Original Research Article

Effect of conching process parameters on Casson viscosity of emulsifier-free milk chocolate

ABSTRACT

Milk chocolate is a type of chocolate composed of cocoa nibs, milk powder, sugar and cocoa butter. Generally, emulsifiers are commonly added to chocolates in order to modify their flow properties. Therefore, it is intriguing to explore the influence of conching process parameters on the viscosity of milk chocolate without emulsifiers. This paper aims to investigate the impact of various conching process parameters on the Casson viscosity of emulsifier-free milk chocolate. The effect of conching process parameters *viz.* conching temperature, conching time and rotation speed of the machine on the Casson viscosity of emulsifier-free milk chocolate was studied. The study was conducted at Food Processing Lab of KCAET, Tavanur, Kerala in the year 2022-2023. The Casson viscosity of the chocolate samples was determined using a controlled stress-strain rheometer. The results showed that Casson viscosity of emulsifier-free milk chocolate varied from 6.5 and 14.5 Pa·s. The study shows that Casson viscosity increased with decrease in conching temperature and conching time. Whereas increase in Casson viscosity was observed with increase in rotation speed of machine. The coefficient of determination (R^2) for the regression model was 0.97 shows the significant effect of conching process parameters on Casson viscosity of emulsifier-free milk chocolate.

Keywords: *Chocolate conching, emulsifier-free milk chocolate, Casson viscosity, rheological properties.*

1. INTRODUCTION

Milk chocolate is composed of a mixture of cocoa nibs, milk powder, and sugar that are dispersed within cocoa butter [1]. It is characterized by its smooth texture, creamy flavour and lighter colour compared to dark chocolate. Milk chocolate typically contains lower percentage of cocoa solids, ranging from 30-40% with the remained being sugar, milk powder and other ingredients. The addition of milk powder gives milk chocolate its distinctive creamy taste and contributes to softer and good mouth texture. The rheological properties of milk chocolate are influenced by both its formulation and the various processing steps involved [2]. These steps include mixing, pre-refining, refining, conching, and tempering, which collectively contribute to the production of milk chocolate [3]. Conching, in particular, plays a crucial role in shaping the final taste, aroma, and texture of the chocolate mass, while also allowing for the adjustment of rheological parameters. The quality parameters of chocolate viz. viscosity, texture and aroma highly depend on conching temperature, duration and shearing conditions [4],[5],[6].

The rheological properties of milk chocolate have a direct influence on its final mouthfeel and aroma perception, making them crucial factors in determining its overall quality. The conching process, by coating solid particles with the fat phase, affects the flow properties of the chocolate [7]. Additionally, the removal of water during conching leads to changes in the rheology of the chocolate mass, as the reduction in moisture content allows for a decrease in viscosity. This moisture removal is particularly significant since water tends to accumulate on the surface of sugar particles within the chocolate mass, influencing its rheological properties [7]. This paper aims to study the effect of conching process parameters on Casson viscosity of emulsifier-free milk chocolate.

2. MATERIALS AND METHODS

The formulation of chocolate consists of the following ingredients: sugar (41%), cocoa butter (21%), skimmed milk powder (21%), cocoa liquor (17%), and vanilla powder (0.005%). The milk chocolate samples were prepared using the developed conching cum tempering machine. Based on preliminary trials, three different conching temperatures (60, 70, 80 ^{0}C), conching times (11, 14, 17 h), and speeds of rotation (60, 75, 90 rpm) were selected as experimental parameters. The viscosity of the conched chocolate mix samples was determined for each treatment. The process was optimized using Design Expert software (version-13). Viscosity of chocolate was measured using a controlled strain–stress rheometer (MCR 52, Physica/Anton Paar) at a temperature of 40°C. Viscosity values were taken according to the International Confectionery Association (ICA) guidelines [8].

The melted chocolate sample was prepared following the procedure provided by ICA. The shear stress versus shear rate graph was generated using the Anton Paar RheoCompass software. The values obtained during the ramp up and ramp down stages were recorded and utilized for further analysis using the Casson model. The flow curves of chocolate, which exhibit non-Newtonian flow behavior and possess a yield stress, are commonly analyzed using the Casson model [9],[10],[11]. The Casson model is a widely recognized rheological model employed to describe the flow characteristics of fluids with a yield stress [12]. This model is particularly suitable for capturing the nonlinear, yield-stress-pseudoplastic nature exhibited by certain fluid products, such as chocolate. In the context of fitting flow data to the Casson model for chocolate, a more accurate fit can be achieved by considering an exponent value of 0.6 instead of the standard value of 0.5 [13]. The equation representing the Casson model is provided below:

$$\tau^{0.6} = \tau_0{}^{0.6} + \eta_{PL}{}^{0.6}\gamma^{0.6} \qquad \text{..... (1)}$$

Where τ is the shear stress in Pa, τ_0 is the yield stress, η_{PL} is the plastic viscosity and γ is the shear rate. The value of R^2 is determined to check the goodness of fit of the model.

