

COMPARATIVE STUDY OF PHYSICAL PROPERTIES OF SOME COMMERCIAL CHOCOLATES IN THE CROATIAN MARKET

Đurđica Ačkar, Patrik El Habbab[#], Antun Jozinović^{*}, Daniela Paulik, Jurislav Babić, Drago Šubarić

Josip Juraj Strossmayer University of Osijek, Faculty of Food Technology Osijek, Franje Kuhača 18, 31000 Osijek, Croatia

original scientific paper

Summary

The aim of this research was to investigate colour, texture, and rheological properties of commercial dark and milk chocolates available in the Croatian market. Chocolates were purchased in local stores, and 8 milk chocolate bars and 6 dark chocolate bars, from 5 different producers were obtained. Lightness (L^*) of milk chocolates ranged from 33.8 to 41.5, and 29.2 – 33.8 for dark chocolates. Hardness of chocolates determined by breaking test decreased with increasing cocoa solids content, while among milk chocolates, samples M4, which was the thickest, and M5, with the lowest content of milk solids, had significantly higher hardness than all other samples. Casson plastic viscosity ranged between 1.1 Pas and 7.21 Pas for dark chocolates, and 4.2 – 24.79 Pas for milk chocolates. Since the analysed chocolates are popular among the customers, these values are a good orientation for targeting certain properties when developing new recipes.

Keywords: milk chocolate, dark chocolate, rheology, texture, colour

Introduction

Chocolates are popular confectionery products among all consumer groups – from children to elderly. The variety of products – from dark, milk, white and ruby to different fillings and forms/shapes contributes to high popularity of this treat. According to Statista (2025), chocolate sales averages around 10 billion kilograms, comprising more than 10% of all confectionery sold worldwide (Figure 1). During

consumption, chocolate melts in the mouth and flavour is released. The flavour of chocolate is determined both by volatile (alcohols, esters, fatty acids) and fat-soluble non-volatile compounds, and fat and sugar contribute to the sensation. Particle size and flow properties of chocolate are also important for a mouthfeel and acceptability of the products by the consumers and colour is the first quality attribute consumers evaluate when choosing food (Boruczkowska et al., 2025).

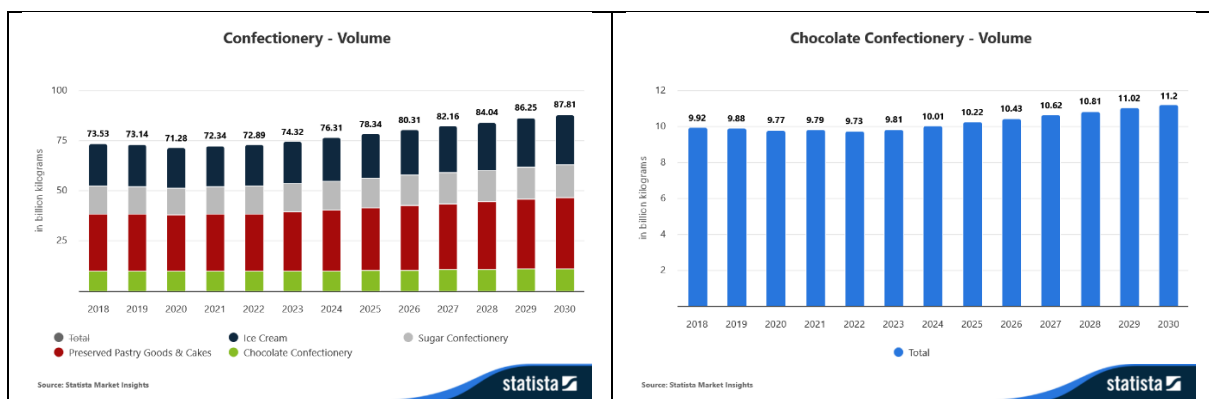


Figure 1. Quantities of confectionery and chocolate sold worldwide with estimated quantities for future period (Source: Statista, 2025)

In addition to sensory analysis, physical properties of food (chocolate) may be assessed by analytical tools. For instance, colour of chocolate may be evaluated by sensory analyst, but it can also be measured by chromameter, which gives results comparable to human eye, mimicking perception of the eye through

registering three primary colours: red, green and blue. In the food industry chromameters are often used, despite their limitations when colour is dependent on texture and turbidity, and CIELab system is commonly employed. This is a three-dimensional system in which lightness (L), green to red (a^*) and

^{*}Corresponding author: ajozinovic@ptfos.hr

[#]Graduate student

blue to yellow (b*) colour components are placed in a coordinate system, giving the colour of the sample (Boruckowska et al., 2025).

