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Effects of D-Tagatose and Inulin as Sugar Substitutes on the Chemical, Rheological and Sensory Properties of Prebiotic Dark Chocolate

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Abstract. Chocolate is very popular among consumers of all ages. Replacing sucrose by low digestible carbohydrates (LDCS) will result in lowering its energy content and glycemic index, as well as in preventing tooth decay. Inulin, and D-tagatose were used as sucrose substitutes in dark chocolate formulas. The inulin:tagatose ratios in the mixtures were 100:0, 75:25, 50:50, 25:75, and 0:100. With a reduction in the inulin content and increase in tagatose content, the moisture contents of the chcolate samples decreased, while their aw increased.as the amont of D-tagatose increase in formula the hardness of the samples went up. With regard to color indices, the least amounts of L*,a*,b*,c* and hue° were observed in chocolate samples with 100% inulin. The data also showed that reductions in inulin resulted in decreaes in apparent and plastic viscosity and increases in τ_0 and τ_1 . Overall acceptability of the chocolate samples increased by increase of the tagatose level.It can be concluded that in chocolate samples an inulin-tagatose ratio of 25%-75% and 100% tagatose are the best sucrose substitutes.

Keywords: Dark Chocolate, Inulin, Tagatose, Stevia, Rheology

1. Introduction

Chocolate has got exclusive taste ,flavor ,texture and biological active component which they have got antioxidant effects. In resent decade the consumption of low calorie foods is recommended for people with particular medical problems like, diabetes, obesity and heart diseases. In order to decrease calories and glycemic index and also prevention from dental cavities, there is possibility to replace the sucrose with low digestible carbohydrates and bulking agents like inulin , simple sugar like D- tagatose,polyols and senthetice sweeteners (1).Among these substitutes, sugar alcohols have been used most frequently(2),but their laxative, cooling and hygroscopic properties are few limiting factors for their widespread utilization in most foodstuffs (2,3) .Therefore, its reasonable to do new researchs to find favaorable substitutes with minimum side effects on the consumers as well as on the special characteristic of product. In this study, inulin and d-tagatose are used as sugar substitutes. D-Tagatose ,a natural ketohexose ,is an isomer of D-galactose.it is a reducing sugar.the sweetness of D-Tagatose is 92% of the sucrose when compared in 10% of these sugars solutions. D-Tagatose has a sucrose-like taste with no cooling effect or after taste. It is also a flavor enhacer. D-Tagatose has numerous health benefits including,no glycemic effect , treat the obesity and reduces the

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symptoms associated with type 2 diabetes. (4).Inulin is a polydisperse fructan.the fructose units in this structure of linear polymer of fructose and links by β(1,2)linkage .In addition inulin reduces the calories and fat,as a fiber effects,lipid modulation and bifidus stimulation. Researchers found no influence on serum glucose (5 , 6).In this study Inulin, and D-tagatose were used as sucrose substitutes in dark chocolate formulas.these replacers reduce calories and have several nutritional effects indeed.The inulin:tagatose ratios in the mixtures were 100:0, 75:25, 50:50, 25:75, and 0:100 and the Physical, Chemical, Rheological and Sensory Properties of Prebiotic Dark Chocolate were evaluted.

2. Materials and Methods

Alkalized cocoa powder (10-12%) (shokinag cocoa ,Germany), deodrised cocoa butter (KLK-Kepong ,Malysia),Inulin GR (Orafti,Belgium), Dtagatose(Damhert,Belgium), Sucrose(Karoon Co.,Iran), Soy Lecithin (Cargill,Netherland),Stevia (Stevian Biotechnology co.,Malysia) and vanilla powder(panda,china) were used for the production of dark chocolates .Experimental chocolate samples were produced by mixing Sucrose, D-tagatose and Inulin powders(51.4%),cocoa powder(16%) ,cocoa butter (32%)and lecithin(0.5%) and vanillin (0.1%). since Inulin and D-tagatose are less sweet than the sucrose ,the samples were additionally sweetened with stevia .concentration of stevia was adjusted from the following equation: [0.92% x D-tagatose content(% w/w) + 0.1% x Inulin content(% w/w)] +120% x stevia content(% w/w)=1% x sucrose content(% w/w)

Coefficients 0.92, 0.1,120 and 1 reflect to the relative sweetness of x D-tagatose, Inulin, stevia and Sucrose(standard).