The Casson plastic viscosity is considered for further studies. The viscosity values were entered into the Stat-Ease Design Expert software version-13 to get the response surface 3D graphs and ANOVA table. The results were discussed below.

3. RESULTS AND DISCUSSION

The shear stress vs shear rate and viscosity vs shear rate graph were obtained in the Anton Paar RheoCompass and it is shown in Fig. 1. A graph of viscosity vs shear rate is also shown in Fig. 2 to identify the behavior of milk chocolate. By considering the values obtained during experiment were fitted in Casson model, the Casson plastic viscosity values of different chocolate samples were obtained. These values used to obtain response surface graph (Fig. 3) as well as to get model equation.

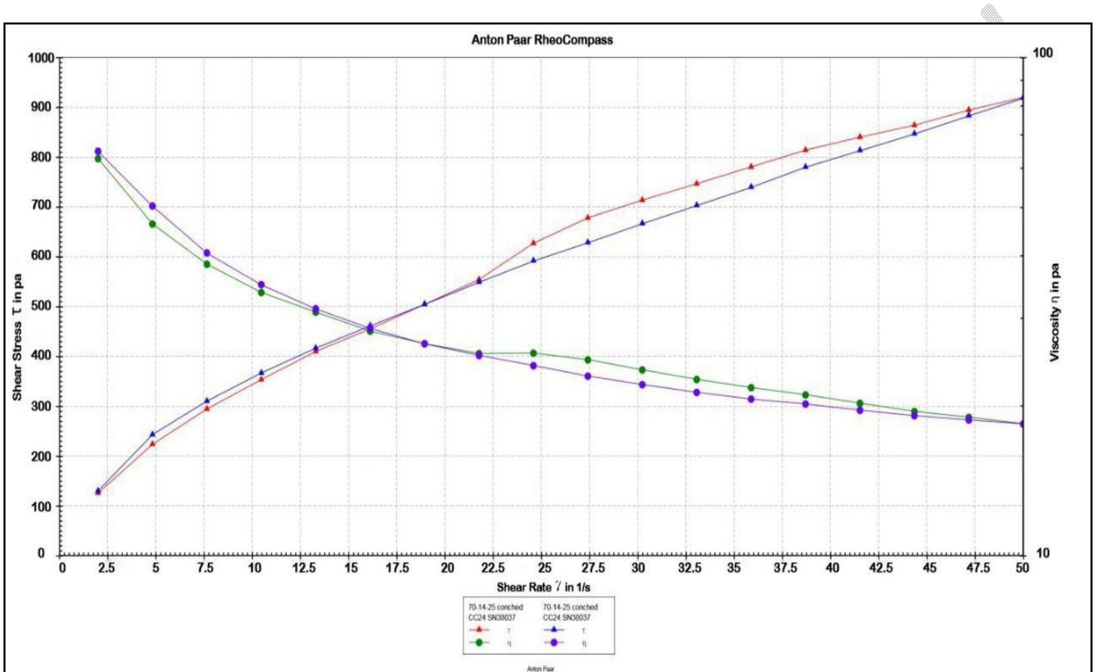

Fig. 1 Shear stress vs shear rate and viscosity vs shear rate of emulsifier-free milk chocolate conched at 70 ^{0}C for 14 hours at 75 rpm

Figure 2 illustrates the relationship between apparent viscosity and shear rate. The Casson viscosity values were range between 6.5 and 14.5 Pa·s. The graph clearly demonstrates that the apparent viscosity decreased with increase in shear rate, indicating the pseudoplastic or shear thinning nature of chocolate [14]. It is noteworthy that all chocolate samples exhibited similar shear thinning behavior.

