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Crystallization and rheological properties of soya milk chocolate produced in a ball mill

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ABSTRACT

The aim of this paper is to define the optimal conditions for the pre-crystallization of chocolate produced in a ball mill, that contains 20% soya milk. Chocolate mass and soya milk are refined in a ball mill employing three refining times (30, 60 and 90 min) and pre-crystallization temperatures (26, 28 and 30 °C).

Increasing the refining time leads to organized chocolate systems with soya milk. The nucleation time of the system refined for 90 min and pre-crystallized at 30 °C is three times longer compared to that pre-crystallized at 26 °C. By prolonging the refining time, the system becomes dominantly viscous due to the refining and homogenization (tanδ > 1). Taking into consideration all three parameters, i.e., viscosity, yield stress and the area of the thixotropic loop, a refining time of 90 min at the pre-crystallization temperature of 30 °C seems optimal.

1. Introduction

Chocolate is a complex rheological system with solid particles (cocoa, milk powder and sugar) dispersed in cocoa butter which is the fat phase. The solid phase is non-uniform due to different distributions of particles by size, shape and surface properties (Beckett, 2008). Milling and conching of the chocolate mass are simultaneously performed in a ball mill. Depending on the milling time an optimal particle size distribution is obtained (Afoakwa et al., 2008a). A stable suspension of solid particles in cocoa butter is obtained mechanically, i.e., by prolonged mixing, grinding and a constant recirculation of the chocolate mass at a particular temperature (Prawira and Barringer, 2009). Stable chocolate mass is the one tempered before molding with the aim of forming crystal nuclei of cocoa butter in the stable crystal form V (Jovanović et al.,1998; Garti and Sato, 1988; Timms, 2003). Crystals formed in this manner enable adequate molding and solidification of chocolate, i.e., achieving the optimal physical and sensory properties (Popov-Raljić and Laličić-Petronijević, 2009).

Rheological measurements of the chocolate mass actually predict the mass behavior during processing as well as chocolate sensory properties, structural organization and interactions within the system. Chocolate mass exhibits non-Newtonian rheology, defined by plastic flow, and characterized by yield stress (Solstad, 1983). In addition, chocolate mass shows thixotropic and rheopectic properties (Pieper, 1986; Mezger, 2002). Increasing the shear rate leads to a gradual destruction of the structure caused by wit the bonds within packed sugar crystals and cocoa solids being broken. The area of the thixotropic loop is a measure of loss energy due to the bond breaking during shearing, as well as a measure of thixotropic changes within the system. If the area of the thixotropic loop equals zero, the system does not depend on time, i.e., it is merely pseudoplastic (Steffe, 1996).

Chocolate rheology is mainly defined by its ingredient composition, fat content, choice of emulsifier, processing conditions, temperature, solid particle size distribution and the method of particle packing (Briggs, 2003; Schantz et al., 2003; Schantz and Rohm, 2005; Bollinger et al., 1998).

Taylor and colleagues showed the importance of tightly packed particles and their reciprocal interaction in chocolate and synthetic chocolate, in which cocoa butter is replaced by soya oil while maintaining a similar solid particle distribution (Taylor et al., 2009). Their research also shows that the Carreau model, when compared to the Casson model, provides more detailed data about chocolate, especially if it has a high content of solid particles. In addition, they showed the significance of the influence emulsifiers have on a decrease of apparent viscosity. Schantz and Rohm (2005) more clearly showed the influence of the selection of emulsifiers in milk chocolate determining that the PGPR: lecithin ratio in dark

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chocolate is supposed to be 50:50, whereas in milk chocolate it should be 25:75.

Afoakwa et al., 2008b) proved that the increase of an average particle size results in a decrease of the Casson plastic viscosity, shear stress, yield stress and apparent viscosity. This reduction is more obvious at lower fat contents, while it is not registered in fat contents of 30% and more.

The composition of chocolate has a significant influence on its rheology. Sokmen and Gunes (2006) defined the effects of maltitol, isomalt and xylitol sweeteners on the rheological properties of chocolate by using the Bingham, Herschel-Bulkley and Casson model. The Herschel-Bulkley model proved to be the best for defining chocolate with a reduced energy content, and it also showed that while maltitol increases the yield stress, isomalt increases the plastic viscosity and xylitol increases the flow index. Farzanmehr and partners (Farzahnmehr and Abbasi, 2009) showed that sugar substitutes in chocolate recipes lead to a reduced hardness and an increased humidity. Furthermore, their recommendation is that a reduced energetic effect with undisturbed physicochemical and sensory properties is obtained by means of reducing fat by 5%.

The presence of soya proteins β-conglycinin and glycinin. β-conglycinin appears in seven polymorphic forms. Each polymorphic form is a trimer and consists of the same or a combination of different subunits (Renkema, 2001), which have two regions: stretched and central. β-conglycinin is inclined to the association and dissociation processes. Also, glycinin has 7 acid and 5 base polypeptide units, connected by disulphide bonds and hydrophobic interactions. Glycinin is a dimer of a quaternary structure. Both soya milk proteins, due to their complex structure, create intermolecular bonds which influence high elastic properties of chocolate. At higher temperatures and a neutral pH β-conglycinin and glycinin form gel (Maruyama et al., 2006).