Chocolate masses were prepared in a laboratory ball mill (85 rpm,50˚C, 3 hours) and were ground until average particle size reached approximately to 25 µm. vanillin and stevia added at final stage. chocolate after tempering and demoulding wrapped in aluminum foil and stored at refrigerator(10˚C). The moisture, invert sugar, fat, protein and pH of chocolates were determined according to 931.04, 933.04, 945.34, 939.02 and 970.21 methods of AOAC, respectively (7). Water activity (Aw) was also measured using the Aw-sprint TH500 (Novasina, Pfäffikon, Switzerland) at 25˚C. Hardness of solid tempered chocolate was measured using H50KS universal testing machine (Hounsfield, Surrey, UK) with a penetration of a cylindrical flat-end probe(d = 1.6 mm, 500 newton load cell) .maximum penetration was 6mm in sample (100 * 20 * 10 mm) at the penetration speed of 1mm/s and was reported as the maximum force (N).HunterLab Colorimeter was used for colour measurements of solid chocolate size(150x150mm) .L*,luminance ranges were from zero(black) to 100((white);a*(green to red) and b*(blue to yellow) with values from -120 to +120 . hue angle (h˚)=arctan(b*/ a*); chroma (C*)=[(a*)2 +(b*)2]1/2 calculated .Sensory attributes of dark chocolates including sweetness, snapness, flavor, taste, texture melting rate, mouth feel, color and overall acceptability were evaluated using ranking test and(the high quality = 6 and the low quality =1) based on a balanced incomplete block design by 15 trained panelists.

Analysis of ANOVA, variance and least significant differences tests were also used ($P < 0.05$) to detect differences between mean values using SPSS software (Version 14.0, SPSS Inc., Chicago, IL).

3. Results and Discussion

3.1. Effects of Sugar Substitutes on Physicochemical, Hardness and Color Parameters

As it is shown in Table 1 the increase of inulin leads to a proportional increase in moisture content inulin has hydrophilic groups on its formula which is the cause of increasing and preserving of moisture in sampls with high content of inulin. inulin and oligofructose can keep breads and cakes moist and fresh for longer period of time (8). It was reported that Cookies with inulin and less fat tend to have a higher moisture content and are therefore less crisp (9). The lowest moisture contents belongs to chocolates containing 100% D-tagatose, there were no difference between this formula and control . Originally tagatose powder had lower moisture with regard to inulin powder .tagatose itself showed less tendency to absorb and preserve of moisture. Gaio reported that moisture content of dark chocolate samples with tagatose were lower than control with sucrose(10).

As D-tagatose contents were increased , Aw contents increased too and there was no difference between sample (75%tagatose-25%inulin, 100%tagatose and control ($P< 0.05$).inulin increased moisture content but lowers Aw ,this show that inulin can bind with moisture and decrease Aw .Oligofructose and inulin will reduce water activity ensuring high microbiological stability (8).

The hardness of chocolates related to the sugar type added to formula .sample with 100%inulin was the softer and its hardness increased as tagatose content raised .Formulation with 100% tagatose was the hardest and similar to control. Drewnowski(1997) reported that cookies with inulin(low fat) were less crisp(9) .Gaio also reported that the hardness of the chocolate with sucrose or tagatose was identical, and falled to the same rang during increasing temperatures(10).

CIELAB parameters L*, b* ,C* and h◦ and c* Increased as Inulin contents decreased ($p<0.05$)(table 2).inulin absorbed moisture and light scattering and lightness decreased and chocolate seemed darker .Bolenz reported that The product with 20% inulin was the most brown ,and had the lowest l* among other fillers in milk chocolate . Dark chocolate became lighter as tagatose content increased. tagatose as a reducing sugar caused fading of the color and l*,a* and b* increased as tagatose content increased. Tagatose differs significantly from sucrose as regards darkness(10)

In sensory evalution,as tagatose amounts increased ,sweetness, snapness, flavor, taste, texture melting rate, mouth feel, color and overall acceptability got higher scores (Table 4). Samples 4 and 5 had no difference with control ($p<0,05$).Nevertheless, in terms of the other sensory parameters, chocolates formulated with high ratios of inulin received lower sensory scores which were significantly different from the others ($P <0.05$) But sample 1 (100%inulin)had the darkest color and was more favorite for dark chocolate.Moreover, samples 5 and 1, respectively, showed the highest and lowest overall acceptability. Golob reported that stickiness ,mouth loading and solubility of three types of chocolates with inulin were evaluated worse(11).It is known that the supplement of inulin influences on the viscosity and worse solubility of the product (12).On the other hand tagatose improved the sensory parameters .Gaio claimed that at a dosage of just 0.2-1%, tagatose improves the flavour profile of most soft drinks made with high intensity sweeteners. In another study that Gaio reported ,Tagatose was the product that comes closest to sucrose when used in dark chocolate(10).