Texture is another physical property important from sensory perspective. Although Civille and Seltsam (2014) claim that instruments cannot mimic texture sensation in the mouth and that texture can only be evaluated by humans, texture analysers are often used in the food industry. They give the advantage of repeatability, although they do not mimic overall texture sensation in the mouth (biting force, mastication, sound...). Force instruments apply puncture, compression–extrusion, cutting–shear, compression, tensile, torsion, bending and snapping, or deformation, depending on their configuration (Bourne, 2002) and give insight into forces needed to break, chew or masticate the food sample, and/or its gumminess and adhesiveness.

Perhaps most important physical property of chocolate in industrial level is rheology. Flow properties are important not only from sensory aspect, but for handling chocolate during production – pumping, piping, moulding, coating. Standard ICA (International Confectionery Association) method refers to rheological measurements by rotational viscometer with concentric cylinders at 40 °C and use of Casson model to calculate Casson plastic viscosity and Casson yield stress (Goncalves and Lannes,

2010). Plastic viscosity is important for pumping, coating, filling rough surfaces, and mouthfeel. High-viscosity chocolates have pasty mouthfeel and stick in mouth for longer period of time. Yield stress is a transition point between pseudo-solid and pseudo-liquid state and shows minimum force needed to force chocolate to flow.

The aim of this research was to investigate colour, texture and rheological properties of commercial dark and milk chocolates available in the Croatian market in order to examine acceptable ranges of instrumental analyses results that could be used as a basis for targeted properties when developing new recipes.

Materials and methods

Chocolates were purchased at convenience stores in Osijek, Croatia, as chocolate bars of 75 – 100 grams, depending on the availability. Total of 8 milk chocolate bars and 6 dark chocolate bars, from 5 different producers were obtained, with specifications shown in the Table 1. Dark chocolates D1 and D2 were labelled as chocolates for cooking and eating, and chocolates M6, D3 and D6 were labelled as high-protein chocolates.

Table 1. Specifications of commercial chocolates, available in the Croatian market, used in the research

CHOCOLATE	COCOA SOLIDS (%)	MILK SOLIDS (%)	TOTAL FAT (%)	MILK INGREDIENTS	SPECIFIC INGREDIENTS	BAR MASS (g)
M1	25		32.3	skimmed milk powder whey powder, milk fat	palm, shea hazelnut paste	80
M2	30	23	30.4	whole milk powder, skimmed milk powder		75
M3	30	23	30.4	whole milk powder, skimmed milk powder		75
M4	31	7	34.0	whole milk powder		100
M5	31	18	32.9	whole milk powder, whey powder		80
M6 [#]	32	19	35.0			80
M7	33		31.0	skimmed milk powder whey powder, milk fat	hazelnut paste	80
M8	40		33.0	skimmed milk powder milk fat		85
D1*	43		27.7		palm, shea	100
D2*	43		29.0			100
D3 [#]	55		35.0		whey protein	80
D4	60		38.0			100
D5	72		42.1			100
D6 [#]	74		38.5		dietary fibre (8%), milk protein (18%)	80

*Chocolates for cooking and eating; [#]high-protein chocolates

Chocolates were stored in the original packaging at ambient temperature until analyses, but no longer than one week.

Immediately after opening, **colour** of the bottom surface (which is flat, without markings/ornaments and crevices) was determined using Chroma Meter C-400 (Konica Minolta), in CIEL*a*b* and L*C*h systems. Prior to measurement, the instrument was calibrated using white tile. Obtained parameters were:

- L* - lightness (from 0 – black to 100 – white)
- a* - positive values mark red domain, and negative mark green
- b* - positive values are yellow and negative are blue
- C – Chroma, colour intensity (positive values –brighter; negative – duller)
- h° – hue, colour tonality (from 0° - red to 90° - yellow, 180°- green and 270°- blue).

These colour systems were chosen because they reflect the perception of colour by human eye. The difference between the two system is that L*a*b* has rectangular, and L*C*h cylindrical coordinates.

Texture properties were determined using Texture Analyser TA.XT (Stable MicroSystems, Great Britain), using breaking method (Figure 2a) (Three Point Bend Rig) and by penetration (Figure 2b) (heavy-duty platform and 2 mm cylinder probe). Hardness and brittleness values were obtained using integrated software of the texture analyser.