In the process of chocolate making the solid particles are milled by different refiners in order to turn chocolate mixture into a uniform suspension with appropriate size distribution of solid particles. The milling process affects properties of chocolate mass like rheology, texture and sensory properties (Beckett, 2008).

The aim of this paper is to examine potentials for the production of chocolate with soya milk instead of dairy milk without affecting its physical or sensory properties. The chocolate is produced in the laboratory ball mill, so it is necessary to define the optimal refining time and chocolate pre-crystallization temperature.

2. Material and methods

2.1. Material

The raw materials used in the production of chocolate masses are the following: sugar (Crvenka AD, Serbia), cocoa butter (Theobroma, The Netherlands), cocoa mass (Cargill, Ghana), dairy milk powder (Imlek, Serbia), soya milk powder (Provesol PSA, Brazil), hazelnut paste (Arslanturk, Turkey), ethylvanillin (FCC, Norway), lecithin (Soyaprotein AD, Serbia), PGPR – polyglycerol polyricinoleat (Danisco, Malaysia).

The ingredients of the milk chocolate (experimental control) mass are: sugar 47.2%, dairy milk (fat 25%, protein 34%) powder 20.0%, cocoa butter 19.84%, cocoa mass 10.3%, hazelnut paste 2.1%, flavor 0.06%, lecithin 0.25%, PGPR 0.25%.

The ingredients of the soya milk chocolate mass are: sugar 47.2%, soya milk (fat 26%, protein 44%) powder 20.0%, cocoa butter 19.84%, cocoa mass 10.3%, hazelnut paste 2.1%, flavor 0.06%, lecithin 0.25%, PGPR 0.25%.

2.2. Methods

2.2.1. Preparation of the chocolate mass

The chocolate mass is produced in the laboratory ball mill with a homogenizer (capacity 5 kg). The raw materials necessary for the production of the chocolate mass are measured and simultaneously dosed into the homogenizer (except 10% of cocoa butter which is dosed 10 min before taking out the mass from the ball mill), in which mixing is done within the period of 20 min, at the temperature of 50 °C and a mixer rotation speed of 50 r/min. In order to refined homogenized chocolate mass, it was then transferred into the ball mill (ball diameter 9.1 mm; ball mass 30 kg; mixer rotation speed 50 rpm; mill inner diameter 0.250 m; height 0.31 m.; the volume of space provided for balls and 5 kg of chocolate mass is 0.0152 m^3).

The applied refining time in the mill is 30, 60 and 90 min on 50 °C.

2.2.2. Pre-crystallization of the chocolate mass

The pre-crystallization of the refined chocolate mass is performed in the laboratory precrystallizer – a modified Brabender farinograph. The process of pre-crystallization is controlled indirectly by the changes of the mass resistance on the occasion of mixing, which is registered on a force/time diagram – the thermorheogram. The Torque value is a criterion for the viscous behavior of the chocolate mass and is dependent on the crystallization extent of the mass in question (Pajin, 2009). The applied pre-crystallization temperatures are as follows: 26, 28 and 30 °C.

2.2.3. Rheological properties of the chocolate mass

The rheological properties were determined in a rotation viscosimeter RheoStress 600 HP, Haake, using the O.I.C.C. method at the temperature of 40 ± 0.1 °C (IOCCC, 2000).

The flow curves were determined using the method of the hysteresis loop within the shear rate interval of 1–60 s^{-1}. The shear rate was increased from 1–60 s^{-1} during a period of 240 s, then maintained at the maximum speed of 60 s^{-1} for 60 s, while the decrease of the shear rate of 60–1 s^{-1}also lasted for 240 s.

Dynamic oscillatory measurements were applied for determining the elastic modulus G′ and viscosity modulus G″. On the basis of the determined LVE range the measurement conditions were defined: ω (angular frequency) within the interval of 6.28 to 62.8 rad/s (frequency 1–10 Hz) under the constant shear stress of 5 Pa. The ratio between the viscous and elastic portions of a rheological system possessing viscoelastic properties is defined by the tanδ parameter (Pajin, 2009):

$$\tan\delta = G''/G'$$

The ideal elastic behavior is expressed as δ = 0° or tanδ = 0, for here G′ completely dominates G″. The ideal viscous behavior is expressed as δ = 90° or tanδ = ∞ because here G″ completely dominates G′. When the viscous and elastic behaviors are completely balanced (meaning G′ = G″), then tanδ = 1 or δ = 45°. The parameter tanδ is ideal for defining the transformation from the soluble state (sol) into gel (gel) (Schramm, 2000).

The *Creep and recovery test* is done in the LVE range where the deformation amplitude is proportional to the applied shear stress amplitude. A constant shear stress of 5 Pa was applied throughout the creep phase during the period of 150 s, while the recovery phase lasted for 450 s.

The creep curve is determined on the basis of the Burgers model, which can be defined by the following equations:$J(t) = J_o + J_m \cdot \{1 - \exp(-t/\lambda)\} + t/\eta_o$ for the creep phase$J(t) = J_{max} - J_o - J_m \cdot \{1 - \exp(-t/\lambda)\}$ for the recovery phasewhere: J_o, initial compliance J; J_{m}, viscoelastic value J; J_{max}, maximum value J in the creep