-30-80	221.86	328.98	397.36
S-30-100	236.27		347.97	MS-30-100	223.96	331.66	399.55
S-35-60	216.42		371.95	MS-35-60	226.18	334.44	401.64
S-35-80	219.21		352.36	MS-35-80	228.44	337.02	381.07
S-35-100	221.75		354.53	MS-35-100	230.81	339.54	394.60
S-40-60	223.93		346.01	MS-40-60	232.89	342.08	386.85
S-40-80	226.01		348.28	MS-40-80	235.01	344.39	387.26
S-40-100	228.14		361.57	MS-40-100	221.45	346.52	391.35
M-30-60		338.38	387.29	SM-30-60	217.31	332.55	379.04
M-30-80		341.70	390.21	SM-30-80	219.73	334.83	381.29
M-30-100		344.32	392.81	SM-30-100	221.82	336.49	383.67
M-35-60		346.85	395.14	SM-35-60	224.13	339.18	385.83
M-35-80		349.22	397.12	SM-35-80	226.35	341.53	387.79
M-35-100		351.75	399.41	SM-35-100	228.74	/	389.89
M-40-60		354.38	401.89	SM-40-60	231.18	/	392.19
M-40-80		356.83	405.01	SM-40-80	233.39	325.73	394.34
M-40-100		334.83	406.08	SM-40-100	235.67	327.61	385.47

$T1_{max}$/°C, temperature peak of the first phase; $T2_{max}$/°C, temperature peak of the second phase.

Table 5.
The characteristic peaks of sweeteners and spread ingredients.

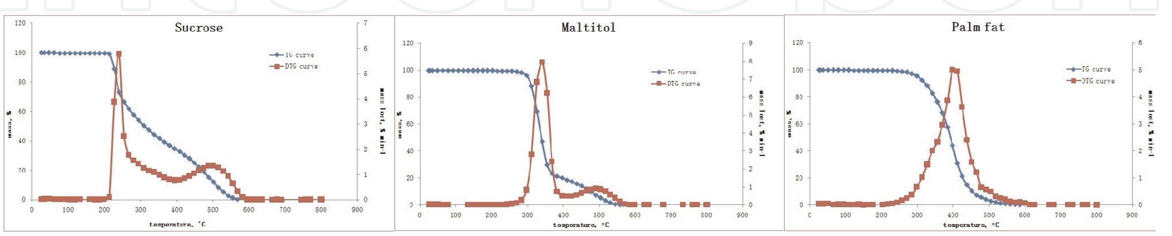

Figure 4.
TG curves and DTG curves of sucrose, maltitol, and palm fat.

Spreads with 70% sucrose/30% maltitol and 30% sucrose/70% maltitol have the variations of peak visibility (**Figure 6**). The result of these variations is actually the peak overlapping due to the final thermal decomposition of sweetener and initial thermal decomposition of palm fat. The other reasons of peak overlapping are inhomogeneous structure, the refining process, and the presence of emulsifier

Quality factor	Impact factor	Temperature (°C)								
		30			35			40		
Mixer speed rotation (o/min)		60	80	100	60	80	100	60	80	100
						S				
External appearance	0.6	2.4	1.8	1.5	1.5	1.5	1.5	1.5	1.5	2.1
Texture	0.8	3.2	2.8	2.4	2.8	2.8	2.4	2.8	2.8	3.6
Chewiness	1	4	4	4	4	4	4	4.5	4.5	4.5
Flavor	0.6	3	2.7	3	2.7	3	2.4	3	3	3
Taste	1	4	4	4.5	4.5	4.5	4.5	4.5	4.5	5
Σ		16.6	15.3	15.4	15.5	15.8	14.8	16.3	16.3	18.2
Quality category		VG	VG	VG	VG	VG	VG	VG	VG	E
Mixer speed rotation (o/min)						M				
External appearance	0.6	2.1	2.7	2.7	2.4	2.7	3.0	2.1	2.4	2.4
Texture	0.8	3.2	3.6	4.0	2.8	3.6	3.6	3.2	3.6	4
Chewiness	1	4	4	4	3.5	4	4.5	4	4.5	4.5
Flavor	0.6	2.4	2.7	2.4	2.4	3	3	2.7	2.7	2.7
Taste	1	4	4	4.5	4	5	5	5	5	5
Σ		15.7	17.0	17.6	15.1	18.3	19.1	17.0	18.2	18.6
Quality category		VG	VG	E	VG	E	E	VG	E	E