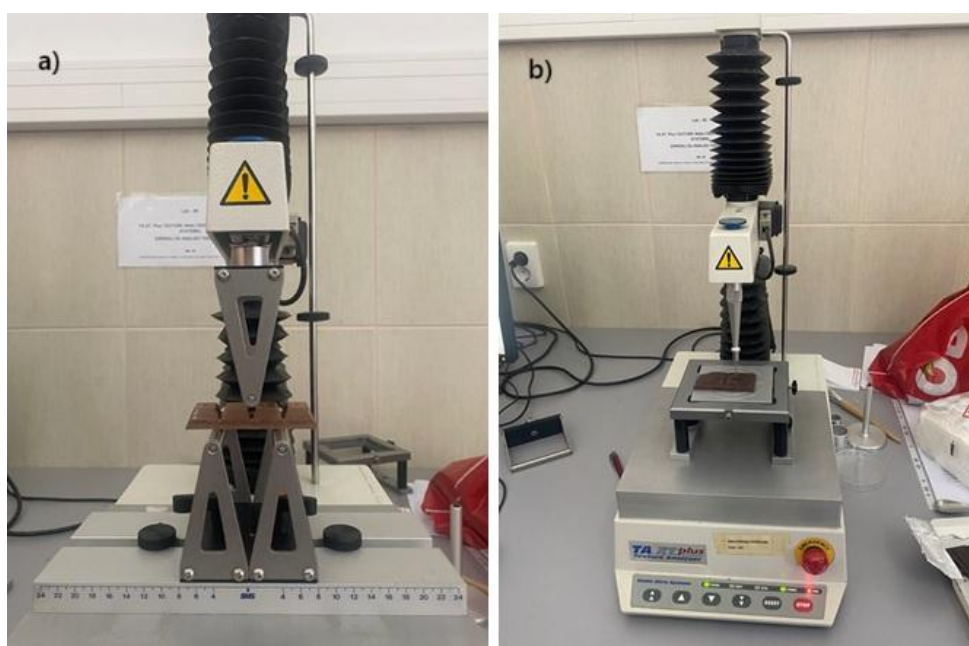


Figure 2. Texture analysis of chocolate samples by breaking test (a) and penetration test (b)

Rheological properties were determined using rotational rheometer HAAKE ViscotesteriQ (Thermo Fisher Scientific, USA) and IOCCC method (2000), at 40 (± 0.1) °C. Prior to measurement, samples were thermostated at 50 °C in the water bath, and liquid chocolate was transferred to the measuring cup of the rheometer. Samples were homogenised at 40 °C for 5 minutes at rotational speed of 5 s⁻¹, after which the rotational speed was gradually increased to 50 s⁻¹ over period of 180 s, kept at 50 s⁻¹ for 60 s and gradually decreased to 2 s⁻¹ over period of 180 s.

Rheological parameters were determined through Casson model, where:

- τ_0 , Casson yield stress (Pa)
- μ_p , Casson plastic viscosity (Pas),

and the values were obtained using integrated software of the rheometer.

Statistical analysis was performed using Excel, and Statistica® 14.0.0.15 Breakdown & one-way ANOVA LSD test ($p < 0.05$) and Correlation matrices ($p < 0.05$).

Results and discussion

Chocolate colour is the first attribute consumers notice when consuming the product. Typically, they attribute darker colour to higher content of cocoa, and, when consuming milk chocolate, lighter brown colour suggests higher contents of milk components. Indeed, chocolate colour is mainly influenced by the content of non-fat cocoa solids and, for milk chocolates, by the content of dairy ingredients (milk powder, whey). However, L* values shown in the Table 2, do not reflect the trend of the increase of the cocoa solids or the milk solids contents. Namely, among milk chocolates, after the sample M8, with the highest cocoa solids content of 40%, sample M1, with the lowest declared content of cocoa solids (25%) had the lowest L* value (37.66), followed by samples with 30% cocoa solids and 23% milk solids (M2 and M3), sample with 31% cocoa solids and 18% milk solids (M5), sample with 33% cocoa solids and finally, sample with 32% cocoa solids. There is no observed correlation between lightness of milk chocolates and cocoa or milk solids content (Table 3). Chroma (C) values followed the order: M8 < M7 < M2 < M3 < M1 < M4 < M5 < M6. Although this order better reflects the cocoa solids contents shown through correlation in Table 3, there is also no linear trend.

All measured a* values of milk chocolates are in positive domain, ranging from 8.52 for sample M8 to 10.55 for sample M1. Higher a* values correspond to more pronounced redness of the samples, which should correlate to cocoa solids content. However, the present research does not reveal this trend, similar to lightness and chroma values.

L* values observed for dark chocolates are more in line with cocoa solids contents, however the trend is not strictly linear. Just like milk chocolates, redness (a*) of dark chocolates cannot be correlated to the cocoa solids

content (Table 3), hence, the sample with 72% cocoa solids had the lowest a* value and the sample with 74% cocoa solids the highest one among dark chocolates.

