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DEVELOPMENT OF SOLID FAT CONTENT-BASED PREDICTIVE MODEL FOR MARGARINE FORMULA DESIGN

JIAJIA GONG[1]; NANXI SHU[1]; XIAN SUN[1]; XINYU CAO[1]; YUANFA LIU[1] and YONG-JIANG XU[1*]

ABSTRACT

The curve of solid fat content (SFC) is a fundamental but significant physical characteristic of fat, which markedly affects the texture and sense of food. A bivariate Gompertz model with temperature and saturated fatty acids (SFAs) as variables was used in this study to fit the SFC curve of enzymatically interesterified vegetable oil from palm olein (PO) and palm stearin (ST), to determine the ideal proportion of plant-based fat substrate. The fitting result (R^2 = 0.99) showed that this model had respectable predictive power. When the PO/ST ratio was 83:17, the SFC curve of the prepared plant-based margarine was close to that of butter, as calculated using the acquired SFC curve fitting formula. Bread characteristics and sensory analysis showed that the acceptance level of the bread made with this formulation was similar to that of natural animal fats. The results demonstrated that using the Gompertz function to build a simulated fit of SFC curves for enzymatically interesterified fat blends is a beneficial tool for optimising margarine formulation.

Keywords: bread, enzymatic interesterification, plant-based margarine, solid fat content.

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INTRODUCTION

In recent years, to meet the needs of mass consumers while reducing production costs (Silva *et al.*, 2021; Sabate *et al.*, 2014), plant-based margarine that substitutes animal fats has gradually become a hot research topic in the food industry (Aini *et al.*, 2007; Collier *et al.*, 2022; Patel *et al.*, 2020; Zhang *et al.*, 2019). Changes in the chemical composition of margarine naturally lead to changes in its physical properties (Doan *et al.*, 2018; Li *et al.*, 2022; Zhang *et al.*, 2004). Physical characteristics, especially the solid fat content (SFC) (Dollah *et al.*, 2016; Engelen *et al.*, 2008), determine many of the fundamental characteristics of margarines, including their general appearance, ease of packaging, spread ability (Zhou *et al.*, 2021), grease exudation, and sensory properties (Soares *et al.*, 2012). The use of SFC to characterise margarine is the most practical way for selecting margarine fat feedstocks (Zhang *et al.*, 2014). Meanwhile, the measurement of SFC is relatively quick and simple (Nelis *et al.*, 2021; Reiner *et al.*, 2018), making the process easy to monitor.

The SFC curve generally describes the variations in the consistency and plasticity of food at different temperatures (Naeli *et al.*, 2018; Saghafi *et al.*, 2019). The most important factors that affect the SFC curve are fat composition (TAG and fatty acid profile), fat storage temperature and polymorphic crystal morphology (Schmid *et al.*, 2020). Saberi *et al.* (2012) developed a hybrid formula in which a high proportion of diacylglycerol oil was incorporated into plastic fat as a functional oil to substitute full-fat products. To calculate the SFC curve of mixed fat, Dos *et al.* (2013; 2014) merged the solid-liquid equilibrium model with the direct minimisation approach of the Gibbs free energy function. However, the above method requires a large amount of input data, and the steps are tedious. And by comparing three different S-shaped function

[1] State Key Laboratory of Food Science and Technology, School of Food Science and Technology, National Engineering Research Center for Functional Food, National Engineering Laboratory for Cereal Fermentation Technology, Collaborative Innovation Center of Food Safety and Quality Control in Jiangsu Province, Jiangnan University, 1800 Lihu Road, Wuxi, 214122, Jiangsu, China

* *Corresponding author e-mail: yjxutju@gmail.com*

models (Gompertz model, power decay model and logistic model), Augusto *et al.* (2012) discovered that the Gompertz model can better characterise changes in the SFC curve. Later, Farmani (2015) expanded on these findings by presenting a two-variable Gompertz model that describes SFC as a simultaneous function of both temperature and saturated fatty acid content. Since this method is relatively fast and reliable, the Gompertz model was also used to forecast the kinetics of mould growth (Wawrzyniak, 2021) and the texture and colour development of chicken breast meat during thermal processing (Rabeler *et al.*, 2018).

To satisfy the specific performance requirements of plant-based margarine, oil products with varying physical and chemical properties are frequently modified by hydrogenation (Pimentel *et al.*, 2003; Zhu *et al.*, 2020), separation and transesterification in the food industry (Alan *et al.*, 2019; Sivakanthan *et al.*, 2019). Palm oil is generated in huge amounts at affordable prices from a steady source, is high in vitamin A and E, has strong oxidative stability, and is suitable for high-temperature baked products processing. In addition, palm oil fractionated products have similar textural characteristics and fatty acid composition to butter, are solid at room temperature, and have the same β′ crystalline behaviour as butter and can be used as a first choice for margarine manufacture. We use palm stearin (ST) and palm oil (PO) as feedstock oil for the enzymatic interesterification. The main goal of this work is to use the Gompertz fitting model to express the SFC curve of binary esterified fats in relation to temperature and saturated fatty acid (SFA) content. The emphasis is on finding the ratio of plant-based margarine formulation that is similar to the change in SFC of the target butter by constructing a simulation. This plant-based margarine formulation was applied to a bread system to compare with the textural and organoleptic properties of bread made with traditional animal fats. The model suggested in this research may be used to forecast and design the SFC of esterified fats, and this method has the potential to boost formulation development efficiently, minimise product development cost and time.