3.2. Effects on the Rheological Properties

In order to find the approperate model and evalution of the rheological behavior , their shear stress vs. shear rate data was fitted on few applicable mathematical models including windhab, Herschel-Bulkley , Casson), Bingham,Power Law.The fitting of experimental data with suitable model was evaluated on the basis of the coefficient of determination (R2) and standard error (S.E.) parameters. Based on statistical calculations ,the windhab , Herschel-Bulkley and Casson models, provided the highest R2 values and lowest standard errors respectively(Table3). As a result, we can say that the substitution of sucrose, in spite of having influence on the rheological parameters, had no effect on fitting of mathematical models.As it is shown in table 5 ,by decrasing the inulin and increasing of tagatose contents ,yield stress increased. highest and lowest yield stress achieved in control and sample 1(100%inulin).sample 5 had no difference with control($P <0.05$).linear yield stress also increased as tagatose content increased. The apparent viscosities (shear rate=40 s^{-1}) of samples were shown in Table 5. sample 1 had the highest apparent viscosity and its diffrense with other samples and control was notable. apparent viscosity decrased, as inulin contents decreased .the lowest of apparent viscosity was shown in sample 4.sample 100%tagatose had no difference with control.By decreasing of inulin content , plastic viscosity had decreasing trend.the highest plastic viscosity belonged to sample 1.control and samples 4 and 5 had any diffrenses($P <0.05$). flow behaviour index decreased as inulin decreased.the lowest content was shown in control without differences with samples 4 and 5($P <0.05$). Result Showed that the inulin reduces the yield stress in chocolate . low yield stress in the samples with high percent of inulin indicating that ,interaction forces in between inulin particles were weak and for overcome to their forces and flow of the chocolate less force in needed .the difference on the structures inulin(oligosaccharide) with D-tagatose(mono saccharide)and sucrose(disaccharide) will be one of the factors for the interaction between the particles in chocolate making and their strength against flow . the reduction of yield stress happened when inulin used as a filler in chocolate making.(13).the samples with high percent of D-tagatose had only slight difference in yield stress as compared with the control. this is because of the structural similarities of this two sugar.

Results of this study indicated that when inulin is used in high percent ,will cause the increment of the plastic and apparent viscosity. in low percent the flow property improves but apparent viscosity reduces. Inulin in low and non fat foods like: salad dressing, chocolate and mouss desert increases their viscosity and texture improves too(14).Golob(2004)reported that inulin has potential of moisture absorption and protection of it, so the viscosity increase(11) . Grittenden and Playne (1997) believe that high molecular weight oligosachrides and polysachrides increase viscosity and improve texture and mouth feeling(15).Golob(2004)reported that inulin as supplement in chocolate has adverse effect on viscosity and solubility of chocolate but in low amount causes reduction and improvment of viscosity(11). Blonze and his coworkers(2006)used inulin(20%) as a filler in chocolate, viscosity and yield stress was lower than control (13).the result of their research was in agree with our results. The lowest viscosity was achieved when the ratio of inulin and tagatose was 25% and 75% respectively. Viscosity of sample with 100% tagatose did not show significant difference with the control and it had acceptable viscosity, this case also reported by Gaio company for milk and dark chocolates which were contain tagatose and sucrose(23).

4. Conclusion

It can be concluded that in chocolate samples with inulin-tagatose ratio of 25%-75% and 100% tagatose are the best sucrose substitutes. since inulin is a dietetic fiber and tagatose and inulin both have prebiotic properties, chocolate samples prepared with these sugars are also desirable from a nutritional point of view and they can be considered as functional foods.

Table 1: Effects of Various Formulations on Mean Values of Physicochemical, Mechanical and Caloric Characteristic of Dark Chocolates

Formulation Weight ratio of sugar substitutes (g/100g chocolate)	Moisture content (g)	*A*w	Hardness (N)	Reducing sugar before hydrolysis (%)	Reducing sugar after hydrolysis(%)	Energy (Kcal/100 g)	calorie reduction%
1(100%inulin)	1.79±0.015[a]	0.281±0.001[a]	21.50±0.22[a]	2.20± 0.06	50.98±0.12	379.6	27.5
2(75%inulin-25%tagatose)	1.52±0.03[b]	0.315±0.004[b]	22.65±0.93[ab]	13.98±0.13	50.9±0.36	383.5	26.7
3(50%inulin-50%tagatose)	1.34±0.01[c]	0.325±0.003[c]	24.35±0.38[b]	25.6±0.33	51.2±0.03	387.4	26
4(25%inulin-75%tagatosse)	1.05±0.041[d]	0.335±0.005[d]	26.12±0.76[bc]	39.1±0.2	51.18±0	391.2	25.2
5(100%tagatose)	0.71±0.02[e]	0.336±0.002[d]	27.82±0.58[c]	51.3±0	51.4±0.09	395.1	24.5
6(control)	0.68±0.01[e]	0.333±0.004[cd]	26.80±1[c]	0.37±0.02	51.9±0.17	523.6	-