Milk chocolates had more pronounced yellow component (b*) than dark chocolates, which contributed to their light brown colour, characteristic for this chocolate type. Hue (h) angle places all samples in the domain of red to yellow.

Colour of chocolate is not influenced only by the contents of ingredients, but on the cocoa roasting conditions prior to use in chocolate as well. Cocoa beans may or may not undergo moisture treatment before roasting, final roasting temperature usually ranges between 120 °C and 140 °C, however it may be below 100 °C in some cases, and roasting time may vary as well (Becket et al., 2017). During roasting, Maillard and Amadori reactions may proceed to different extent, giving different compounds such as pyrazines, methylxanthines, melanoidins, acrylamides, biogenic amines, and polycyclic aromatic hydrocarbons (PAHs) (Konar et al., 2025), resulting in different extent of brown colour formation, which, in turn, will influence the colour of the final product. In addition, during storage fat bloom may occur, increasing the lightness due to formation of thin layer of cocoa butter on the surface (Indiarto et al., 2025).

Therefore, colour of chocolate is a complex result of chocolate composition, production and storage conditions, not sole results of ratio of ingredients.

This is further supported by the fact that lightness of milk chocolates in this research is higher than lightness of vegan milk chocolates in research of Indiarto et al. (2025), with a* and b* values in the similar range, and lightness of dark chocolates is higher than the values observed by Kamali et al. (2025) for dark chocolate and dark chocolates with the addition of oleogels, with lower b* values, and a* in comparable range.

Table 2. Colour parameters of selected milk (M) and dark (D) commercial chocolates determined by chroma meter

SAMPLE	L*	a*	b*	C	h°
M1	37.66 ± 0.34 ^e	10.55 ± 0.14 ⁱ	10.76 ± 0.24 ^h	15.23 ± 0.13 ^k	45.94 ± 0.30 ^h
M2	39.37 ± 0.21 ^f	9.34 ± 0.11 ^g	10.50 ± 0.05 ^g	14.04 ± 0.07 ⁱ	48.38 ± 0.23 ^j
M3	39.47 ± 0.32 ^f	9.29 ± 0.88 ^g	10.77 ± 0.16 ^h	14.48 ± 0.19 ^j	48.34 ± 0.09 ^j
M4	41.43 ± 0.07 ^h	9.71 ± 0.16 ^h	11.78 ± 0.34 ^h	15.31 ± 0.20 ^k	50.95 ± 0.21 ^k
M5	39.68 ± 0.07 ^f	10.40 ± 0.15 ⁱ	11.51 ± 0.13 ⁱ	15.59 ± 0.17 ^l	47.63 ± 0.20 ⁱ
M6	41.52 ± 0.33 ^h	10.26 ± 0.01 ⁱ	12.64 ± 0.18 ⁱ	16.22 ± 0.13 ^m	50.60 ± 0.51 ^k
M7	40.69 ± 0.26 ^g	9.79 ± 0.06 ^h	9.28 ± 0.10 ^h	12.69 ± 0.31 ^h	44.54 ± 0.48 ^g
M8	33.82 ± 0.28 ^d	8.52 ± 0.15 ^f	6.21 ± 0.11 ^f	10.56 ± 0.17 ^g	35.91 ± 0.45 ^f
D1	30.39 ± 0.20 ^{b,c}	7.56 ± 0.08 ^d	4.67 ± 0.07 ^d	8.91 ± 0.05 ^d	31.48 ± 0.24 ^c
D2	30.65 ± 0.20 ^c	7.95 ± 0.10 ^e	4.73 ± 0.24 ^e	9.33 ± 0.19 ^e	31.41 ± 0.38 ^c
D3	30.19 ± 0.21 ^b	6.83 ± 0.08 ^c	4.55 ± 0.10 ^c	8.21 ± 0.11 ^c	33.68 ± 0.38 ^e
D4	29.29 ± 0.06 ^a	6.39 ± 0.17 ^b	2.86 ± 0.08 ^b	6.86 ± 0.03 ^b	24.50 ± 0.45 ^b
D5	29.31 ± 0.30 ^a	5.33 ± 0.05 ^a	1.66 ± 0.07 ^a	5.59 ± 0.03 ^a	17.57 ± 0.49 ^a
D6	30.98 ± 0.49 ^c	8.31 ± 0.05 ^f	5.60 ± 0.16 ^f	10.02 ± 0.17 ^f	32.48 ± 0.45 ^d