Table 6.
Sensory evaluation of spread quality using the scoring procedure.

(lecithin). This peak was observed on 230°C by analyzing spreads with maltitol (**Figures 5** and **6**), close to temperature decomposition of sucrose. Maltitol spreads do not contain sucrose; the peak decomposition of cocoa powder, soya powder, and whole milk is on temperature over 500°C, so this peak belongs to lecithin. The peak of lecithin thermal decomposition is 200°C [18, 48].

The refining process and ingredient decomposition make the peak become lower and wider. In general, the most stable spreads with 100% maltitol and sweetener combination are produced on higher process parameters. The peak position and temperature can be used to detect the unknown spread ingredient, comparing it to known peaks.

4.6 Sensory characteristics of spreads

Sensory analysis of spreads was made 7 days after the stabilization. The scoring method of the five-member panel evaluated the following parameters of quality (score 0–5, **Tables 6–8** [2, 16–18]): the external appearance (the shape, the color, and the structure), the texture, the chewiness, the taste, and the flavor (aroma). Score is multiplied by the appropriate impact factor to calculate the points. The sum of points defines the quality category: excellent (E), very good (VG), good (G), sufficient, (S), and insufficient (I) [17].

The total score of all spreads in this study ranged from 15.1 to 19.1 gives the spreads with very good and excellent quality (**Tables 7** and **8**). Spreads with maltitol (100 and 70%) have a better structure and external appearance. However, the addition of maltitol has a negative effect on flavor (spreads with maltitol have less pronounced flavor). Increasing the process parameters, excellent sensory