The relationship between the process variables and the Casson viscosity were best fitted with second order quadratic model with the following equation:

$$\text{Casson Viscosity} = 11.41 - 2.71\,A - 1.08\,B + 0.1913\,C + 0.0500\,AB - 0.1250\,AC - 0.7925\,BC - 0.3158\,A^2 - 0.6483\,B^2 - 1.27\,C^2 \quad \ldots\ldots (2)$$

Where,

A = Conching temperature (^{0}C)

B = Conching time (h)

C = Speed of rotation (rpm)

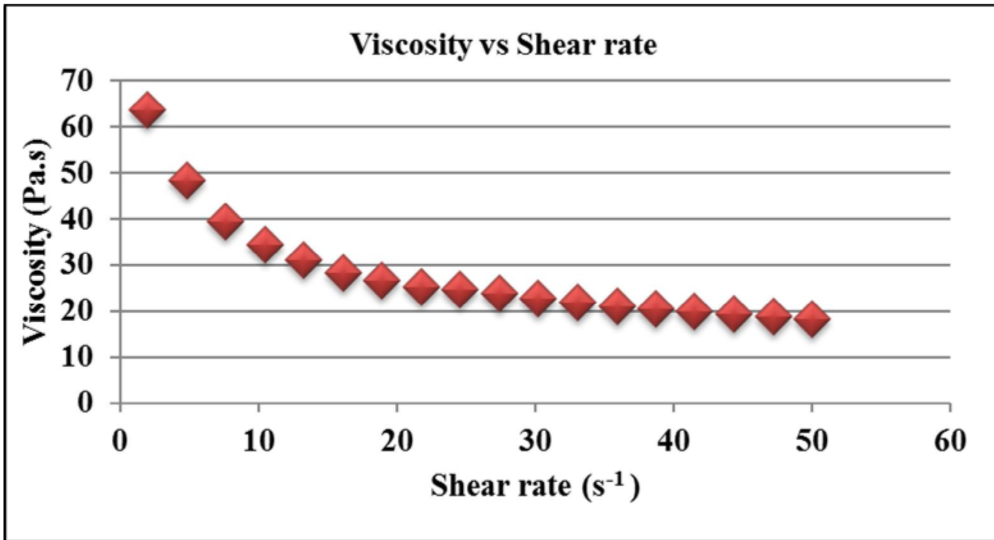

Fig. 2 Shear thinning behavior of emulsifier-free milk chocolate

The Fig. 3 displays effect of conching process parameters on Casson viscosity during conching process.

The analysis of variance (ANOVA) revealed that the process parameters, viz. conching temperature and conching time, exerted a highly significant effect ($P< 0.01$) on the Casson viscosity of the chocolate mix. However, the impact of the speed of rotation on Casson viscosity was found to be relatively less significant ($P>0.05$). Additionally, certain second-level interactions between the process parameters were determined to be significant. Notably, the third-level interactions among the process parameters exhibited a highly significant effect. The R-squared value of the model, which represents the proportion of the total variation in the response variable explained by the model, was calculated to be 0.97.

The Casson viscosity of the conched chocolate samples exhibited a range of 6.5 to 14.5 Pa.s under different process conditions. The minimum Casson viscosity of 6.5 Pa.s was observed at a conching temperature of 80^{0}C, conching time of 17 hours, and a speed of rotation of 75 rpm. On the other hand, the maximum Casson viscosity of 14.5 Pa.s was obtained at a conching temperature of 60^{0}C, conching time of 11 hours, and a speed of rotation of 75 rpm.

Figure 3 depicts the relationship between the Casson viscosity of the conched chocolate samples and variations in conching temperature (60-80^{0}C), conching time (11-17 h), and speed of rotations (60-90 rpm). The results revealed that an increase in conching temperature and conching time led to a decrease in the Casson viscosity, while the opposite effect was observed with speed of rotations. The decrease in Casson viscosity with an increase in conching time was observed [15]. Specifically, as the conching temperature rose from 60 to 80^{0}C, the Casson viscosity of the chocolate mix decreased from 14.5 to 6.5 Pa s. Comparable observations were obtained for dark chocolate mass during the conching process [16].

