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ORIGINAL PAPER

Diversity of sensory profiles and physicochemical characteristics of commercial hot chocolate drinks from cocoa powders and block chocolates

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Abstract
The aim of this study was to determine the sensory profiles and related physicochemical properties of commercial hot chocolate drink preparations. Nine samples of hot chocolate drinks including instant cocoa powder with (CPM) or without powdered milk (CP) and block chocolate (BC), available in Germany, were evaluated by a sensory panel using quantitative descriptive analysis with fifteen attributes describing appearance, odour, texture and flavour. Composition showed distinct effects on sensory properties, with each product category (CPM, CP, and BC) being represented by a characteristic sensory profile. CPMs are characterized by the significantly smallest particle size, lowest viscosity and lightness, highest pH, and cocoa-like sensory properties. CPs showed intermediate particle size, viscosity, lightness, and pH, and were described by sugar and milk properties. BCs had the significantly largest particle size, highest viscosity and lightness, and lowest pH. Noticeable in the sensory description of BCs are large particles, oil droplets and a less cocoa-like and unbalanced taste. Generally, cocoa and milk properties are opposites and proportional to cocoa and protein content, respectively. Beverage rheology is greatly influenced by fat content, while colour is directly linked to the protein content. Milk reconstitution from powder does not match milk as dispersant and consequently enhances cocoa properties of hot chocolate drinks.

Keywords Hot chocolate · Sensory profile · Physicochemical properties · Multivariate analysis

Introduction

Hot chocolate drinks are traditionally consumed in Southern and Central America and in Europe by people of all age, and without a specific time of consumption [1]. They are commonly prepared either from cocoa powder mixtures, from chocolate flakes or from block chocolate by dispersing these either in milk or in water, and they are marketed at largely differing prices. Although a wide variety of flavours and presentations are available on the market, the main ingredients are cocoa powder or cocoa liquor, sugar, and milk components. Because of the insolubility of the cocoa particles and depending on the fat content, chocolate drinks tend to separate by sedimentation and creaming; in most cases, consumption immediately after preparation is recommended.

Partly as a function of the basic formulation, chocolate drinks exhibit significant differences in terms of usage and sensory properties [2]. Colour, appearance, odour, taste and texture contribute to the acceptance of the beverage and are decisive for consumer preference. The cocoa in the beverage formulations plays an outstanding role for the general sensation. The cocoa type strongly determines the intensity of sensory attributes such as colour, flavour, mouthfeel and consistency, and bitterness [3]; it is especially the cocoa polyphenols that have been linked to astringency and bitter flavour. The fat (= cocoa butter) in the ready-to-consume drinks mainly affects appearance and texture (e.g. creaminess and mouthfeel) and it also serves as aroma carrier and flavour multiplier [3, 4]. Moreover, fat and protein content influence between-ingredient interactions, resulting in the variation of colour, flavour, and texture of the product pronouncing the relevance of milk in terms of creaminess, smoothness and balanced taste [4, 5]. In dairy drinks, sugar

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is tied not only to sweetness but also improves smell, helps to develop flavour, and gives the drink a body which has a direct influence on mouthfeel through the changes of the flow behaviour [2, 6].

Commercial chocolate drinks show considerable variations regarding their main components hence different sensory profiles have to be expected. To match expectations of a targeted consumer group the determination of sensory attributes by a trained panel and/or by consumers, and linking these to physicochemical properties give key information for product development and marketing [3]. However, studies that related sensory attributes to physicochemical properties of hot chocolate beverages [3–5, 7, 8] mainly focused on instant cocoa powder without considering other preparations that are nowadays available, for instance block chocolate, or cocoa mixtures that include milk powder, and therefore represent just-add-water instant products. At present, both of the mentioned product types are relevant for considering, on the one hand, tradition and, on the other hand, convenience.

The aim of this study was to determine the sensory profiles of commercial hot chocolate drink preparations and how these are related to nutritional and physicochemical properties. For this purpose, a screening of chocolate drinks available in German supermarkets with respect to ingredients and preparation instructions was done to categorize the available products, and representative products from the most common categories were selected. Sensory profiles, and physicochemical and rheological parameters related to sensory properties were analysed for selected commercial products. In addition, a principal component analysis was performed to identify any relation between the analytical and sensory properties.

Materials and methods

Market analysis and material selection

A market analysis in German retail stores was carried out to collect information on the drinking chocolate products that are available. In this screening, a total of 53 products were identified. These were further assigned to one of six different categories: made of pure cocoa powder (7), of cocoa powder with sugar (18) and milk powder (9), block and flakes chocolate (12), chocolate pads and capsules (5), and chocolate syrup (2). Based on this assignment, three products of each of the main three categories were selected on the basis of ingredients labelling and cocoa content, and purchased in local supermarkets. Sample codes are CP for cocoa powder with sugar, CPM for cocoa powder with sugar and powdered milk, and BC for block and flakes chocolate (Table 1).