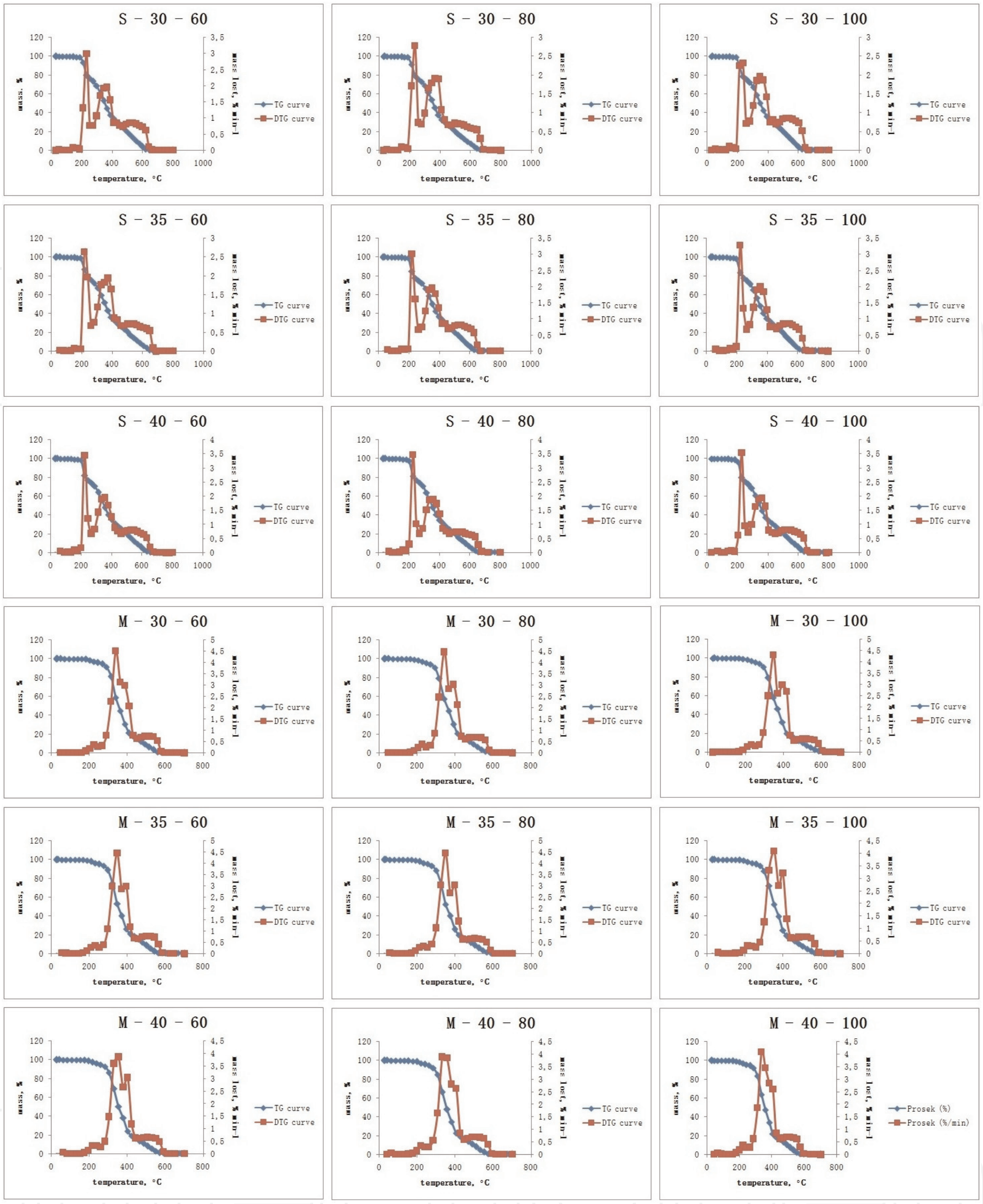

Figure 5.
TG curves and DTG curves of spreads with 100% sucrose and 100% maltitol.

properties of spreads with maltitol are achieved. The hardness of maltitol spread texture is higher which is not good (high hardness, less spreadability).

Qualitative data analysis (QDA) method consists of evaluating (from 1 to 5) individual quality elements and their input into polar coordinates. On each polar coordinate, there are five labels. By merging the labels marked with individual quality elements, a quality diagram of the entire spread is obtained (**Figure 7**). This method is highly suitable for monitoring the quality of products in regular production [17, 45]. As the diagram area is larger, the quality category of spread is larger too.

It was noticed that spreads with 100 and 70% maltitol have less pronounced flavor and slightly bitter and fruity taste (as a secondary sensory characteristic) [2]. Flavor, taste, and chewiness are the most dominant quality factors, with the average

