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Fatty acid profile and solid fat content of Peruvian cacao for optimal production of trade chocolate

Composicion de acidos grasos y contenido de solidos grasos de cacao peruano para la produccion de chocolate óptimo

ABSTRACT

Using technical procedures, the fatty acid (FA) profile and solid fat content (SFC) of the Peruvian cultivar cacao beans CCN 51 and ICS 6 and the "optimal chocolate", obtained from the mixture of the first two, were determined to assess their quality. These cacao beans were found to have important nutritional values. The FA profile of the cacao beans were similar ($p>0.05$); however, in the FA profile, the 'optimal chocolate' had significant differences ($p\leq 0.05$) in terms of palmitic, arachidic and linolenic acid. The n6:n3 ratio for "optimal chocolate" was 12.0 ± 1.7 . Cacao beans had the same SFC, and SFC was highly temperature dependent, as determined using a mathematical model for chocolate. The SFC of chocolate refers to hard cacao butter content at temperatures between 20 and 25°C, and solid fat was heat resistant from 25 to 30°C, which is considered valuable in trade chocolate production. The quality-related properties of these lipid fractions imparted nutritional and physical aspects to the optimal dark chocolate for human consumption.

Key words: Cacao; Cacao butter; Cocoa powder; Nutritional value; Polyunsaturated fatty acid; Unsaturated fatty acid.

RESUMEN

La composición de ácidos grasos (CAG) y el contenido de sólidos grasos (CSG), de la fracción lipídica de los cultivares peruanos de cacao CCN 51 e ICS 6 así como del "chocolate óptimo", obtenido de las mezclas de las primeras dos, fueron determinados por técnicas analíticas para conocer su calidad. Estas variedades tuvieron valores nutricionales importantes. La CAG de los granos de cacao fueron similares, sin embargo la CAG del "Chocolate óptimo" tuvo diferencias significativas ($p<0,05$) para los ácidos grasos palmítico, araquídico y linoleico. El ratio n6:n3 fue de $12,0 \pm 1,7$. El CSG de los granos de cacao fueron los mismos y tuvo una fuerte dependencia con la temperatura, también se definió un modelo matemático para el chocolate. El CSG le confiere al chocolate una consistencia dura a temperaturas de 20 a 25°C y resistentes al calor de 25 a 30°C, siendo tales propiedades una ventaja en la comercialización de chocolates. La calidad de estas fracciones lipídicas tuvieron

Gabriela Cristina Chire-Fajardo^{1*},
Milber Oswaldo Ureña-Peralta¹, Richard W. Hartel²

1. Departamento de Ingeniería de Alimentos, Facultad de Industrias Alimentarias, Universidad Nacional Agraria La Molina, Lima, Perú.

2. Food Science Department, University of Wisconsin-Madison, Madison, Wisconsin, U.S.A

*Dirigir correspondencia: Gabriela Chire.
Departamento de Ingeniería de Alimentos. Facultad de Industrias Alimentarias. Universidad Nacional Agraria La Molina. Av. La Molina s/n., Lima 12, Perú.
Teléfono: 6147800. Anexo 246.
Email: gchire@lamolina.edu.pe

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aspectos nutricionales y físicos en el chocolate oscuro para consumo humano.

Palabras clave: Ácido graso insaturado; Ácido graso poliinsaturado; Cacao; Cocoa en polvo; Manteca de cacao; Valor nutricional.

INTRODUCTION

Cacao beans are obtained from cacao pods, the fruit of the cacao tree (*Theobroma cacao* L.) which grows in all tropical zones of Peru. Cacao butter, constituting 50%-57% of a dry cacao bean, is an important part of the bean owing to its various physical, chemical and sensorial properties.

Identifying the type and quantity of fatty acids (FAs) in cacao butter through research and development laboratories

and in the processing and quality control units of manufacturing companies is imperative². Cacao beans obtained from Ayacucho and Cusco were processed and mixed (50:50) to produce cacao liquor (cacao paste) as a raw material for bitter drinking chocolate production³; the improved product had a FA profile of palmitic (27.70%), stearic (30.70%), oleic (35.90%) and linoleic (3.50%) acids with lower presence of other FAs. Similarly, fat content in cacao beans from Ecuador and Ghana is 43.45% and 41.93%, respectively⁴.