Table 1 Categories, ingredients, preparation instructions and average nutritional values of hot chocolate drinks

Category code	Ingredients	Instructions (g product/ 100 g liquid)	Average nutritional values in the ready-to-consume drink (g/100 g)			
			Cocoa	Fat	Sugar	Protein
Block chocolate (BC)						
BC1	Cocoa liquor, sugar, cocoa butter, emulsifier (soy lecithin), natural flavouring (vanilla)	16.2	6.89	7.42	9.22	3.35
BC2	Cocoa liquor, sugar, cocoa butter, emulsifier (lecithin)	7.0	3.40	4.87	5.56	3.31
BC3	Cocoa liquor, sugar, cocoa butter, cocoa powder, emulsifier (soy lecithin)	17.5	8.99	8.59	8.03	3.53
Cocoa powder formulations without powdered milk (CP)						
CP1	Cane sugar, cocoa powder (min. 32%), emulsifier (sunflower lecithin)	6.5	2.05	3.61	6.38	3.37
CP2	Sugar, cocoa powder (min. 32%), dextrose (19.9%), emulsifier (soy lecithin), flavouring (vanillin)	9.7	2.93	3.67	8.15	3.50
CP3	Sugar, dextrose (25%), low-fat cocoa powder (18%), emulsifier (soy lecithin), salt, flavouring (vanillin)	9.7	1.79	3.24	9.29	3.24
Cocoa powder formulations with powdered milk (CPM)						
CPM1	Chocolate powder 48.4% (sugar, cocoa powder (32.3%), dextrose, emulsifier (soy lecithin), flavouring), skimmed-milk powder (17.2%), lactose, coconut oil, sugar, salt	19.4	2.54	2.62	10.10	1.57
CPM2	Sugar, cocoa powder (17%), sweet whey powder, coconut oil, skimmed-milk powder, stabilizer, sodium phosphate, salt	17.8	2.56	2.54	9.30	1.52
CPM3	Sugar, cocoa powder (26%), sweet whey powder, whole milk powder (10%), salt	17.8	4.80	1.30	9.58	1.69

Beverage preparation

The chocolate drinks were prepared by weighing the respective amount of raw formulation (from instructions provided by the manufacturer, see Table 1) into a beaker. One litre dissolution liquid—tap water for CPMs, and UHT whole milk with 3.5% fat (Kaufland Warenhandel GmbH & Co. KG, Neckarsulm, Germany) for BCs and CPs—was pre-heated to 75 ± 2 °C using a heating plate. The liquid was then poured into the beaker, and the mixture was further stirred with an agitator for 5 min to reach visual homogeneity. Subsequently, 80 ± 5.0 mL of each preparation were filled into 100 mL glasses labelled with three-digit random numbers, and kept at 60 ± 1.0 °C prior to sensory analysis for 30 min at maximum.

Determination of sedimentation and creaming

Phase separation of the chocolate drinks, which is related to visual perception, was determined under gravity in 15 mL graduated tubes (15 mm × 120 mm) filled with 10 mL freshly prepared sample. The tubes were placed in a heating cabinet with an observation window (Memmert GmbH & Co. KG, Schwabach, Germany) at 40 ± 1 °C. The oil creaming and particle sedimentation levels were visually read from the graduation 30 min after sample preparation and are further expressed as creaming index (CI) and sedimentation index (SI), respectively. Each measurement was carried out in triplicate. CI (%) and SI (%) were calculated from the initial sample volume V (mL) and the upper oil phase and sediment volumes V_C (mL) and V_S (mL), respectively [9],

$$\mathrm{CI} = \left(V_\mathrm{C}/V\right) \times 100, \tag{1}$$

$$\mathrm{SI} = \left(V_\mathrm{S}/V\right) \times 100. \tag{2}$$

Determination of droplet size distribution

Droplet size distributions, which can be related to sensory mouthfeel and rheological properties, were determined at 40 ± 1 °C with a HELOS® KR laser diffraction analyser (Sympatec GmbH, Clausthal-Zellerfeld, Germany). The chocolate drinks were diluted to achieve an optical density of 10–30%. Distilled water that was placed first in the cuvette was used as solvent, and the samples were added dropwise and homogenized by intense magnetic stirring for 1 min. The particle diameter measuring range was 0.5–175 µm. Each measurement was made in duplicate. The Sauter mean diameter $d_{3,2}$ (µm) and the distribution width $\left(x_{90} - x_{10}\right)$ (µm) were selected for characterization of the particle size distribution of the chocolate drinks, where x_{90} and x_{10} (µm) refer to the particle sizes that correspond to 90 and 10% of the cumulative undersize distribution, respectively.