Different letters within columns indicate significant differences($p<0.05$)

Table 2: Influence of Various Formulations on Color Parameters

samples	L^*	a^*	b^*	C^*	hue°
1	16.09±0.11[a]	4.95±0.04[a]	3.08±0.01[a]	5.83±0.04[a]	35.7±0.26[a]
2	18.4±0.14[b]	6.05±0.06[b]	4.11±0.01[b]	7.26±0.12[b]	38.93±0.32[b]
3	19.58±0.07[c]	6.6±0.03[c]	4.75±0.01[c]	8.14±0.05[c]	41.06±0.30[c]
4	20.08±0.07[d]	7.48±0.03[d]	6.65±0.02[d]	10.04±0.07[d]	50.94±0.37[d]
5	22.17±0.12[e]	9.47±0.04[e]	9.53±0.03[e]	13.53±0.18[e]	57.63±0.07[e]
6 (Control)	17.6±0.02[f]	7.48±0.01[d]	6.01±0.02[f]	9.63±0.08[f]	45.99±0.12[f]

Table 3: Effects of Sugar Substitutes on Fitting of Experimental Data with Mathematical Models Based on Determination Coefficient and Standard Error Parameters

	model	R^2	SE		model	R^2	SE
1	Windhab	0.99999	0.70149	4	Windhab	0.99999	0.14727
	Hershel-Bulkley	0.99998	0.75222		Hershel-Bulkley	0.99996	0.42377
	Casson	0.99969	3.7528		Casson	0.9991	2.117
	Bingham	0.99986	6.2756		Bingham	0.99751	3.5236
	Ostwald-de Waal	0.99529	14.504		Ostwald-de Waal	0.98482	8.6659
2	Windhab	0.99996	0.18151	5	Windhab	0.99998	0.19568
	Hershel-Bulkley	0.99997	0.55242		Hershel-Bulkley	0.99979	0.77177
	Casson	0.99938	3.0326		Casson	0.99893	2.4355
	Bingham	0.99825	4.9815		Bingham	0.99494	3.9452
	Ostwald-de Waal	0.99121	11.382		Ostwald-de Waal	0.96511	9.8542
3	Windhab	0.99998	0.2285	6(Control)	Windhab	0.99998	0.42941
	Hershel-Bulkley	0.99997	0.48609		Hershel-Bulkley	0.99981	1.0525
	Casson	0.99905	2.6329		Casson	0.99979	1.5806
	Bingham	0.99664	3.4961		Bingham	0.99837	4.3604
	Ostwald-de Waal	0.97036	9.5716		Ostwald-de Waal	0.9781	11.379

Table 4: Influence of Various Formulations on Sensory Properties Dark Chocolates

Sample	Color	Flavor	Taste	Melting rate	Sweetness	Mouth feeling	Hardnees	Texture	Overall Acceptabillity
1	5.33^{a}	1.66^{a}	1.93^{a}	2.06^{a}	2^{a}	1.8^{a}	1.66^{a}	1.8^{a}	14.86^{a}
2	4.6^{ab}	2.1^{a}	2.33^{a}	2.6^{a}	2.73^{a}	2.26^{a}	2.66^{b}	2.26^{a}	18.26^{b}
3	3.6^{c}	3.46^{b}	3.2^{b}	3.9^{b}	3.73^{b}	4^{b}	3.33^{bc}	3.53^{b}	28.60^{c}
4	1.86^{d}	4.8^{c}	4.4^{c}	4.4^{b}	4.06^{b}	4.46^{b}	4.13^{cd}	4.66^{c}	35.46^{d}
5	1.4^{d}	4.4^{bc}	4.7^{c}	4.3^{b}	4.2^{b}	4.33^{b}	4.8^{d}	4.46^{c}	36.93^{d}
6(Control)	4.3^{b}	4.53^{c}	4.66^{c}	3.8^{b}	4.33^{b}	4.13^{b}	4.46^{d}	4.26^{cb}	33.46^{d}