MATERIAL AND METHODS

Materials

Samples of commercially acceptable margarine were purchased from a local store in Wuxi. Beef tallow (BT) was purchased from Muge Co., Ltd. (Chongqing, China). Refined, bleached, and deodourised ST and PO were provided by Kerry Specialty Oils Co., Ltd. (Shanghai, China). The oils and fats were stored at room temperature in a dark place until use. The immobilised lipase Lipozyme 435 was donated by Novozymes (Bagsvaerd, Denmark). Supelco 37 Component FAME Mix was purchased from Sigma–Aldrich China (Shanghai, China). All other reagents and solvents used were of analytical or chromatographic grade from local suppliers.

Preparation of Enzymatic Interesterification

Before interesterification, ST and PO were melted by heating. Blends of ST and PO (12.5%, 25.0%, 37.5%, 50.0%, 62.5%, 75.0%, 87.5%, ST w/w) were interesterified using Lipozyme 435 (4.0%, w/w) by heating and magnetic stirring with agitation of 400 rpm at 90°C for 4 hr. At the end of the reaction, the immobilised enzyme was immediately removed by centrifugation to obtain an interesterified oil sample (Pang *et al.*, 2019).

Determination of SFC

The SFC of all samples was performed by using PQ001-20–010 V low-resolution pulsed nuclear magnetic resonance (pNMR) (Niumag Instruments, Suzhou, China). The pNMR tubes (diameter = 10 mm) were filled with 2.5 mL of the samples. Approximately 2.5 mL of each sample in the NMR tube was first kept at 90°C to melt for 30 min. The NMR tubes were rapidly placed in a DC-0506 constant low temperature bath (Sunny Hengping Scientific Instrument, Shanghai, China) and maintained at 0°C, for 90 min. The temperature rose from 5°C to 60°C, and the SFC was measured at every increment of 5°C, with each temperature maintained for 30 min before measurement (Li *et al.*, 2018).

Determination of SFA Content

Gas chromatography (Nexis GC2030, Shimadzu, Japan) was used to assess the fatty acid compositions of the samples, which included an autoinjector (AOC-20i Plus, Shimadzu, Japan), a flame ionisation detector and a capillary column (60 m × 0.25 mm × 0.25 µm, Thermo Fisher Scientific, Waltham, MA, USA). Fatty acid determination was carried out using the method of Ye *et al.* (2019) with slight improvement. 2-3 drops of the samples were mixed successively with KOH-CH_3OH (0.5 M, 2 mL), incubated for 30 min with shaking at 65°C for saponification, and BF_3-CH_3OH (1:3, v/v, 2 mL) and then incubated for 10 min at 70°C for the methyl esterification reaction. After cooling to room temperature, the fatty acid methyl ester was extracted with 2 mL of chromatographic grade n-hexane, and the supernatant was transferred to a 2 mL centrifuge tube by vigorous shaking for 3-4 min, and a small amount of water was sucked up by adding anhydrous Na_2SO_4, before being passed through a 0.22 μm organic filtration membrane into a 2 mL injection vial for gas chromatographic analysis.

Gas chromatography conditions; the whole procedure took 42 min, the column was first retained at 130°C for 3 min, then warmed up to 200°C and retained for 10 min within 14 min; then warmed up to 220°C and retained for 5 min within 10 min; the flow rate of the constant carrier gas (nitrogen) was set at 1.8 mL/min; the split ratio was 20; and the injection volume was 1 μL. Fatty acid characterisation and relative quantification using 52 fatty acid methyl ester mixed standards.

Modelling and Statistical Analyses

Temperature and SFA were the most influential factors and were chosen as independent variables for modelling the SFC curves (Farmani, 2015). The sigmoidal Gompertz function was used to simulate the SFC of enzymatically interesterified ST/PO blends [Equation (1)] by SigmaPlot 14.0 (Systat Software Inc., USA).

$$Y = \alpha^{e-e^{-\left(\frac{X-c}{b}\right)}} \qquad (1)$$

SigmaPlot 14.0 was used to assess the goodness-of-fit of the models, which included the correlation coefficient (r), determination coefficient (R^2) and standard error of estimate (SE) between the experimental and predicted values.