Rheological properties

All rheological measurements were performed using a strain-controlled HAAKE MARS 60 rotational rheometer with a UTM Peltier temperature controller (Thermo Fischer Scientific Germany BV & Co. KG, Brunswick, Germany) and a CC25 DIN concentric cylinder geometry (inner diameter, 25.1 mm; outer diameter, 27.2 mm; bob length, 37.6 mm; cone angle, 120°). After filling the cylinder with a sample volume of 16 ± 1 mL, the chocolate drinks were allowed to equilibrate for 5 min at 40 ± 0.1 °C under a high shear rate of 1000/s to prevent sedimentation by vortices.

Flow curves were measured by applying a downward step rate sweep in the range of 1000/s–1/s. Data recording was realized by a logarithmic ramp with 10 data points per decade and 10 s per data point. The Ostwald-de Waele model $\tau = K\dot{\gamma}^n$, with shear stress τ (Pa), viscosity index K (Pa s), shear rate $\dot{\gamma}$ (1/s) and flow behaviour index n (−), was used to fit the flow curves. The apparent viscosity η_{50} at a shear rate of 50/s, reflecting the shear rate in the mouth [3], was used for statistical comparison. Each rheological analysis was carried out in triplicate.

Colour measurements

Colour properties are related to visual perception of the chocolate drinks, and were measured and recorded using a LUCI 100 spectral colorimeter (D65 xenon light source, 10° observer) with a mobile measuring head (Dr. Bruno Lange GmbH, Berlin, Germany). The freshly prepared samples were transferred into quartz glass vials of 32 mm diameter and 23 mm height, agitated and then measured against a dark background at room temperature (22 ± 1 °C).

The measurements were based on the CIELab colour space and the lightness L^* (–) and the hue angle h_{ab} (°) were used as colour descriptors [10]. Each measurement was done eight times.

Measurement of pH

pH of the chocolate drinks, which is related to taste, was measured in duplicate for the chocolate drinks at 40 ± 1 °C using an InoLab Level 2 pH meter with a SenTix® 81 standard electrode (WTW Xylem Analytics Germany GmbH, Weilheim, Germany).

Descriptive sensory analysis

Descriptive sensory analysis was realized in accordance with standard ISO 13299 [11] by a trained panel of 15 judges (10

Table 2 Descriptors used by the trained panel for establishing a sensory profile of hot chocolate drink

Attribute	Definition
Appearance	
Suspended particles	Number of visible floating particles in the beverage after stirring
Oil droplets on the surface	Creaming droplets, sometimes visible with a bit of front light and surface gloss
Odour	
Milky (O)	Reminiscent of fresh milk
Cocoa (O)	Evocative of the odour of cocoa powder and chocolate (including dark and milk chocolate)
Caramel	Sweetish impression, usually caused by heating sugar
Fruity	Impression of fresh and ripe fruit
Earthy	Reminiscent of fresh wet soil. Impression as a result of lack of ventilation
Flavour	
Sweet	A basic taste characterized by a solution of sucrose, glucose or fructose
Bitter	A primary taste characterized by organic acids, phenols, tannins or roasting substances. No synonym for acid
Milky (F)	Reminiscent of fresh milk. Also, opposite of watery and thinned
Cocoa (F)	Evocative of the flavour of cocoa powder and chocolate (including dark and milk chocolate)
Acid	A basic taste characterized by the solution of an organic acid
Balanced	None of each identifiable characteristics feature outweighs
Texture	
Astringent	Contraction of the oral mucosal surface. Characteristic of an after-taste sensation, which is almost like a drying effect in the mouth area
Creamy	Film formation in mouth such as a homogeneous product which causes a creamy/fatty mouthfeel. Describes the physical properties of a drink. Intense body would describe a strong full mouthfeel as opposed to being thin

female, 5 male) aged between 20 and 45. In two introductory sessions, 15 pre-defined descriptors covering appearance, odour, flavour and texture (Table 2) were elaborated by the panellists [12]. For each sample and each descriptor, the panellists were asked to score the perceived intensity on an unstructured scale of 10 cm length, with verbal expressions “attribute not perceived” and "attribute intensely perceived” as anchors.

