Journal of Food Engineering 126 (2014) 120–125

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Prediction of firmness and physical stability of low-fat chocolate spreads

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ARTICLE INFO

Article history:
Received 25 June 2013
Received in revised form 29 October 2013
Accepted 31 October 2013
Available online 21 November 2013

Keywords:
Chocolate spread
Modelling
Fat reduction
Firmness
Physical stability

ABSTRACT

The research was addressed to develop mathematical predictive models to be applied in the formulation of low-fat chocolate spreads. To this purpose, fats (palm oil, palm kernel fat and their blends) and oils (sunflower oil and extra virgin olive oil) with different physical properties were considered. The effect of lipid type and content on spread firmness and physical stability was assessed by measuring mechanical properties and oil release. Results were described by opportune mathematical models defined by using best-fitting analysis. The effectiveness of the models was finally validated considering the formulation of a chocolate spread having defined firmness and physical stability. The developed mathematical tools could support the choice of the lipid nature and concentration allowing the preparation of chocolate spreads with tailored nutritional properties. In the attempt to reduce fat content, the minimum lipid concentration required to obtaining a homogeneous spread can be predicted by the developed mathematical models.

1. Introduction

One of the greatest public health challenges of the 21st century is the achievement of the reduction of total fat intake to improve wellbeing and reduce the health and economic burden of overweight, obesity and their clinical *sequelae* (Azais-Braesco et al., 2009). On this regard, health authorities and regulatory bodies in developed countries are at various stages of evaluating and executing policies to promote healthy eating habits with the long term aim of preventing or attenuating the incidence of health-related diseases. The challenge is to stimulate the consumers to select foods that fit into a healthy diet and to stimulate the food industry to produce healthier foods.

Food industries are thus required to develop novel low-fat products but also to provide the market with low-fat versions of already existing foods. The latter are expected to mimic the texture, flavour, taste and stability of their full-fat counterparts with little margin of difference (Devereux et al., 2003). Availability of ingredients with very specific properties helps the creation of low-fat foods (Omayma et al., 2007). However, the management of ingredient combination remains a challenge for manufacturers since the definition of successful formulas still requires a number of trials and errors. At present the transition from food concept to an acceptable, marketable prototype should be as fast as possible, generally shorter than 6–8 months. For this reason, traditional ways of product development by formula modification and control of the overall quality attributes are always less sustainable (Manzocco and Nicoli, 2002). They are too time consuming to meet market demand and fraught with risk which often may end in failure.

In the last decades, predictive tools have been applied to the acceleration of product and process development, with particular emphasis to microbial aspects (McMeekin et al., 1993; Wijtzes et al., 1998; McDonald and Sun, 1999; Membré and Lambert, 2008). In this case, mathematical models are developed to predict the responses of microorganisms to specified environmental variables. Further examples are the prediction of the dose–response relationships of functions attributable to foods or specific food components (Aggett, 2012). Such an approach has been also expanded to food formulation. In fact, the changes in the product properties can be estimated from composition data by using computer-aided predictive food design programs (Hu, 1999). Similarly, once the properties of the target product have been identified, predictive food design can be used to calculate its possible formula. When properly implemented, such an approach can be extended to any desired formulation whose properties are known.

Chocolate spreads are widely consumed delicious products. They are chocolate flavoured pastes that are eaten spread on bread but also used as bakery and biscuit fillings. They are required to taste as chocolate and not to solidify during storage at room temperature. This peculiar property is guaranteed by a considerable amount (i.e. higher than 40% w/w) of fats mixed with different dry ingredients. Based on a label survey of chocolate spreads available on the market, dry ingredients are mainly sugar and cocoa powder but also milk powder, hazelnuts and flavours. The lipid fraction of the spreads is generally represented by plastic fats with different ratio between solid and liquid phases. Due to availability

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http://dx.doi.org/10.1016/j.jfoodeng.2013.10.042

and low cost, palm derivatives, which may contain highly saturated fatty acids and are partially crystalline at room temperature, are among the most widely used (Shin et al., 2010; El-Hadad et al., 2011).

As the structure of chocolate spreads is strictly linked to the performance of the lipid fraction, their fat reduction is particularly challenging (Daubert et al., 1998). Since chocolate spreads are required to be physically compatible with low moisture foods, fat reduction cannot be pursued by increasing moisture. By contrast, low-fat chocolate spreads could be obtained by exploiting the plasticizing properties of lipids with different crystallization level. In particular, blends of palm oil derivatives as well as liquid oils could be used to modulate the fat content. It is a matter of fact that if the fat content decreases, the amount of dry ingredients in the paste increases. This would decrease both the fat and caloric content of the spreads but could deeply change their physical properties and stability. In order to accelerate the product development process, ensuring physical properties analogous to those of the conventional spread, a predictive approach to food design could be applied.