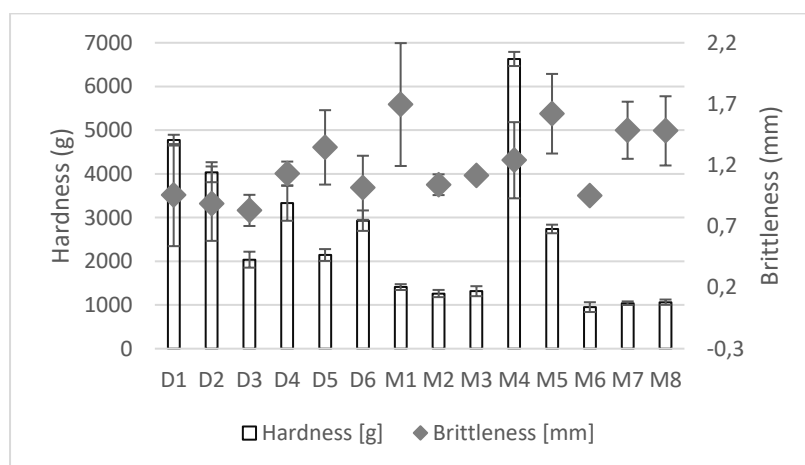
Values with different superscripts in the column are statistically different (p < 0.05)

Table 3. Correlations between colour parameters and cocoa- and milk solids contents in analysed chocolates (marked values are significant at $p < 0.05$)

	L*	a*	b*	C	h°
L*	1.000000				
a*	0.418898	1.000000			
b*	0.876659	0.766159	1.000000		
C	0.740722	0.889371	0.965103	1.000000	
h°	0.948965	0.116654	0.692562	0.496065	1.000000
cocoasolids	0.818780	0.832744	0.987209	0.968964	0.613505
milk solids	-0.702538	-0.251415	-0.476681	-0.421150	-0.669951

Another physical property of chocolate influencing consumers' perception is texture (hardness and brittleness). This property is a result of chocolate composition: cocoa solids content, cocoa butter content, type and amount of substitute fats, and thickness of chocolate bar. Hardness is a measure for mechanical resistance of a material to deformation, and in texture analysis it is defined as "the peak force during the first compression cycle" (Sahin and Sumnu, 2006). The results of hardness determined by texturometer are presented in Figures 3 and 4. Hardness of chocolates determined by breaking test (Figure 3) decreased with increasing cocoa solids content, with the exception of D3 and D6 samples. D3 sample was an 80g-bar, which is thinner than 100 g-bars, while D6 contained fibre, unlike other samples and these probably influenced the results. Diaz et al. (2025) reported that the addition of dehydrated blackberry and blueberry pulp reduced, while goldenberry increased hardness of dark chocolate. Although the observed effect cannot be linked to the fiber contents of added pulps (fresh blackberry and goldenberry contain 5.2 – 5.3 fibre/100 g fruit, and blueberry has 2.4 g fibre/100g (Kaume et al., 2011; Antibarro-Ortega et al., 2025; Duralija and Konjević, 2022)), it is obvious that the addition of fruit/fibre indeed causes changes in texture of chocolate. Among milk chocolates, samples M4 and M5 had significantly higher hardness than all other samples.

Sample M4 is significantly thicker than other samples and sample M5 had the second lowest amount of milk solids. Hardness by penetration separates chocolates for cooking (D1 and D2) from other dark chocolates (D3 to D6). Among D3 to D6 chocolates, hardness by penetration (Figure 4) increased with increase of cocoa solids content, with the exception of D6 sample, which contained added fibre. Among milk chocolates, the samples with lower contents of milk solids (M6 – M8) had lower hardness by penetration than samples with higher content of milk solids (M1 – M3). Sample M4 had the highest hardness by penetration, in line with the results obtained by breaking test, again, most probably due to significantly higher thickness. Correlation analysis revealed a negative correlation between hardness determined by breaking test and milk solids, but no other correlation with composition of chocolate was established. On the contrary, Abdolmaleki et al. (2025) observed negative correlation between the maximum force index (hence, hardness) and fat content in chocolate samples. However, they produced chocolate samples in the laboratory, and they had more consistent samples, with controlled changes of composition. Since each producer uses different recipes, different types of fats, different ingredients, it is very hard to reveal the exact component that had the most pronounced effect on texture.