The hot chocolate drinks were evaluated in duplicate in a total of six sessions, in each of which three products were presented monadically under artificial illumination (colour temperature 6500 K) in a sensory lab according to standard ISO 8589 [13]. Water and white bread were available as palate cleansers. Prior to tasting, the panellists were asked to homogenize the hot chocolate drinks by stirring with a spoon five times. For evaluation, the scores were measured with a ruler to an accuracy of 1 mm. The results of each panellist were normalized to zero mean and unit standard deviation per attribute to minimize the effect of individual participant scale usage.

Statistical analysis

Statistical analysis of analytical parameters and questionnaire responses was conducted using SPSS 23 (IBM Deutschland GmbH, Ehningen, Germany). For all analytical and sensory results, arithmetic mean values ± half deviation ranges for duplicate or arithmetic mean ± standard deviation for ≥ triplicate measurements were calculated. One factor analysis of variance (ANOVA), followed by Student–Newman–Keuls post hoc testing was performed for each sensory and physicochemical property. A P value < 0.05 was considered as significant. Furthermore, principal component analyses (PCA) were conducted together for sensory and physicochemical properties.

Results and discussion

Physicochemical properties of chocolate drinks

As regards, physical stability of the ready-to-consume chocolate drinks, susceptibility to sedimentation differed markedly depending on the type of drink, and SI, was significantly higher for the cocoa powder preparations (Table 3). The highest SI was observed for CP2 (2.07%), the lowest SI for block chocolate BC1 (0.5%) (Supplement A1). SI of dissolved CPs was significantly higher than that of CPMs, which is probably related to cocoa solids that are larger than milk solids and that are present in a higher amount in CPs. Creaming was only observed in drinks made with block chocolate, with the CI values ranging between 4–15% directly linked to the fat content of the respective formulations (see Table 1). All BCs also have cocoa liquor with a

Table 3 Averaged values of physicochemical properties of hot chocolate drink categories

Physicochemical property	Product category		
	BC	CP	CPM
Physical stability			
SI (%)	0.69 ± 0.21^b	1.43 ± 0.49^a	0.92 ± 0.08^b
CI (%)	8.67 ± 4.74	–	–
Particle size indicators			
$d_{3,2}$ (µm)	5.53 ± 0.37^a	4.42 ± 0.20^b	3.49 ± 0.724^c
$(x_{90} - x_{10})$ (µm)	38.02 ± 8.18^a	19.79 ± 1.91^b	18.90 ± 2.67^b
Viscosity			
η_{50} (mPa s)	3.41 ± 0.80^a	2.64 ± 0.15^b	1.45 ± 0.38^c
Colour properties			
L^* (–)	47.91 ± 3.73^a	45.68 ± 5.10^b	32.00 ± 2.14^c
h_{ab} (°)	59.67 ± 2.13^a	52.78 ± 3.51^b	44.28 ± 1.27^c
pH (–)	6.19 ± 0.14^c	6.73 ± 0.11^b	7.08 ± 0.20^a

Values with different letters within a row differ significantly at $P < 0.05$

BC Block chocolate, *CP* Cocoa powder formulations without powdered milk, *CPM* Cocoa powder formulations with powdered milk, *SI* sedimentation index, *CI* creaming index, $d_{3,2}$ Sauter mean diameter, $(x_{90} - x_{10})$ distribution width, η_{50} apparent viscosity at a shear rate of 50/s, L^* lightness, h_{ab} hue angle, *pH* pH

cocoa butter content of 50–55% as ingredient, whereas CPs and CPMs come with cocoa powder that contains 10–22% cocoa butter [14]. In addition, cocoa butter within cocoa liquor is, in contrast to cocoa powder, mainly free and unbound, so that a direct relation between CI and beverage free fat content is self-evident.

The Sauter mean diameter $d_{3,2}$ and the particle size distribution width $(x_{90} - x_{10})$ were significantly higher for drinking chocolate made from block chocolate than for those made from cocoa powder (Table 3). BCs had a average $d_{3,2}$ and average $(x_{90} - x_{10})$ span larger than 5 µm and 30 µm, compared with average $d_{3,2}$ of 4.42 ± 0.20 µm and average $(x_{90} - x_{10})$ 19.79 ± 1.91 µm (drinks from CPs) and 3.49 ± 0.72 µm and 18.90 ± 2.67 µm (drinks from CPMs), respectively. Normally, a higher sedimentation rate would be expected with increasing particle size [15, 16] but particle analysis does not distinguish between solid cocoa particles and liquid droplets. The manual preparation procedure is poor in terms of emulsification intensity so that rather coarse droplets, and in consequence, higher Sauter mean diameters are produced. As regards the BC samples, creaming and sedimentation are simultaneously occurring but oppositely directed flow processes, which interfere because of interactions between solid particles and oil droplets [17, 18]. Therefore, sedimentation of BC drinks is hindered by a stronger creaming process, and fine cocoa solids were floated with ascending oil droplets as it could be observed visually by a dark cocoa particle layer immediately below the creaming layer.