Baking Application

Bread making. The breadmaking process undergoes two-steps alcoholic fermentation using the ingredients mentioned in *Table 1*. All the materials, condensed milk and lipid matrix except egg, were placed in an electric mixer (Shuangmai Bakery Equipment Co., Ltd, Wuxi, China) and mixed into a smooth dough. The dough was removed from the machine and fermented at a temperature of 40°C and a humidity level of 90% for 30 min. The dough was then enriched with egg, condensed milk and lipid matrix. The stirring process was continued until the dough was formed. After that, the dough was divided into small pieces and kneaded into a spherical form, with each piece weighing 50 g. Similarly, these doughs were fermented before being cooked in a preheated oven (Shuangmai Bakery Equipment Co., Ltd, Wuxi, China) at 180°C for 15 min. The bread samples were cooled at room temperature before placing into sample bags and stored at 25°C until analysis.

Bread characteristics. The baking loss, specific volume and texture properties of bread were measured. Baking loss is defined as the ratio of quality loss to dough weight before and after baking. The specific volume of bread was calculated from the ratio of weight to volume measured by the millet displacement. Texture properties were measured by TA-XTPlus (Stable Microsystems, Surrey, UK). Test conditions included probe type P/36R, a 25% compression ratio, a pre-test speed of 2.0 mm/s, a test speed of 1.0 mm/s, and a post-test speed of 2.0 mm/s.

Sensory analysis. The evaluation group was made up of seven female and 13 male assessors, all of whom were from the Department of Food Science and Technology at Jiangnan University. They were asked to evaluate the shape, colour, smell, taste and texture of the bread with a 5-hedonic scale from 1 to 5 (dislike very to like exceedingly). Every assessor received instruction on how to provide a grade for each sensory prosperity.

Statistical Analysis

Each experiment was carried out in triplicate. Statistical analysis was performed by SigmaPlot 14.0 and SPSS 16.0 (SPSS, Inc., Chicago, IL, USA). The data are expressed as the mean ± standard deviation (SD). The significant differences among samples were considered at a level of 5% ($P < 0.05$).

TABLE 1. THE INGREDIENTS OF BREADS MADE WITH DIFFERENT FATS

Ingredients	Weight (g)	Source
High-gluten bread flour	300	Commercial
Water	120	Commercial
Yeast	3	Commercial
Bread improver	0.9	Commercial
Salt	3	Commercial
Sugar	42	Commercial
Whole egg	50	Commercial
Condensed milk	25	Commercial
Butter, beef tallow or plant-based margarine	30	Commercial or EIE st/po blend

RESULTS AND DISCUSSION

SFC and SFA Content

In general, the two most important factors affecting SFC are the temperature during measurement and the composition of fat (Haupler *et al.*, 2014). The results of the SFC and SFA content of the fat samples obtained before and after enzymatic esterification at different ratios of PO and ST are shown in *Table 2*. The SFC curve for each oil sample has an S-shape that degrades with rising temperature. The high content of SFA in ST gives it a wider plasticity range than PO, whose SFC only drops to 0 when the temperature rises to 60°C, whereas PO is no longer present as a solid at 30°C. Accordingly, the SFA and SFC steadily rise as the ST content in the blends increased. When the ST content is lower than 50%, the plastic range of the SFC curve of the initial binary blend is lower than that after enzymatic interesterification. After enzymatic interesterification, the SFCs of binary blends of PO and ST are greater than 20% when the temperature is 25°C. The enhanced flexibility of the binary blends after the transesterification reaction when compared to single components or the initial binary blend demonstrates its bread processing potential. Puffing performance in bread applications is best achieved at processing temperatures of 15% to 25% SFC, with SFC values too low resulting in an oily feel and lower sensory attribute scores. The SFC of butter should be more than 10% at 20°C -25°C, while that of bakery shortening should be more than 20% at 25°C (Aini and Miskandar, 2007). Therefore, the enzymatically interesterified binary blends of PO and ST can be used as a potential substitute for butter or bakery shortening in bread recipes.

Modelling of SFC of Enzymatic Interesterification

Modelling of a single factor (temperature or SFA). Taking temperature and SFA as independent variables and SFC as dependent variables, the SFC curves were depicted using the sigmoidal Gompertz model [Equation (2) and (3)].

$$SFC = ae^{-e^{-(\frac{T-c}{b})}} \tag{2}$$

$$SFC = ae^{-e^{-(\frac{SFA-c}{b})}} \tag{3}$$

The Gompertz fit curves for the enzymatically interesterified binary blends temperature ($SFC_{f(T)}$) model and the SFA content ($SFC_{f(SFA)}$) model are presented in *Figure 1*. The coefficients a, b and c were calculated for each enzymatically interesterified fat using sigma plot software. The results of the fits are shown in *Table 3*. For the $SFC_{f(T)}$ model, α values ranged between 59 and 94, b ranged between -15 and -5, and c ranged between 17 and 27. The values of α, b, and c for the $SFC_{f(SFA)}$ model ranged from 97 to 177, 12 to 22, and 45 to 74 respectively. Both models displayed high determination coefficients (R^2 >0.96), where r and R^2 of the $SFC_{f(T)}$ model were both as high as 0.99. The results showed that both models adequately captured the experimental data, and that the Gompertz function could be used to simulate how temperature or SFA content would affect SFC.