**Figure 3.** Texture properties of commercial dark (D) and milk (M) chocolates determined by breaking test

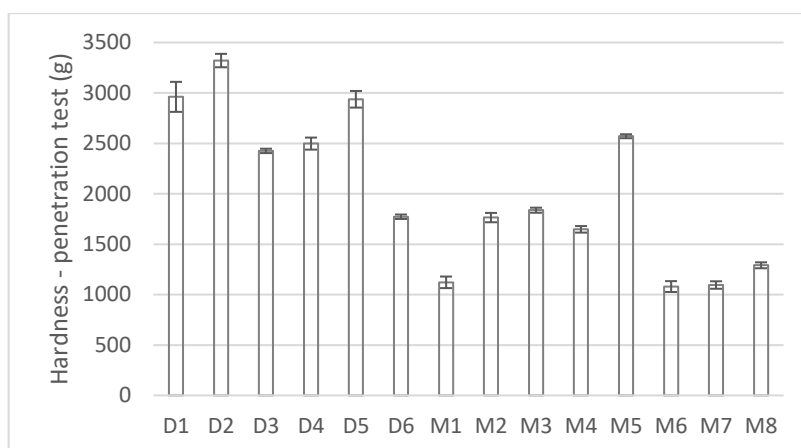


Figure 4. Texture properties of commercial dark (D) and milk (M) chocolates determined by penetration test

Table 4. Correlations between texture properties, cocoa- and milk solids, and fat contents in analysed chocolates (marked values are significant at p<0.05)

	Hardness	Hardness(pen)	Brittleness
Hardness	1.000000		
Hardness(pen)	0.134413	1.000000	
Brittleness	0.385835	0.896618	1.000000
Cocoasolids	0.120268	-0.415695	-0.013723
Milksolids	-0.51613	0.069000	-0.279421
Total fat	0.378406	-0.385888	0.054433

Liquid chocolate is a suspension of solid particles in fat and its viscosity is influenced by fat contents, size and shape of the suspended particles. Rheological properties of chocolate are important not only for the sensory acceptance, but for handling chocolate during production as well. Chocolate viscosity determines its appearance, texture, mouthfeel and flavour (Beckett et al., 2017). Figure 5 and Table 5 reveal characteristic non-Newtonian shear-thinning flow of investigated chocolates. The highest viscosity was observed for milk chocolate M5, followed by dark chocolates for cooking (D1 and D2) and milk chocolate M6. Dark chocolate D5 had the lowest viscosity, whereas all other samples had similar curves (Figure 5). Free fat present in a chocolate largely determines flow properties of chocolates –as the free fat content increases, solid particles become more and more distant and viscosity drops (Beckett et al., 2017). However, part of the fat is bound by and within solid particles and therefore the results in this research cannot be correlated to the total fat content. In addition, particle size and shape influence viscosity as well. Larger number of smaller particles have larger surface area that needs to be covered by fat, whereas large particles may pack together or bound fat.

Irregularly shaped particles have to re-align in order to facilitate flow (Beckett et al., 2017). All of these contribute to Casson yield stress, which represents the force needed to start chocolate flow. The highest yield stress was observed for milk chocolate M5, while the lowest was observed for dark chocolate D1. Chocolates D5, M2 and D6 had similar yield stress as well D3, M4 and D4; and M7, M6 and M8.

Dark chocolates had Casson plastic viscosity between 1.1 Pas (D5) and 7.21 Pas (D1), which is comparable to the viscosity of dark chocolates in the research of Sedaghati et al. (2025) who reported Casson plastic viscosity 2.39 – 2.53 Pas, and the research of Thilakarathna et al. (2025), who reported 5.60 –7.90 Pas for dark chocolates. Plastic viscosity reflects the energy required to sustain fluid flow (Thilakarathna et al., 2025) which is very important for production processes such as pumping, moulding, enrobing, shell making, weight control (Servais et al., 2004) and neither too low or too high viscosities are desirable, whereas very high viscosities will reflect in negative sensory properties, due to sticky and pasty mouthfeel (Castro-Alayo et al., 2023). The quality of raw materials, use of CBEs, sugar substitutes, addition of dietary fiber, bioactive components etc. reflect in

plastic viscosity changes and care should be taken when developing recipes. For example, CBEs with higher contents of saturated long-chain fats will form stable crystals which will increase viscosity of the chocolate, while CBEs rich in medium-chain fatty acids tend to form less stable crystal which will lead to lower viscosity values (Sedaghati et al., 2025). D1 sample in the present research has palm and shea fats, rich in long-chain saturated fatty acids, labelled at the packaging and the highest plastic viscosity value among all investigated chocolates, which is in line

with the previous statement. On the other hand, sample M1 had labelled palm, shea, and hazelnut paste and the second lowest plastic viscosity. Hazelnut oil is rich in unsaturated fatty acids (Sun et al., 2022) and probably, although long-chain, these fatty acids decrease crystalline stability and reduce viscosity. In addition, milk fat, cocoa butter and all other components of chocolate mass may interact differently and result in unique viscosities. This is probably the reason for no established statistical correlations (results therefore not shown).