All chocolate drinks showed a low shear viscosity and negligible shear rate dependency. Fitting the flow curves to the Ostwald-de Waele model led to flow behaviour indices n from 0.97 to 1.03, indicating Newtonian flow. As a consequence, apparent viscosity was directly taken from the viscosity curves (η_{50}), and is also included in Table 3. The significantly highest η_{50} was observed for BC with $3.41 \pm 0{,}80$ mPa s, followed by drinks from CPs with 2.64 ± 0.15 mPa s and CPMs with 1.45 ± 0.38 mPa s. These differences can be attributed to particle size, fat content and to the different dispersants, with a close link between fat content and viscosity of the drinking chocolate preparation. The three drinks made from BCs showed only slight differences as regards particle size and fat content which explains their similar viscosity. A similar behaviour was observed for the three CP drinks which, in addition to lower particle size, contained cocoa powder instead of cocoa liquor and cocoa butter that is responsible for a lower viscosity. Although the three drinks from CPM are characterized by a lower particle size, associated with milk and cocoa powder content, the leading cause for the low viscosity is the fact that water instead of milk was used as dispersant. In line with Dogan et al. [4], fat content seems to exhibit the major influence on chocolate drink viscosity.

Regarding colour, the most pronounced differences are evident between the water-suspended instant products (CPM) and the milk-prepared products (BC, CP). Whereas the average lightness L^* of the BC and CP is 47.91 ± 3.73 and 45.68 ± 5.10, respectively, average lightness of the drinks prepared with water is significantly lower (32.00 ± 2.14). L^* is therefore most strongly influenced by the milk medium used, since skimmed-milk powder after reconstitution does not provide the same optical properties as conventional milk [19]. Hough et al. [7] and Hough and Sánchez [8] published that the amount of suspended cocoa had a significant effect on L^* of hot chocolate drinks. This tendency was, however, not observable in the present study. The different categories of chocolate drinks can, in addition, be significantly distinguished by the hue angle: BCs with average h_{ab} of $59.67 \pm 2.13°$, CPs with $52.78 \pm 3.51°$, and CPMs with $44.28 \pm 1.27°$.

Apart from cocoa content and dispersant type the differences in L^* and h_{ab} may have further reasons, one of those being the cocoa powder. In this case, beverage pH increases with higher cocoa powder concentration [16]. Moreover, Roefs et al. [20] showed that there is a relationship between lightness and pH of drinking chocolate due to structural changes of the casein micelles [20]. The pH differed significantly within the three drinking chocolate categories (see Table 3). The significantly highest pH was observed in the CPM products prepared with water (7.08 ± 0.20); these products showed the significantly lowest L^* and h_{ab} and presumably contain alkalized cocoa powder. The lowest pH was observed for the three drinks made from block chocolate (6.19 ± 0.14) which presumably contain non-alkalized cocoa liquor. According to Roefs et al. [20], drinking chocolates appear lighter, the more acid they are; this is in line with most of the L^* results within the drinking chocolate categories and entirely consistent with the h_{ab} results obtained in this study.

Sensory profiles of chocolate drinks

Significant differences between the individual products ($P \leq 0.05$) were evident for all 15 attributes tested during descriptive analysis (Table 4). Particularly and in contrast to all other products, CPM3 showed the strongest tendency towards being perceived as earthy, bitter, acid and astringent. This product contains the highest amount of cocoa of the water-suspended cocoa powders (4.80 g/100 g, see Table 1). The cocoa content of CPM1 and CPM2 is lower (2.54 g/100 g and 2.56 g/100 g, respectively), and therefore non-significant differences in the intensities for these cocoa-related attributes were detected.

Although the drinks from block chocolate BC3 and BC1 had a higher cocoa content (8.99 g/100 g and 6.89 g/100 g, respectively), intensity of cocoa odour and flavour was not perceived as more intense, and earthy, bitter and astringent were comparable to the water-suspended CPM products. The milk-dissolved chocolate drinks BC1, BC3, CP2 and CP3 were significantly creamier compared to the water dissolved products. Furthermore, BC1 and BC3 showed the highest ratings for oil droplets on the surface, and in addition, BC2 and BC3 for suspended particles. Several products from the BC group were judged to be more fruity (BC2), acidic (BC1 and BC3) and less balanced (BC2 and BC3) in comparison to the drinks made from cocoa powder suspended in milk or water. On the other hand, CP3 showed the highest intensity for the attributes milky odour and flavour, sweet and balanced; and was lowest for the cocoa-related properties (earthy, bitter, acid, astringent). CP1 and CP2 also showed a pronounced milky odour and flavour but were less sweet, more earthy, more bitter and astringent as compared to CP3; this is in line with the lowest cocoa concentration of CP3 (1.79 g/100 g) and the highest sugar content (9.29 g/100 g).