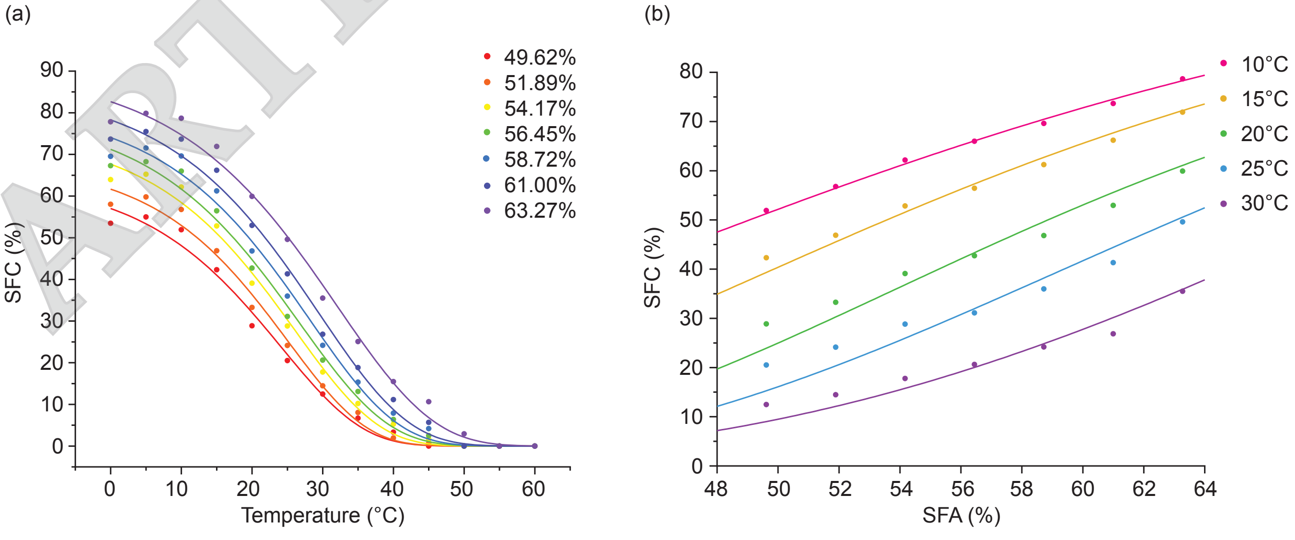

Figure 1. Gompertz fitting curves for the solid fat content (SFC) curves of interesterified binary blends as a function of temperature ($SFC_{f(T)}$) (A) and saturated fatty acids (SFA)($SFC_{f(SFA)}$) (B). The dashed dots reflect the experimental results, and the lines show the corresponding fitting results.

TABLE 2. SOLID FAT CONTENT (SFC) AND SATURATED FATTY ACID (SFA) CONTENT OF ST/PO MIXTURES BEFORE (NIE) AND AFTER (EIE) ENZYMATIC TRANSESTERIFICATION AND SFC AND SFA CONTENT OF BUTTER

Samples	SFC (%)													Fatty acid composition (%)
	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C	45°C	50°C	55°C	60°C	SFA
0%[a]	55.0420	55.7366	45.1330	29.8808	11.3472	2.3508	0	0	0	0	0	0	0	47.34
12.5%[a]-NIE	61.6182	59.6689	48.4927	31.6786	17.4298	8.1464	0	0	0	0	0	0	0	49.62
12.5%[a]-EIE	53.4623	54.9795	51.9072	42.3090	28.8541	20.5037	12.4815	6.6877	3.3256	0	0	0	0	
25%[a]-NIE	65.0612	62.7384	54.8077	40.1981	25.9753	14.9924	3.2108	0	0	0	0	0	0	51.89
25%[a]-EIE	58.0329	59.8008	56.7847	46.8778	33.2569	24.1364	14.4646	8.0420	1.9497	0.6554	0	0	0	
37.5%[a]-NIE	67.9192	68.3934	60.6487	48.3791	34.6678	22.9779	9.4978	3.6729	0	0	0	0	0	54.17
37.5%[a]-EIE	63.9534	65.2303	62.1730	52.8297	39.0881	28.8184	17.7611	10.2172	5.2344	1.6182	0	0	0	
50%[a]-NIE	70.9692	71.3754	65.9377	55.1881	42.4448	30.1224	14.8853	7.7484	1.8758	0	0	0	0	56.45
50%[a]-EIE	67.2877	68.2418	65.9830	56.4444	42.7235	31.1107	20.6115	13.0862	6.3578	2.4988	0	0	0	
62.5%[a]-NIE	73.4672	74.6189	70.6447	61.8331	49.6828	37.8554	21.8983	13.6479	7.8638	4.3805	0.4054	0	0	58.72
62.5%[a]-EIE	69.5310	71.5462	69.6177	61.2337	46.8144	35.9789	24.1676	15.3244	7.8951	4.1770	0	0	0	
75%[a]-NIE	74.5712	77.8024	74.5557	67.9036	56.6178	44.9584	28.6208	20.4564	13.1008	8.7705	1.5369	0	0	61.00
75%[a]-EIE	73.6653	75.4786	73.6607	66.1881	52.9546	41.3178	26.8380	18.8330	11.1397	5.6702	0	0	0	
87.5%[a]-NIE	77.0707	79.9744	77.4587	72.1281	62.1258	51.3334	35.7878	27.4069	17.4293	12.8375	5.5579	0.137	0	63.27
87.5%[a]-EIE	77.8422	79.8660	78.6748	71.9053	59.9188	49.5963	35.5045	25.0776	15.4596	10.6471	2.9149	0	0	
100%[a]	80.8897	83.3384	82.1692	78.0216	69.2908	59.2899	43.7033	34.2419	24.7788	18.471	8.8189	0.5629	0	65.55
Butter	55.5229	55.5853	51.0080	42.1736	30.1547	22.7078	13.4762	8.96634	4.0529	0.9761	0	0	0	57.95