Based on these considerations, the research was addressed to develop mathematical models to formulate low-fat chocolate spreads according to a predictive food design approach. In particular, the research was divided in different steps. Initially fats and oils were selected on the basis of their physical properties and characterised. The effect of lipid content on spread firmness and physical stability was then studied and described by opportune mathematical models. Finally, the feasibility of the models was validated considering the formulation of a chocolate spread having defined firmness and physical stability.

2. Materials and methods

2.1. Materials

Refined, bleached and deodorized palm oil (PO) and palm kernel fat (PF) were kindly provided by Unigra (Conserile, Italy). Sunflower oil (SO), extra virgin olive oil (EVOO), powdered sugar and defatted cocoa powder were purchased in a local market.

2.2. Fat blends

Palm oil and palm kernel fat were mixed as reported in Table 1. Before mixing, PO and PF were heated at 60 °C until complete melting in a water bath. The appropriate masses for the blends (Table 1) were then weighed into a glass beaker, mixed with a magnetic stirrer, cooled at room temperature and stored at 20 °C for 24 h before analysis.

2.3. Chocolate spreads

Powdered sugar and defatted cocoa powder were premixed in the ratio 5:1 (w/w). Spreads were made keeping constant the ratio between the dry ingredients and adding increasing amounts of each lipid (SO, EVOO, PO, PF or fat blends) so that the final lipid content of the spreads ranged from 18 to 50% (w/w). For instance, the dry ingredient contents of a sample containing 40% (w/w) lipids were 50% (w/w) sugar and 10% (w/w) cocoa powder. About 50 different formulations were prepared. Ingredients were manual stirred with a spatula until a homogeneous paste-like spread was obtained. PF, PO and their blends (Table 1) were heated at 60 °C before addition to the dry ingredients. Chocolate spreads were then cooled at 20 °C before analysis.

Table 1
Fat blends composition.

Fat blend	PO (% w/w)	PF (% w/w)
PO70–PF30	70	30
PO60–PF40	60	40
PO50–PF50	50	50
PO15–PF85	15	85

2.4. Fatty acid composition

The fatty acid composition of samples was determined by capillary GC analysis after alkaline treatment in accordance to the European Official Methods of Analysis (1991).

2.5. Thermal behaviour measurements

Calorimetric analyses were made using a TA4000 differential scanning calorimeter (Mettler-Toledo, Greifensee, Swiss) connected to a GraphWare software TAT72.2/5 (Mettler-Toledo, Greifensee, Swiss). Heat flow calibration was achieved using indium (heat of fusion 28.45 J/g). Temperature calibration was carried out using hexane (m.p. 93.58 °C), water (m.p. 0.08 °C), and indium (m.p. 156.68 °C). 10–15 mg of sample was carefully weighed in 160 mL aluminium DSC pans and closed without hermetic sealing. An empty pan was used as a reference. Samples were heated under nitrogen flow (0.5 mL/min) at 60 °C for 10 min to destroy crystallization memory, cooled to −60 °C and then heated from −60 to 60 °C. The scanning rate was 2 °C/min. The start and the end of melting transition were taken as on-set (T_{on}) and off-set (T_{off}) points of transition, that are the points at which the extrapolated baseline intersects the extrapolated tangent of the calorimetric peak in the transition state. The machine equipment program STAR ever. 8.10 (Mettler-Toledo, Greifensee, Swiss) was used to plot and analyse the thermal data.

2.6. Polarised light microscopy measurements

The microstructure of the lipid mixtures *was evaluated* by sandwiching one drop of the mixtures between a slide and a cover slip. The samples *were* imaged at 200X objective using a Leica DM2000 (Leica Micro-systems Canada Inc., Richmond Hill, Canada). Images were acquired with a digital camera connected with the microscope.

2.7. Firmness

Firmness was measured by a puncture test using an Instron 4301 (Instron Ltd. High Wycombe, UK). The instrumental settings and operations were accomplished using the software Automated Materials Testing System (version 5, Series IX, Instron Ltd., High Wycombe, UK). A uniaxial compression test was performed using an Instron Universal Testing Machine (mod. 4301, UK) at ambient conditions (20 ± 2 °C, ambient humidity). The samples were poured in 20 mm diameter cups and tested by using a 6.2 mm diameter cylinder mounted on a 100 N compression head. Crosshead speed was set at 25 mm/min and samples were penetrated for 5 mm. Force-distance curves were obtained from the puncture tests and firmness was taken as the force (N) required to puncture the sample.

2.8. Oil release

The oil release was measured following the methodology described by Da Pieve et al. (2010). One gram of each sample was carefully weighted in a tube and centrifuged at 10,000 rpm for 15 min at 20 °C using a microcentrifuge (Mikro 120, Hettich