Obviously, the three hot chocolate beverage categories can be distinguished by their sensory attributes, as can be concluded from the radar chart (Fig. 1). Between-category differences were significant for all attributes except for astringent and sweet taste. Drinks made from CPM are characterized especially as cocoa-like, whereas on the other hand, drinks from CP exhibit a particularly strong correlation to milk properties; BC drinks are distinguished from the others by the attributes related to suspended particles and oil droplets, as well as a fruity taste.

Table 4 Sensory properties of hot chocolate drink samples

Attribute	Sample								
	BC1	BC2	BC3	CP1	CP2	CP3	CPM1	CPM2	CPM3
Suspended particles	-0.43 ± 0.45^{cd}	1.24 ± 0.76^{b}	$1,90 \pm 0.52^{a}$	-0.32 ± 0.59^{cd}	$-0,18 \pm 0.62^{c}$	$-0,47 \pm 0.33^{cd}$	-0.68 ± 0.32^{d}	-0.47 ± 0.44^{cd}	-0.59 ± 0.40^{d}
Oil droplets on the surface	1.04 ± 0.46^{a}	0.60 ± 0.73^{b}	1.07 ± 0.57^{a}	-0.71 ± 0.53^{c}	-1.06 ± 0.26^{d}	-0.98 ± 0.41^{cd}	-0.99 ± 0.46^{cd}	0.57 ± 0.52^{b}	0.46 ± 0.58^{b}
Milky (O)	-0.31 ± 0.77^{c}	0.08 ± 0.84^{b}	-0.46 ± 0.68^{c}	0.84 ± 0.78^{a}	0.78 ± 0.62^{a}	1.19 ± 0.51^{a}	-0.56 ± 0.70^{cd}	-0.61 ± 0.77^{cd}	-0.94 ± 0.65^{d}
Cocoa (O)	-0.03 ± 1.09^{abc}	-0.64 ± 0.91^{c}	0.04 ± 1.00^{abc}	-0.27 ± 0.91^{bc}	-0.12 ± 1.00^{abc}	-0.19 ± 0.92^{abc}	0.51 ± 1.00^{a}	0.49 ± 0.76^{a}	0.20 ± 0.96^{ab}
Caramel	0.43 ± 1.18^{a}	0.51 ± 1.02^{a}	-0.18 ± 0.96^{ab}	-0.05 ± 0.96^{ab}	-0.14 ± 0.82^{ab}	0.54 ± 0.69^{a}	-0.14 ± 0.72^{ab}	-0.39 ± 1.09^{b}	-0.57 ± 0.91^{b}
Fruity	0.23 ± 1.04^{b}	1.01 ± 1.14^{a}	0.22 ± 1.13^{b}	-0.13 ± 0.71^{b}	-0.05 ± 0.94^{b}	-0.35 ± 0.80^{b}	-0.23 ± 0.93^{b}	-0.28 ± 0.79^{b}	-0.42 ± 0.70^{b}
Earthy	0.10 ± 0.97^{bcd}	0.11 ± 1.03^{bcd}	0.56 ± 0.91^{ab}	-0.46 ± 0.71^{de}	-0.64 ± 0.42^{e}	-0.86 ± 0.26^{e}	-0.06 ± 0.77^{cd}	0.49 ± 1.14^{abc}	0.76 ± 1.11^{a}
Sweet	0.04 ± 1.13^{bc}	-0.48 ± 0.99^{cde}	-0.58 ± 0.79^{de}	-0.08 ± 0.76^{bcd}	-0.06 ± 0.91^{bcd}	1.06 ± 0.69^{a}	0.50 ± 0.76^{b}	0.40 ± 0.84^{b}	-0.80 ± 0.66^{e}
Bitter	0.23 ± 0.99^{b}	$-0,60 \pm 0.61^{d}$	0.93 ± 0.72^{a}	-0.37 ± 0.73^{cd}	-0.14 ± 0.73^{bc}	-1.35 ± 0.45^{e}	-0.08 ± 0.70^{bc}	0.24 ± 0.71^{b}	1.15 ± 0.59^{a}
Milky (F)	-0.16 ± 0.77^{c}	0.47 ± 0.88^{b}	-0.62 ± 0.68^{c}	0.93 ± 0.61^{a}	0.23 ± 0.73^{b}	1.23 ± 0.48^{a}	-0.47 ± 0.72^{c}	-0.55 ± 0.67^{c}	-1.05 ± 0.71^{d}
Cocoa (F)	0.03 ± 0.99^{ab}	-1.38 ± 0.69^{c}	0.24 ± 0.88^{a}	-0.04 ± 0.83^{ab}	0.21 ± 0.81^{a}	-0.42 ± 0.90^{b}	0.44 ± 0.61^{a}	0.56 ± 0.69^{a}	0.37 ± 1.07^{a}
Acid	0.75 ± 1.08^{a}	0.15 ± 1.09^{bc}	0.51 ± 0.93^{ab}	-0.30 ± 0.73^{cd}	-0.34 ± 0.59^{cd}	-0.68 ± 0.52^{d}	-0.54 ± 0.44^{d}	-0.38 ± 0.79^{cd}	0.82 ± 1.18^{a}
Balanced	0.14 ± 0.97^{a}	-0.52 ± 0.95^{b}	-0.54 ± 0.82^{b}	0.32 ± 0.92^{a}	0.28 ± 0.93^{a}	0.55 ± 0.90^{a}	0.33 ± 0.81^{a}	0.06 ± 1.06^{a}	-0.62 ± 0.93^{b}
Astringent	0.22 ± 0.83^{bc}	-0.64 ± 0.85^{de}	0.48 ± 0.90^{b}	-0.25 ± 0.84^{cd}	0.04 ± 0.75^{bc}	-1.01 ± 0.59^{e}	0.00 ± 0.91^{bc}	-0.05 ± 0.81^{bc}	1.21 ± 0.80^{a}
Creamy	0.59 ± 0.88^{a}	-0.32 ± 0.90^{c}	0.70 ± 1.02^{a}	-0.15 ± 0.89^{bc}	0.52 ± 0.71^{a}	0.24 ± 0.87^{ab}	-0.37 ± 0.90^{c}	-0.60 ± 0.91^{c}	-0.60 ± 0.86^{c}