Note: [a] - ratio of ST in the binary blends.

TABLE 3. COEFFICIENTS OF THE SOLID FAT CONTENT (SFC) UNIVARIATE MODEL AND EVALUATION OF THE FITNESS OF MODELS

Models	α	b	c	r	R^2	SEE	p
$SFC_{f(T)}$							
47.34%	59.3259	-5.4818	17.2319	0.9991	0.9981	1.0753	<0.0001
49.62%	64.5227	-11.5390	24.1335	0.9957	0.9915	2.2698	<0.0001
51.89%	68.4122	-11.0720	25.0779	0.9967	0.9933	2.1944	<0.0001
54.17%	75.5154	-11.8076	26.0748	0.9971	0.9942	2.2340	<0.0001
56.45%	80.0798	-12.4763	26.7522	0.9968	0.9936	2.4483	0.0033
58.72%	81.9388	-12.3317	28.2465	0.9965	0.9930	2.6843	0.0033
61.00%	86.2383	-12.6469	29.5222	0.9965	0.9930	2.8328	0.0113
63.27%	90.6925	-13.5145	32.1371	0.9968	0.9936	2.8130	0.0464
65.55%	93.3588	-14.4349	36.0946	0.9957	0.9915	3.2774	0.2524
$SFC_{f(SFA)}$							
10°C	110.5578	17.0671	45.1177	0.9985	0.9971	0.7744	0.9129
15°C	104.1395	13.9546	49.2469	0.9915	0.9832	2.2676	0.2852
20°C	97.6734	12.4474	53.8619	0.9768	0.9541	4.2866	0.1863
25°C	107.0722	14.3258	59.1611	0.9664	0.9340	4.9609	0.0301
30°C	176.8545	21.8828	73.4819	0.9701	0.9410	3.6193	0.0361

Modelling of two factors (temperature and SFA together). The two models mentioned above can be used to forecast the SFC value of enzymatically interesterified fat at a prescriptive temperature or SFA content, but they are unable to explain the shared impact of these two variables on SFC. Consequently, to account for the combined influence of temperature and saturated fatty acid content on SFC, a bivariate Gompertz model was built. The coefficient of the univariate Gompertz model was expressed as the function of another variable to include both temperature and SFA in the model. In this way, the bivariate model was obtained by substituting the coefficients with the corresponding function. Based on this, Farmani (2015) developed a bivariate Gompertz model using temperature and SFA as variables. This model was used to predict the SFC of chemically interesterified blended oil with a correlation coefficient of 0.98 and an MAE of 1.02%. The fitting results (*Figure 2* and *Table 4*) were determined by evaluating the correlations (the coefficients of $SFC_{f(SFA)}$ Gompertz models and temperature, the coefficients of the $SFC_{f(T)}$ Gompertz models and SFA content). As can be observed from the results, there was a higher linear correlation between the coefficients α and c of $SFC_{f(T)}$ Gompertz models and SFA content, with $R^2 > 0.95$, indicating that the temperature model coefficient α and c can be accurately expressed by SFA. Therefore, it was preferable to replace the coefficients α and c of Equation (2) with the mathematical expressions [Equation (4); (5)].

$$\alpha_{(T)} = \beta_1 + \beta_2 \times SFA \tag{4}$$

$$c_{(T)} = \beta'_1 + \beta'_2 \times SFA \tag{5}$$

Then, the final SFC model that was expressed as a function of two variables, temperature and SFA, was attained:

$$SFC = (\beta_1 + \beta_2 \times SFA)\, e^{-e^{-\left(\frac{T - (\beta'_1 + \beta'_2 \times SFA)}{b}\right)}} \tag{6}$$

The coefficients of the final model were calculated by Sigmaplot (*Figure 3*).

$$SFC = (-3.8915 + 1.4657 \times SFA)e^{-e^{-\left(\frac{T-(-8.7518+0.632\times SFA)}{-12.4418}\right)}} \tag{7}$$

$$R^2 = 0.9908$$

This result indicated that the model could accurately predict the SFC curves of ST and PO enzymatically interesterified lipids. This model can be used to calculate the formulations of plant-based margarine.