Table 5: Influence of Various Combinations of Sugar Substitutes on Rheological Parameters Based on Three Models of Prebiotic Dark Chocolats

Models / Sample	Windhab model			Casson model	Herschel-Bulkley model		Apparent viscosity* (Pa·s)
	Real Yield stress	liner Yield stress	η_{∞}	Casson viscosity (Pa·s)	Herschel-Bulkley index	Plastic viscosity (Pa·s)	
1	33.96 ± 0.88^{a}	61.24 ± 1.1^{a}	9.44 ± 0.33^{a}	2.73 ± 0.04^{a}	0.94 ± 0.01^{a}	12.21 ± 0.3^{a}	10.95 ± 0.26^{a}
2	36.93 ± 0.73^{b}	62.66 ± 1.1^{ab}	5.34 ± 0.20^{b}	1.93 ± 0.03^{b}	0.90 ± 0.02^{ab}	8.53 ± 0.38^{b}	6.84 ± 0.15^{b}
3	41.14 ± 0.77^{c}	65.14 ± 1.6^{b}	3.63 ± 0.11^{c}	1.51 ± 0.01^{c}	0.87 ± 0.02^{bc}	6.86 ± 0.4^{c}	5.23 ± 0.18^{c}
4	50.39 ± 0.84^{d}	77.92 ± 1.4^{c}	2.88 ± 0.12^{de}	1.27 ± 0.03^{d}	0.83 ± 0.03^{cd}	6.69 ± 0.25^{c}	4.78 ± 0.14^{d}
5	72.56 ± 0.718^{e}	113.41 ± 1.3^{d}	2.53 ± 0.11^{d}	1.26 ± 0.01^{d}	0.82 ± 0.01^{d}	6.78 ± 0.4^{c}	5.55 ± 0.15^{e}
6(Control)	75 ± 0.80^{f}	127.87 ± 1.1^{e}	3.05 ± 0.14^{e}	1.32 ± 0.02^{d}	0.80 ± 0.04^{d}	7.41 ± 0.7^{c}	5.82 ± 0.14^{e}

*apparent viscosities are reported at a constant shear rate (40 s–1) for comparison purposes

5. References

[1] Livesey G. Tolerance of low-digestible carbohydrates:a general view. Brit J Nutr. 2001;85 suppl 1:S7-16.

[2] Krüger C. Sugar and bulk sweetner. In: Beckett ST.Industrial chocolate manufacture and use. 3rd ed.Oxford: Blackwell Sci; 1999. p. 36-55.

[3] GOLDMAN, F. 2006. Sugar substitute and bulking agent and chocolate. U.S.Patent Application, Number 20,060,088,637

[4] Oh DK. Tagatose: properties, applications and biotechnological processes. Appl Microbiol Biotechnol. 2007;76(1):1-8.

[5] Niness KR. Inulin and oligofructose: what are they? J Nutr 1999;129 suppl 7: S1402-6.

[6] Kaur N , Gupta AK. Application of inulin and oligofructose in health and nutrition . J Biosci 2002 27(2):703

[7] Horwitz W. Official Method of Analysis. 18th ed, Margland: AOAC International; 2005. chapters31,33,44.

[8] Franck A. Technological functionality of inulin and oligofructose. Brit J Nutr 2002; 87 suppl 2; S287- 91

[9] Drewnowski A. 1997. Why do we like fat? J Am Diet Assoc 97(Suppl 7):S316–22

[10] Anonymous. Gaio®tagatose in chocolate.Available in: www.gaio- tagatose.com.2004

[11] Golob T, Micovic E, Bertoncelj J, Jamnik M. Sensory acceptability of chocolate with inulin.Acta agriculturae slovenica 2004; 83 (2): 221-31.

[12] Mičovic, E. 2 3. The qualit of functional product – chocolate with inulin. Master of science thesis, University of Ljubljana, Biotechnical faculty, Department of Food Science and Technology, Ljubljana: 1-105.

[13] Bolenz S, Amtsberg K, Schape R. The broader usageof sugars and fillers in milk chocolate made possible by the new EC cocoa directive. Int J Food Sci and Technol 2006; 41: 45–5

[14] Toneli J, Murr F, Martinelli P, Fabbro IMD, Park K.Optimization of a physical concentration process for inulin. J Food Eng 2007; 80(3): 832-8.

[15] Crittenden RG, Playne MJ. Production, propertiesand applications of food-grade oligosaccharides.Trends in Food Sci &Technol 1996; 7: 353-61.