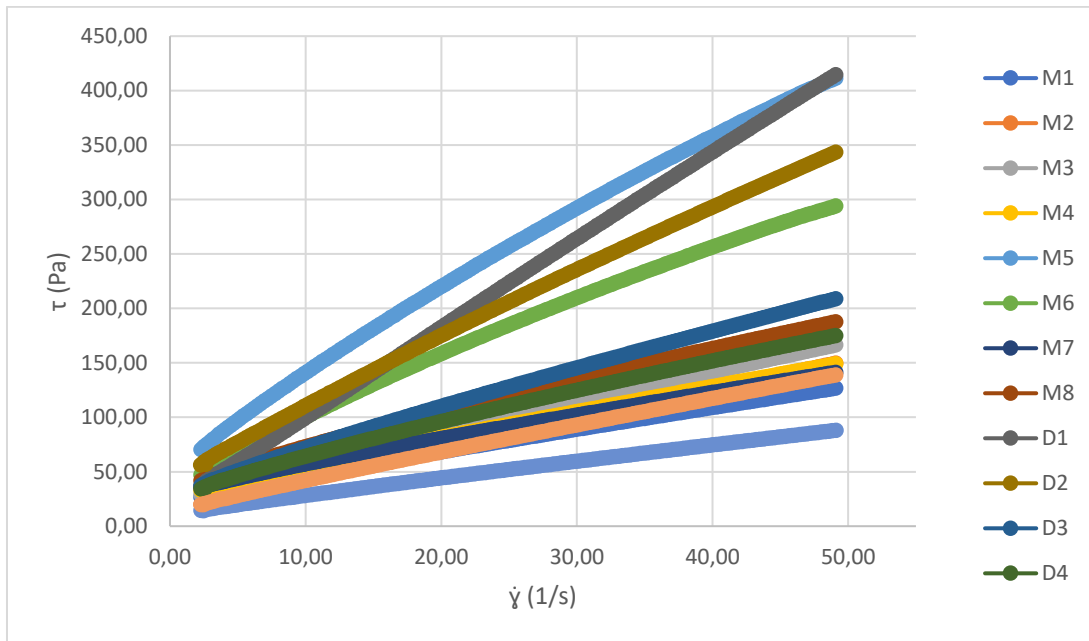


Figure 5. Flow properties of investigated commercial milk (M) and dark (D) chocolates

Table 5. Casson yield stress (τ_0) and Casson plastic viscosity (η_p) of investigated commercial milk (M) and dark (D) chocolates

CHOCOLATE	τ_0 (Pa)	η_p (Pas)	r
M1	10.1 ± 0.13	1.32 ± 0.01	0.9998 ± 0.0001
M2	4.21 ± 0.3	2.09 ± 0.08	0.9997 ± 0.0001
M3	9.22 ± 0.72	1.96 ± 0.02	0.9998 ± 0.0001
M4	13.75 ± 0.75	1.45 ± 0.01	0.9996 ± 0.0002
M5	24.79 ± 0.83	4.85 ± 0.31	0.9999 ± 0.0001
M6	17.34 ± 0.02	3.51 ± 0.13	0.9997 ± 0
M7	16.6 ± 0.76	1.22 ± 0.01	0.9996 ± 0
M8	18.85 ± 0.31	1.78 ± 0.02	1 ± 0.0001
D1	2.39 ± 0.37	7.21 ± 0.03	0.9999 ± 0
D2	16.23 ± 0.47	4.28 ± 0.01	0.9999 ± 0
D3	13.02 ± 0.45	2.39 ± 0.02	0.9999 ± 0
D4	14.15 ± 0	1.83 ± 0.03	1 ± 0
D5	4.06 ± 0.16	1.1 ± 0	0.9997 ± 0
D6	4.69 ± 0.23	1.88 ± 0.02	0.9999 ± 0

Conclusions

Chocolate is a complex system of cocoa parts, milk compounds, sugars, often with added substitute fats and minor ingredients such as emulsifiers and aroma. Therefore, it is hard to predict its physical and sensory properties such as colour, texture, melting and flow properties. Since different ingredients may interact in different manner, depending on their quality, quantity and physico-chemical properties, care must be taken when developing recipes in order to produce a product with desirable technical and sensory characteristics. The results of present research give proper insight in ranges that can be targeted when working on new recipes.

Acknowledgement

This work was supported by the Croatian Science Foundation under the project number HRZZ IP-2022-10-1960.