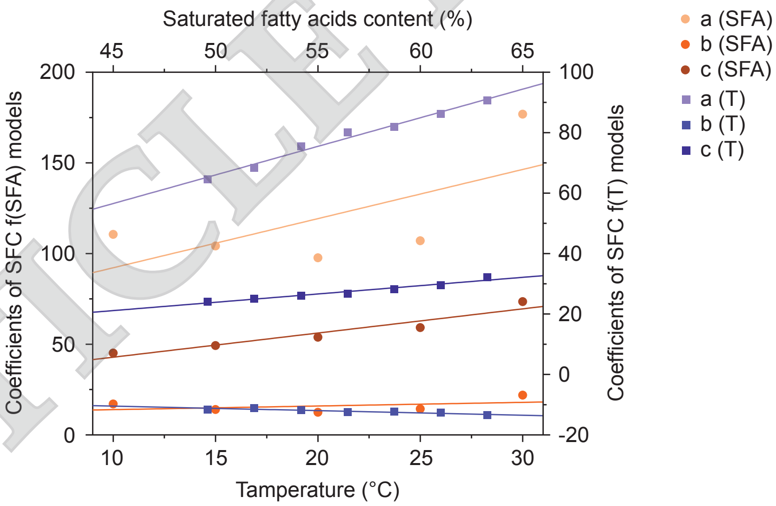

Figure 2. Correlation between each coefficient of solid fat content (SFC) univariate model and another factor. Markers are the experimental values; solid lines show linear regressions.

TABLE 4. EVALUATION OF FITNESS BETWEEN COEFFICIENTS OF SOLID FAT CONTENT $(SFC)_{F(T)}$ MODELS AND SATURATED FATTY ACIDS (SFA) CONTENT AND BETWEEN COEFFICIENTS OF $SFC_{F(SFA)}$ MODELS AND TEMPERATURE

	Function	R^2
f [a (SFA), T]	y = 65.0490 + 2.7105X	0.4336
f [b (SFA), T]	y = 11.9345 + 0.2001X	0.1808
f [c (SFA), T]	y = 29.5169 + 1.3329X	0.9175
f [a (T), SFA]	y = -28.5925 + 1.8920X	0.9831
f [b (T), SFA]	y = -3.6960 - 0.1506X	0.8474
f [c (T), SFA]	y = -3.6391 + 0.5503X	0.9571

The SFC of butter at 25°C was 22.7078% (*Table 2*), and this value was used as the objective. T = 25, and SFC = 22.7078 were substituted into Equation (7), in order to determine the SFA content of plant-based margarine which was 50.4698. Therefore, the final formulation of margarine was 83% PO + 17% ST (w/w), whose SFA was equal to the calculated result. The above formulation was used to make the plant-based margarine sample, and as a verification, the SFC was measured and compared to commercial butter. The results are displayed in *Figure 4*. It can be seen that the 83% PO+17% ST enzymatically interesterified binary blend fitted by this Gompertz model can simulate the SFC curve of commercial butter excellently. At 20°C, the SFC values of both fats and oils were greater than 10%, demonstrating that they could retain a suitable consistency without oil precipitation. Additionally, both fats and oils had SFC values at 40°C that were less than 10%, indicating that they would completely melt in the mouth and not provide a particle sensation. Thus, plant-based margarine has a wide plasticity range similar to butter and an ideal SFC profile for use in bread.

It was evident that the SFC of the interesterified blends can be accurately predicted by the Gompertz model. This method proved to be more beneficial than modelling and optimising reaction conditions based on the response surface method. It helps to