Torres-Moreno et al.² quantified the FAs in unroasted cacao beans from Ecuador and Ghana and found them to contain palmitic (27.61% and 25.01%), stearic (33.76% and 36.40%), oleic (34.73% and 34.31%) and linoleic (2.43% and 2.02%) acids, respectively, with a lower presence of other FAs, suggesting that FA profiles vary with geographical origin. For all samples, C16:0, C18:0, C18:1 and C18:2 were the most quantitatively important FAs. Ecuadorian chocolate showed a healthier FA profile, owing to its high unsaturated FA (UFA) and low saturated FA (SAFA) ratios compared with those of Ghanaian chocolate. Additionally, Ecuadorian chocolate is an important source of stearic FA with a neutral effect on human health².

Solid fat content (SFC) is a parameter that expresses the solid to liquid mass ratio of fat at different temperatures. The SFC affects physical properties such as consistency, stability and some important sensory attributes such as flavor, aroma and overall acceptability⁵. The SFC from 20°C to 25°C qualifies the hardness of cacao butter. The range of temperatures wherein decrease in the SFC is evident represents resistance to heat, whereas rapid fusion from 32°C to 35°C is responsible for cooling and a creamy sensation during tasting. To evaluate the quality of cacao butter, an important and practical parameter used in the industry is the difference between the SFC at 25°C and 35°C (i.e. ΔS). The presence of solid fat at a temperature below 35°C is recognised as a waxy sensation, which is easily detected during tasting⁵.

Apart from providing sweetness, chocolate offers positive health benefits that should be further investigated⁶. This study aimed to determine the FA profiles, ratios related to healthy nutrition and SFC of two Peruvian cacao cultivars CCN-51 and ICS-6 and the "optimal chocolate".

MATERIALS AND METHODS

This research was conducted at a processing plant in Chocomuseo (Lima, Peru) for cacao beans, Cacao Valley (Lima, Peru) for optimal chocolate production and University of Wisconsin-Madison (Madison, Wisconsin, USA) for the analysis of lipid fraction and determination of physical properties.

Analytical methods

Proximate analysis: The basic chemical composition i.e. moisture, ash, proteins and total fat of unroasted cacao beans and the "optimal chocolate" was analysed in triplicate following the AOAC method for cacao beans and their products⁷. Additionally, cacao paste from the beans was analysed in triplicate for moisture and fat composition⁷.

Caloric content was calculated by proximal analysis⁸ expressed in calories per 100 grams of product.

Determination of FAs: The lipid fractions of the cacao and "optimal chocolate" pastes were extracted⁷. Subsequently, using the ISO 12966-1⁹ methodology, we prepared methyl esters of FAs¹⁰. The results are reported as a relative percentage of total FA for the cacao and chocolate pastes.

Determination of SFC: We used the IUPAC Method 2.150b¹¹ with nuclear magnetic resonance to determine SFC. Lipid fraction of the cacao and "optimal chocolate" pastes were extracted with petroleum ether solvent; the fraction was melted, homogenised and filtered, and 2 mL solutions were measured in test tube at 80°C for 30 min. The samples were then placed in a water bath maintained at 0°C for 90 ± 5 min, passed to a bath maintained at 26°C for 40 ± 0.5 h, placed in a bath maintained at 0°C for 90 ± 5 min and, finally, passed to a bath maintained at the following temperatures for 60 min: 0°C, 5°C, 10°C, 15°C, 20°C, 25°C, 30°C, 35°C and 40°C.

Experimental methodology

At a processing plant, CCN 51 (Colección Castro Naranjal) and ICS 6 (Imperial Collage Selection, District of Uchiza, Peru) were processed (roasted, peeled and ground) to obtain cacao paste. The paste samples with their replicates were evaluated and lipid fractions were extracted to evaluate FA profile. Subsequently, nine different samples of chocolate with two replicates were derived from the mixtures of cacao beans (ICS-6:CCN-51 ratios of 1:9, 5:5, and 9:1) and three dark chocolate formulations (60%, 70% and 80% cacao) were processed under the same traditional processing conditions. In addition, physical properties for chocolate production were evaluated (University of Wisconsin-Madison, USA) to determine the "optimal chocolate"¹².