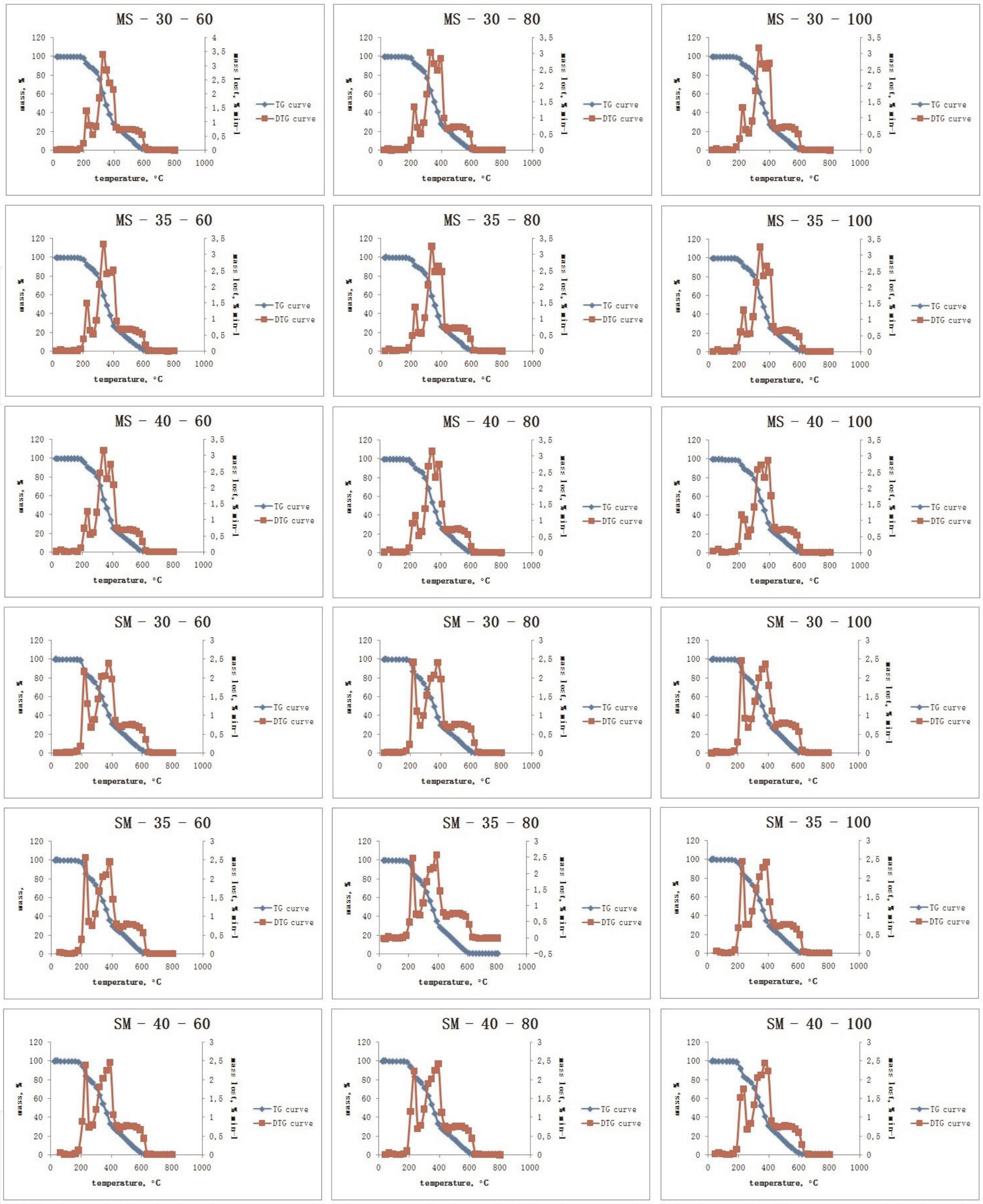

Figure 6.
TG curves and DTG curves of spreads with 70% sucrose/30% maltitol and 70% maltitol/30% sucrose.

score from 4.0–4.44, 4.33–4.61 and 4.11–4.5. Increasing the process parameters and maltitol concentration, the scores for flavor, taste, and chewiness are greater. Unique and complex flavor of the chocolate is one of the most important properties that have made it popular among the consumers [49]. Generally, the effect on sensory properties depends not only on the type of polyol but also on the polyol concentrations and process parameters.

4.7 Troubleshooting

Some troubleshooting can occur during the process production.