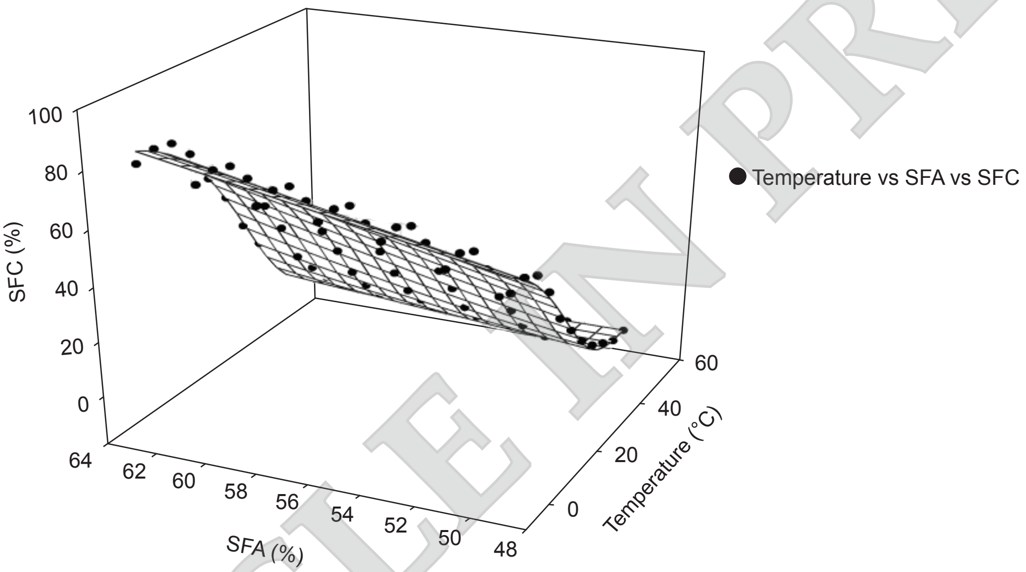

Figure 3. The model of solid fat content (SFC) as a function of temperature and saturated fatty acids (SFA).

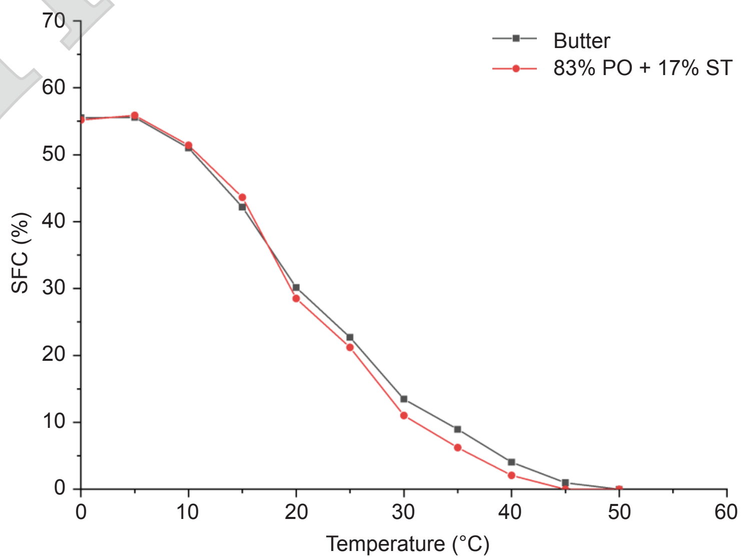

Figure 4. Solid fat content (SFC) of commercial butter and enzymatically interesterified blend.

preselect suitable plant oil raw materials to reproduce the SFC curves that were aimed at replacing animal fat and can effectively reduce the cost and time of new product development.

Application of Plant-based Margarine

In the baking field, fats are often used for shortening, and they can also soften gluten, prevent moisture loss, boost lustre and slow bread ageing, so they are also often used in bread making to improve the quality of bread (Patil *et al.*, 2019). Compared with liquid vegetable oil, adding solid oil can enhance the extensibility and plasticity of the dough hence making the bread more delicate, soft and delicious. Shortening (refined animal fats or hydrogenated vegetable oils and their mixtures) and butter are common fats used in traditional baking. Therefore, in this study we compared bread made from typical animal fats (butter and beef tallow) together with plant-based margarine. As shown in *Figure 5*, the bread with plant-based enzymatically interesterified fat shows a similar appearance to traditional breads with animal fats. All of the loaves also exhibit good shape and fermentation structure. *Table 5* lists the fundamental characteristics of bread, including specific volume, baking loss, and texture properties. The bread prepared from beef tallow was relatively the softest 519.53 g and had the highest specific volume (2.66 mL/g). It is possible that the higher SFC and SFA content of beef tallow further increased the internal network strength of the bread, which may have improved the bread's ability to hold gas. As a result, the bread may have displayed the lowest hardness and the highest specific volume (Meng *et al.*, 2019), though its elasticity and gumminess were somewhat diminished. Furthermore, bread made with plant-based margarine did not differ significantly from those made with butter and beef tallow in baking loss and texture properties.

The sensory evaluation results of different bread are shown in *Table 6*. Plant-based margarine bread had no significant differences in shape, smell, or texture when compared to butter and beef tallow, but they do differ significantly in terms of colour and flavour. Contrary to traditional concept, the bread with plant-based margarine received a higher rating. In general, butter and beef tallow can give bread a creamy flavour and alluring taste. Nevertheless, they failed to manifest a discernible advantage when subjected to meticulous sensory evaluation. In contrast, bread made with plant-based margarine has gained the favour of many tasters, perhaps due to the bland taste of palm oil, which accentuates the natural wheat flavour of the bread. This proved the feasibility of using plant-based margarine instead of animal fat in bread.