Using the surface response method, chocolate was obtained using the mixture with desired physical properties. For validation, the "optimal chocolate" (ICS 6:CCN 51 ratio of 1:9 and 70% cacao) was manufactured again. Fat of the "optimal chocolate" was extracted to evaluate FA profile, calculate the S/U and n6:n3 ratios and to determine SFC (University of Wisconsin-Madison, USA).

Statistical analysis

Experimental values obtained for each evaluated variable (FA, SFC, SAFA, MUFA, PUFA, fat, protein, ash, moisture, crude fibre) were expressed as mean ± standard deviation. The differences of these values between CCN 51, ICS 6 and optimal chocolate were determined by analysis of variance ($p \leq 0.05$) and Student-t test for moisture and fat content of cacao paste obtained from CCN 51 and ICS 6. A simple regression method was applied to investigate the relationship between SFC profile and temperature. All statistical analyses were performed using the STATGRAPHICS Plus[®] programme.

RESULTS

The proximal chemical composition of cacao beans (Table 1) showed a fat content of 43.6% ± 0.12% and 45.8%

$\pm 0.05\%$ for CCN 51 and ICS 6, respectively. In paste, a fat content of $49.35\% \pm 0.30\%$ and $52.50\% \pm 0.11\%$ on a wet basis was observed and $50.43\% \pm 0.31\%$ and $53.01\% \pm 0.11\%$ fat content on a dry basis, respectively. Lastly, the proximal analysis of the 'optimal chocolate' paste (CCN 51:ICS 6 ratio of 1:9, 70% cacao) defined on a wet basis showed a moisture and fat content of $1.60\% \pm 0.22\%$ and $34.56\% \pm 0.03\%$ (Table 1) and a fat content on a dry basis of $35.11\% \pm 0.03\%$; this

helped in determining the integral lipid fraction of the FA profile.

The FA profile and SFC of the cacao butter from the cacao beans and "optimal chocolate" are shown in table 2 and table 3. Values were expressed at 100% of the lipid composition to compare the values of FA among the countries in South America and globally and shows the ratios of S/U and n6:n3 for the "optimal chocolate". The SFC models of cacao butter from the cacao beans and 'optimal chocolate' are shown in figure 1.

Table 1. Proximal analysis (g/100g): calories (Cal/100g) in cacao beans and paste, i.e. CCN 51, ICS 6 and the "optimal chocolate"

Components	Cacao beans		Optimal chocolate
	CCN 51	ICS 6	
Moisture	$6.7 \pm 0.1b$	$6.8 \pm 0.1c$	$1.6 \pm 0.0a$
Fat	$43.6 \pm 0.1b$	$45.8 \pm 0.1c$	$34.6 \pm 0.0a$
Protein	$13.7 \pm 0.3c$	$12.6 \pm 0.1b$	$11.7 \pm 0.0a$
Ash	$3.0 \pm 0.0b$	$3.3 \pm 0.0c$	$2.6 \pm 0.0a$
Crude fibre	$5.4 \pm 0.0c$	$4.5 \pm 0.0b$	$3.6 \pm 0.0a$
Carbohydrate	$33.0 \pm 0.1b$	$31.5 \pm 0.0a$	$49.5 \pm 0.0c$
Calorias	579.2b	588.8c	555.9a

Components	Cacao pastes	
	CCN 51	ICS 6
Moisture	$2.2 \pm 0.0a$	$1.0 \pm 0.0b$
Fat, wb	$49.4 \pm 0.3a$	$52.5 \pm 0.1b$
Fat, db	$50.4 \pm 0.3a$	$53.0 \pm 0.1b$

Values are expressed as mean $\pm$ standard deviation (n= 3). Different letters in the same row indicates significant differences ($p \leq 0.05$) from low to high in alphabetical order.