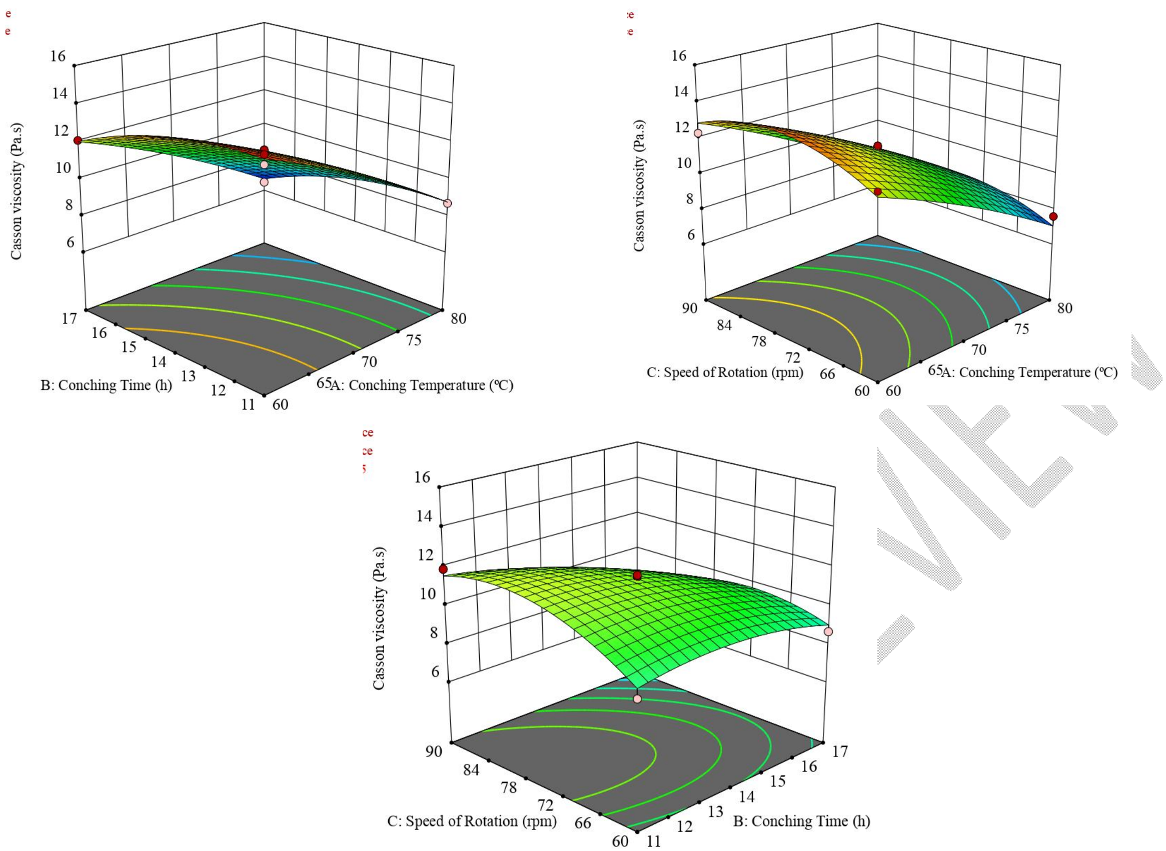

Fig. 3 Response Surface graphs of casson viscosity vs process parameters

The impact of lecithin-polyglycerol polyricinoleate (PGPR) blends on the rheological properties of milk chocolate was investigated [2]. The presence of lecithin in chocolate influences its viscosity, leading to lower viscosity values in comparison to lecithin-free chocolate. For instance, the milk chocolate without the addition of lecithin and PGPR, containing 31% fat content and 0.37 g moisture per 100 g chocolate, exhibited a Casson plastic viscosity of 12.3 Pa s.

The proportion of fat to particulates influences chocolate viscosity. As the cocoa butter content increases, the fat dilutes the particulates and the viscosity decreases. This is a result of the suspended particles gliding past one another with greater ease [17].

Milk chocolate without an emulsifier displayed a Casson plastic viscosity of 14.6 Pa s [18]. The proper coating of particles by fat in the chocolate mixture is dependent on the intensity of mixing in the conching machine. Any disturbance in the chocolate mass can impact its viscosity, including factors such as moisture content, temperature, and all stages of chocolate processing [19]. The values of Casson plastic viscosity were greater than milk chocolate with emulsifier, because lecithin causes dramatic reduction in Casson viscosity value [20]. Commercial lecithin contains a mixture of surface-active phosphatides, a phosphatidic hydrophobic group, and two esterified fatty acids attached to a glycerol molecule [21]. In chocolate, the polar head groups of lecithin molecules orient at the sucrose crystal surface, allowing for the two fatty acid chains to interact with the cocoa butter in the continuous phase [22].

4. CONCLUSION

The Casson viscosity values of emulsifier-free milk chocolate ranged from 6.5 to 14.5 Pa s. Statistical analysis revealed a significant effect of conching temperature and conching time on the Casson viscosity, while the effect of speed of rotation was found to be insignificant. These findings indicate that controlling the conching temperature and conching time can effectively influence the Casson viscosity of emulsifier-free milk chocolate.

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