CONCLUSION

In summary, in this work, the SFC curve of plant-based margarine was modelled and fitted by the Gompertz equation model to reproduce the SFC variations of commercial butter and obtain the optimum margarine formula. The results demonstrated that the bread with this formula, 83% PO + 17% ST, had similar structural characteristics and sensory evaluation to butter or beef tallow bread.

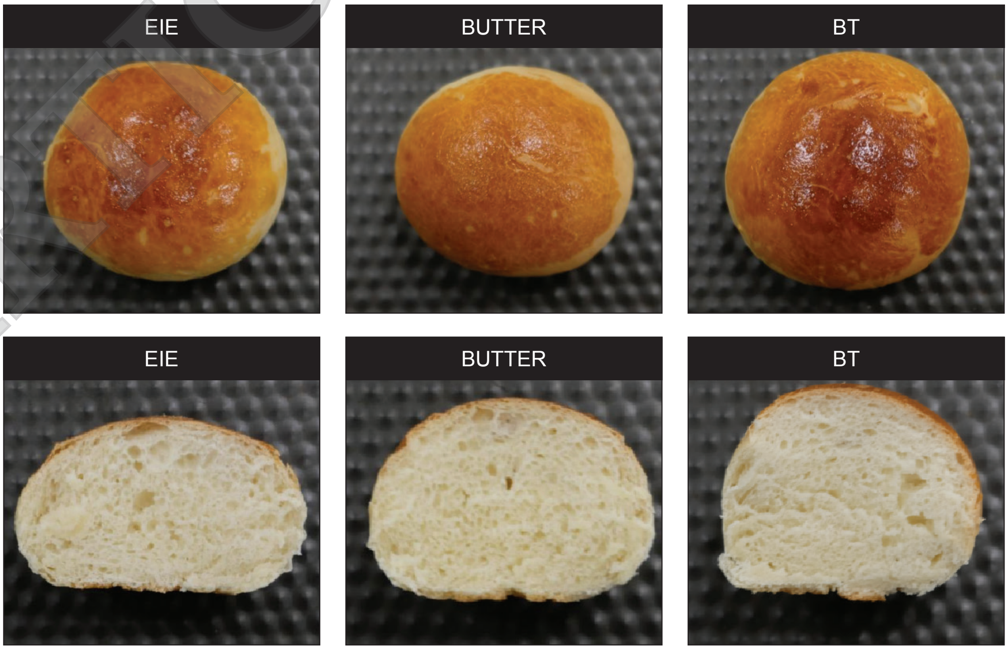

Figure 5. Upper surface crust appearance and breadcrumb structure of breads made with different fats.

TABLE 5. CHARACTERISTICS OF BREADS MADE BY DIFFERENT FAT

	EIE	BUTTER	BT
Baking loss	0.069 ± 0.0045 [a]	0.078 ± 0.0040 [a]	0.076 ± 0.0033 [a]
Specific volume (mL/g)	2.17 ± 0.030 [a]	2.34 ± 0.047 [b]	2.66 ± 0.078 c
Hardness (g)	672.22 ± 169.82 [a]	692.77 ± 173.05 [a]	519.53 ± 45.33 [a]
Adhesiveness (g)	-3.88 ± 3.44 [a]	-1.16 ± 0.28 [a]	-4.43 ± 1.75 [a]
Springiness (g)	0.84 ± 0.027 [a]	0.84 ± 0.037 [a]	0.88 ± 0.0086 [a]
Cohesiveness (g)	0.67 ± 0.037 [a]	0.73 ± 0.079 [a]	0.72 ± 0.024 [a]
Gumminess (g)	443.65 ± 89.93 [a]	496.72 ± 79.86 [a]	376.11 ± 34.43 [a]
Chewiness (g)	369.52 ± 66.73 [a]	418.34 ± 73.90 [a]	330.46 ± 30.55 [a]

TABLE 6. EFFECT OF FAT TYPE ON THE SENSORY ANALYSIS OF BREADS

	EIE	BUTTER	BT
Shape	4.40 ± 0.50 [a]	4.35 ± 0.49 [a]	4.28 ± 0.75 [a]
Colour	4.45 ± 0.69 [a]	3.80 ± 0.62 [b]	4.08 ± 0.57 [ab]
Smell	3.68 ± 0.77 [ab]	3.80 ± 0.83 [a]	3.23 ± 0.73 [b]
Taste	4.45 ± 0.60 [a]	4.03 ± 0.90 [ab]	3.85 ± 0.93 [b]
Texture	3.98 ± 0.73 [a]	3.70 ± 0.66 [a]	3.75 ± 0.79 [a]

These findings could offer a fresh approach for predicting the formula of plant-based margarine, recreate the application scenarios of target fats, drastically reducing the cost and time of product development, and significantly improve the efficiency of product development.

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