If the spread/mass is too viscous after refining/conching, the crystals of sugar alcohols are melted and release water. This problem could be solved by decreasing

Quality factor	Impact factor	Temperature (°C)								
		30			35			40		
Mixer speed rotation (o/min)		60	80	100	60	80	100	60	80	100
						MS				
External appearance	0.6	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.4
Texture	0.8	3.6	3.6	3.2	3.6	3.6	4	3.6	4	3.2
Chewiness	1	4.5	4.5	4	4.5	5	5	4	5	4
Flavor	0.6	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Taste	1	4	4.5	4.5	4	4.5	4.5	4.5	4.5	4
Σ		17.2	17.7	16.8	17.2	18.2	18.6	17.2	18.6	16.0
Quality category		VG	E	VG	VG	E	E	VG	E	VG
Mixer speed rotation (o/min)						SM				
External appearance	0.6	2.1	2.1	2.1	2.1	2.1	2.1	2.4	2.4	2.4
Texture	0.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	3.6	2.8
Chewiness	1	4	4	4	4	4	4.5	4.5	4.5	4
Flavor	0.6	2.4	2.4	2.7	2.4	2.4	2.4	2.4	2.7	2.4
Taste	1	4	4.5	4.5	4	4	4.5	4	5	4.5
Σ		15.3	15.8	16.1	15.3	15.3	16.3	16.1	18.2	16.1
Quality category		VG	VG	VG	VG	VG	VG	VG	E	VG

Table 7.
Sensory characteristics of spreads with sucrose and maltitol.

Quality factor	Impact factor	Temperature (°C)								
		30			35			40		
Mixer speed rotation (o/min)		60	80	100	60	80	100	60	80	100
						S				
External appearance	0.6	2.4	1.8	1.5	1.5	1.5	1.5	1.5	1.5	2.1
Texture	0.8	3.2	2.8	2.4	2.8	2.8	2.4	2.8	2.8	3.6
Chewiness	1	4	4	4	4	4	4	4.5	4.5	4.5
Flavor	0.6	3	2.7	3	2.7	3	2.4	3	3	3
Taste	1	4	4	4.5	4.5	4.5	4.5	4.5	4.5	5
Σ		16.6	15.3	15.4	15.5	15.8	14.8	16.3	16.3	18.2
Quality category		VG	VG	VG	VG	VG	VG	VG	VG	E
Mixer speed rotation (o/min)						M				
External appearance	0.6	2.1	2.7	2.7	2.4	2.7	3.0	2.1	2.4	2.4
Texture	0.8	3.2	3.6	4.0	2.8	3.6	3.6	3.2	3.6	4
Chewiness	1	4	4	4	3.5	4	4.5	4	4.5	4.5
Flavor	0.6	2.4	2.7	2.4	2.4	3	3	2.7	2.7	2.7
Taste	1	4	4	4.5	4	5	5	5	5	5
Σ		15.7	17.0	17.6	15.1	18.3	19.1	17.0	18.2	18.6
Quality category		VG	VG	E	VG	E	E	VG	E	E

Table 8.
Sensory characteristics of spreads with 70% sucrose/30% maltitol and 30% sucrose/70% maltitol.