References

- Abdolmaleki, F., Daneshinya, M., Maleki, H. M. (2025): Calorie content, physicochemical properties, and textural characteristics of dark chocolate enriched with date pulp and sesame fiber, *Food Sci. Preserv.* 33(2), 218-231.
- Antibarro-Ortega, M., Dias, M. I., Petrović, J., Mandim, F., Nunez, S., Soković, M., Lopez, V., Barros, L., Pinela, J. (2025): Nutrients, phytochemicals, and in vitro biological activities of golden berry (*Physalisperuviana* L.) fruit and calyx, *Plants*14, 327.
- Becket, S. T., Fowler, M. S., Ziegler, G. R. (2017): Beckett's Industrial Chocolate Manufacture and Use. John Wiley and Sons Ltd, West Sussex, UK.
- Boruczowska, H., Boruczowski, T., Bronkowska, M., Prajzner, M., ElzbietaRytel (2025): Comparison of colour measurement methods in the food industry, *Processes* 13, 1268. <https://doi.org/10.3390/pr13051268>
- Bourne, M.C. (2002): Food Texture and Viscosity. In: Principles of Objective Texture Measurement, Elsevier.
- Castro-AlayoE. M., Baleazar-Zumaeta, C.R., Torrejon-Valqui, L., Medina-Mendoza, M., Cayo-Colca, I. S., Cardenas-Toro, F. P. (2023): Effect of tempering and cocoa butter equivalents on crystallization kinetics, polymorphism, melting, and physical properties of dark chocolates, *LWT – Food Sci. Technol.* 173, 114402.
- Civille, G. V., Seltsam, J. (2014): Descriptive analysis of food texture: advances in the sensory characterization of food textures. In: Food Texture Design and Optimization, 1st Ed. (Dar, Y. L., Light, J. M., Eds.). John Wiley & Sons, Ltd. pp 321-341.
- Diaz, K., Quispe-Sanchez, L., Baleazar-Zumaeta, C. R., Oblitas, R. C., Mori, R., Mori, S., Chuquizuta, T. S., Oliva, M., Chavez, S. G. (2025): Rheological, bioactive and sensory properties of dark chocolates elaborated with stevia sweetener and freeze-dried berries, *Appl. Food Res.* 5, 100870.
- Duralija, B., Konjević, N. (2022): Blueberry mineral fruit composition, *Pomologia Croatica* 26, 1-4.
- Goncalves, E. V., and Lannes, S. C. da S. (2010): Chocolate rheology, *Cienc. Tecnol. Aliment. Campinas* 30(4), 845-851.
- Indiarto, R., Al-Amin, R. W., Djali, M., Subroto, E., Muhammad, D. R. A., Wiguna, B. (2025): Improving the properties and sensory acceptability of vegan chocolate formulated with oat milk and soy protein isolate by incorporating encapsulated strawberry extract, *Appl. Food Res.* 5, 100674.
- Kamali, E., Sahari, M. A., Barzegar, M., Gavlighi, H. A. (2025): Effect of transesterified amaranth oil oleogel as a cocoa butter replacer on the physicochemical properties of dark chocolate, *Food Chem. X* 26, 102305.
- Kaume, L., Howard, L. R., Devareddy, L. (2011): The blackberry fruit: a review on its composition and chemistry, metabolism and bioavailability, and health benefits, *J. Agric Food Chem* 60, 5716-5727.
- Konar, N., Palabiyik, I., karimidastjerd, A., Toker, O. S., Gorgulu, A. (2025): Recent advances in cocoa chemistry and roasting, *Trends Food Sci Technol* 162, 105036.
- Sahin, S., Sumnu, S. G. (2006): Rheological properties of food. In: Physical Properties of Foods. Springer Science+Business Media, LLC, New York, USA. pp. 39-106.
- Sedaghati, S., Rajabi, H., Ahmadi, J. (2025): Fortification of dark chocolate with co-encapsulated saffron extract and caffeine, *Appl. Food Res.* 5, 101358.
- Servais, C., Ranc, H., Roberts, I. D. (2004): Determination of chocolate viscosity, *J. Texture Stud.* 34, 467-497.
- Statista (2025). Market Insights – Confectionery. <https://www.statista.com/outlook/cmo/food/confectionery-snacks/confectionery/worldwide> (accessed: 29. 9. 2025.)
- Sun, J., Feng, X., Lyu, C., Zhou, S., Liu, Z. (2022): Effects of different processing methods on the lipid composition of hazelnut oil: a lipidomics analysis, *Food Sci. Hum. Wellness* JJ, 427-435.
- Thilakarathna, R. C. N., Siow, L. F., Tang, T.-K., Cheong, L.-Z., Lee, Y.-Y. (2025): Mahua oil fraction: a sustainable and functional 1,3-dipalmitoyl-2-oleoyl-glycerol (POS)-enriched cocoa butter equivalent for chocolate production, *Food Chem.* 477, 143564.