Product abbreviations, see Table 1

Normalized mean values with different letters within a row differ significantly at $P < 0.05$

O odour, *F* flavour

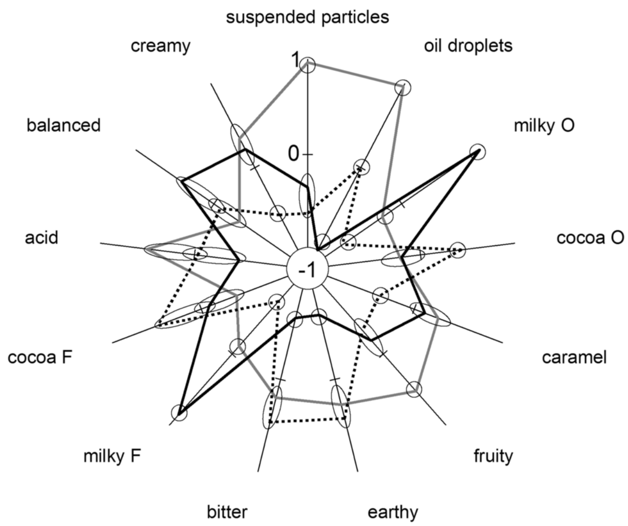

Fig. 1 Averaged sensory attribute intensity of the categories of hot chocolate drinks. Points on the axes within different circles differ significantly ($P<0.05$). Solid grey line: block chocolate dispersed in milk; solid black line: cocoa powder dispersed in milk; and dotted line: cocoa powder with powdered milk dispersed in water. *O* odour, *F* flavour

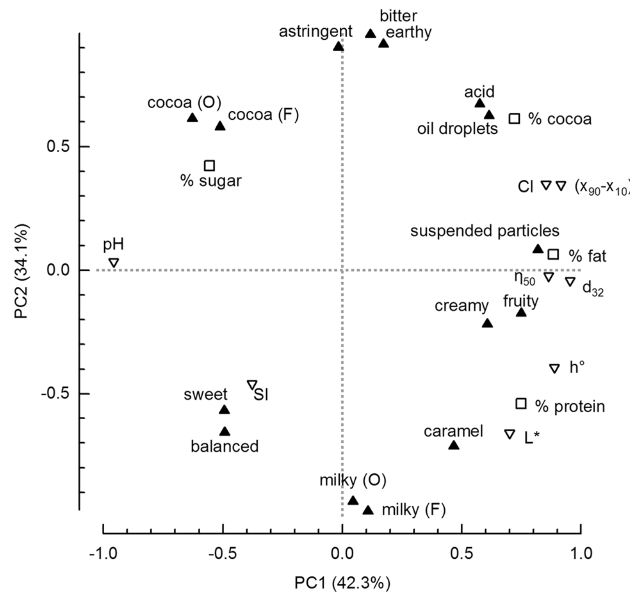

Fig. 2 PCA plot of sensory attributes (closed triangles), physical properties (open triangles), and averaged nutritional values (open squares) of hot chocolate drinks. *O* odour, *F* flavour