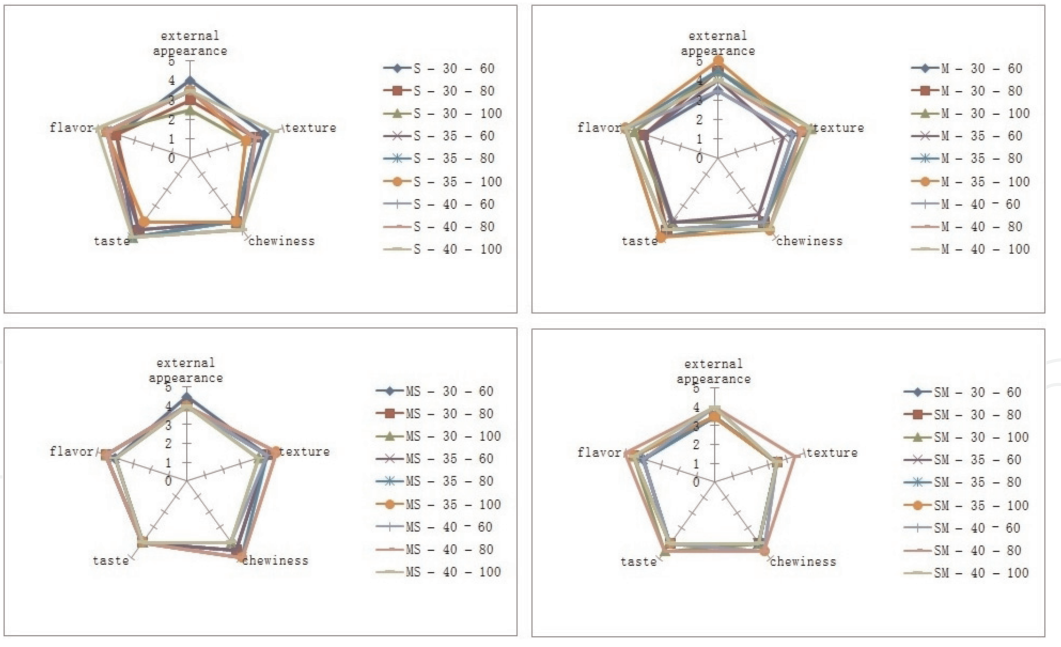

Figure 7.
QDA diagram of spreads.

the process temperature below the melting point of selected sugar alcohol or using the polyol with higher melting temperature and less hygroscopy. This problem could be solved by adding the fat too.

If the spread mass is grainy (sandiness), the moister content should be a problem. This problem could be solved by checking the storage conditions (low relative stability and temperature), polyol recrystallization (especially sorbitol), and polyol particle size and uniformity. The moisture variation (too high moisture) could form the spread mass to thin, as a consequence of hygroscopic polyols, inadequate solid content, and/or process parameters.

5. Conclusions

Consumption of sugar-enriched food has risen dramatically over the past few years. Sugar-enriched food contributes extra calories usually without nutritional values and has a negative effect to human health. Sugar alcohols (polyols) have drawn the significant attention of consumers and producers too. Since these polyols are contemporary, there is a need for enquiring sugar-free products, as a rapidly growing category.

With variable properties and functionalities of polyols, it is essential to think about perfect conditions for the polyol application. A sucrose-free spread with maltitol as a bulking agent was successfully developed. Such spread is compatible with traditional spread with sucrose because the sweetness of maltitol is close to sweetness of sucrose and no additional artificial sweeteners may be needed. The influence of maltitol on rheological, textural, thermal, and sensory properties is dependent on the present levels of maltitol and process parameters (temperature, mixer speed rotation).

The present study demonstrates that spread maltitol resulted in similar properties to spread with sucrose. It can be recommended as an adequate sugar substitute in spread formulations since sugar-free spread was accepted very well among panelists of different ages.

The findings of this study indicate that maltitol, as a sugar substitute bulking agents, has the potential as a pleasant food in the processing of diabetic and reduced calorie spread.

Future experiments will be focused on the optimization and determination of the sugar-free formulation recipe and the effects of bulk sweeteners and process parameters, based on physicochemical and sensory properties.

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Given the rapid growth of engineering fields, namely the food industry with novel food process technologies, novel ingredients, advanced enzyme production and applications, and other complementary technologies, this book will disclose the latest trends in food engineering. This text is a compilation of selected research articles and reviews covering current efforts in research in and application of emerging technologies in the food industry. The chapters in this book are divided into three broad sections. Section 1 deals with introductory information about enzyme application, preserving treatments (such as thermal treatment, active packaging concepts) in a sustainable, cost-effective manner, inclusion in food processing of wild edible plants as a part of cultural and generic heritage, and the upscaling of extraction techniques to increase the bioavailability of bioactive compounds. Section 2 provides data concerning the food industry's emerging technologies. Section 3 reveals the latest trends in food fortification. Overall, this book serves as an inspiring source for both scientific and industrial actors or anyone involved in any aspect related to the food industry.

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