One reason for the cocoa-like characteristic of CPM drinks could be the incorporation of milk powder, which is not able to simulate milk as an emulsion. Drake et al. [21] and Osorio et al. [19] reported that reconstituted milk exhibited a lower intensity of milky odour and flavour than conventional milk, and as a consequence that cocoa-like odour and flavour are perceived more intensively [5, 19, 21]. Parat-Wilhelms et al. [22] found that a milky perception is determined by the casein content. Since the CPMs have a lower protein content (see Table 1) which correlates with the casein content, this also explains the lower milky perception. The darker appearance of the CPM drinks (see Table 3) may also have an influence on flavour perception. Despite the same ingredients, for example, lighter samples of milk-containing coffee beverages were perceived as milkier [22]. In contrast, CP drinks were less cocoa-like, earthy, bitter and acid than CPMs. The milky and caramel character supports the assumption of a negative correlation between cocoa and sweetness perception [5].

Correlation between physicochemical properties and sensory attributes

The relationship between sensory attributes, physical properties, and chemical parameters is shown in the PCA plot in Fig. 2. The first two PCs represent 76.4% of the variation. The first PC (42.3%) is negatively related to pH, and positively related to amount of suspended particles, creaminess and fruitiness, viscous and particle properties, and fat content of the chocolate drinks. PC2 (34.1%) is directly related to cocoa properties (cocoa-like, bitter, earthy, acid and astringent) and cocoa content, and inversely related to sugar and milk properties (sweet, milky, caramel and balanced), colour properties, and protein content. Once again, cocoa and milk properties appeared as opposites [5].

As can be seen from the product coordinates in Fig. 2, the viscous properties are directly linked to fat content and creaminess. Furthermore, they have higher creaming indices CI and more oil droplets on the hot chocolate drinks surface, and there is also a positive correlation to the properties of the suspended particles [$d_{3,2}$, $(x_{90}-x_{10})$]. According to Kristensen et al. [23], viscosity increases with increasing particle volume and smaller particle size. Since the declared cocoa content includes cocoa butter and cocoa powder, its correlation with viscous properties can also be explained by both the highest cocoa content and the highest fat content of the products under investigation.

The cocoa content also determines product pH and acidity, depending on whether cocoa powder or liquor is alkalized. Within the investigated products, BCs had the highest cocoa content and the lowest pH, showing that the cocoa liquor used is not alkalized, as opposed to the cocoa powder contained in CPs and CPMs [14]. The cocoa properties are inversely related to L^* which is determined by the milk and thus indirectly by the protein content. The milk-related sensory properties (milky, caramel, and sweet) are also inversely related to cocoa characteristics (cocoa-like, astringent, earthy, and bitter). It is also evident that SI is particularly strongly related to the milky properties. Folkenberg et al. (1999) reported a negative correlation between these two features. The reason for the differences could be that in this work also water-suspended powders were considered, which have lower SI and milk intensities than the milk-suspended instant powders.

Conclusions

From the investigation of physicochemical properties, it can be concluded that cocoa powders with powdered milk (CPMs) and block chocolates (BCs) show opposed characteristics while cocoa powders without powdered milk (CPs) are right between both. Concerning sensory attributes, CPMs are better described by cocoa properties (cocoa-like, earthy, bitter and astringent), BCs correlate more with the optical characteristics (suspended particles and oil droplets) as well as fruity flavour and acid taste, and CPs are better described by sugar and milk properties (sweet, milky, caramel and balanced). In CPMs, cocoa constituents are more intensively perceived due to an insufficient emulsion structure of the reconstituted milk. The fat content has the largest influence on beverage rheology; fat-rich samples have higher viscosity and creaming indices as well as more oil droplets on the surface, and appear creamier in texture. Cocoa and protein content are related to cocoa and milky perception, respectively. Chocolate drink protein content is also linked to colour; the products appear lighter with higher milk or protein content. This study also identifies relationships that allow the optimization of sensory properties through the targeted adaptation of formulation and physicochemical properties. Nevertheless, different preferences of consumers regarding consumption habits and sensory expectations should be considered when optimizing hot chocolate drinks.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Compliance with Ethics requirements The sensory evaluation was done with staff and students of the Chair of Food Engineering at the Technische Universität Dresden. All panellists were preliminary informed about the aim of the research and the nature of the samples. No personal data were collected or used in any forms.

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