Table 2. Fatty acid profile of the cacao butter obtained from CCN 51, ICS 6 and the "optimal chocolate"

Fatty acid profile	CCN 51 (g/100g)	ICS 6 (g/100g)	Optimal chocolate (g/100g)
C16:0 Palmitic acid	$29.3 \pm 0.1b$	$28.0 \pm 0.3ab$	$26.6 \pm 0.7a$
C18:0 Stearic acid	$32.8 \pm 0.4a$	$33.9 \pm 0.3a$	$33.3 \pm 1.9a$
C18:1 n9c Oleic acid	$32.3 \pm 0.0a$	$32.6 \pm 0.4a$	$32.6 \pm 1.0a$
C18:2 n6c Linoleic acid	$2.9 \pm 0.1a$	$3.1 \pm 0.3a$	$4.0 \pm 0.9a$
C20:0 Arachidic acid	$1.1 \pm 0.0a$	$1.1 \pm 0.1a$	$1.3 \pm 0.1b$
C18:3 n3 Linolenic acid	$0.2 \pm 0.0a$	$0.2 \pm 0.1a$	$0.3 \pm 0.1b$
Saturated (SAFA)	$63.8 \pm 0.3a$	$63.7 \pm 0.7a$	$61.9 \pm 1.0a$
Monounsaturated (MUFA)	$32.5 \pm 0.0a$	$32.9 \pm 0.4a$	$32.8 \pm 0.9a$
Polyunsaturated (PUFA)	$3.4 \pm 0.5a$	$3.3 \pm 0.4a$	$4.4 \pm 1.0a$
Unsaturated (UFA = MUFA + PUFA)	$35.9 \pm 0.5a$	$36.2 \pm 0.8a$	$37.2 \pm 0.1a$
Ratio S/U	$1.78 \pm 0.03a$	$1.76 \pm 0.06a$	$1.67 \pm 0.03a$
n6:n3 ratio	$15.7 \pm 0.6b$	$16.9 \pm 3.0b$	$12.0 \pm 1.7a$

Values are expressed as mean $\pm$ standard deviation (n=2). Different letters in the same row indicate significant differences ($p \leq 0.05$) from low to high in alphabetical order.

Table 3. Solid fat content of the cacao butter obtained from CCN 51, ICS 6 and the “optimal chocolate”.

Temperature (°C)	CCN 51 (g/100g)	ICS 6 (g/100g)	Optimal chocolate (g/100g)
0	90.0 ± 1.0a	89.1 ± 0.4a	89.8 ± 0.3a
5	88.4 ± 0.1a	88.3 ± 0.2a	88.3 ± 0.3a
10	86.0 ± 0.1b	85.5 ± 0.4b	83.6 ± 0.5a
15	79.7 ± 0.4a	78.6 ± 1.4a	78.3 ± 1.2a
20	75.4 ± 0.3a	75.4 ± 0.2a	75.1 ± 0.8a
25	67.0 ± 0.3a	67.6 ± 0.2a	69.1 ± 1.0b
30	46.6 ± 1.1a	49.8 ± 0.5b	55.4 ± 0.9c
35	2.0 ± 0.4a	2.1 ± 0.2b	3.8 ± 0.3c
40	1.4 ± 0.3a	1.7 ± 0.1a	1.2 ± 0.5a

Values are expressed as mean ± standard deviation (n=3). Different letters in the same row indicate significant differences ($p \leq 0.05$) from low to high in alphabetical order.

Figure 1: Model of the solid fat content (SFC) of cacao butter in terms of temperature for CCN 51, ICS 6 and the ‘optimal chocolate’ (average of three measurements)

DISCUSSION

The FA profiles of cacao butter from the CCN 51 and ICS 6 varieties were similar ($p > 0.05$), suggesting an advantage while preparing mixtures in chocolate producing industries.

Notably, the SAFA content ($63.80\% \pm 0.27\%$ and $63.65\% \pm 0.69\%$, respectively) was higher than the UFA content ($35.93\% \pm 0.51\%$ and $36.19\% \pm 0.81\%$, respectively). Regarding stearic FA (C18:0), a neutral saturated FA type²,

we found the values of $32.77\% \pm 0.35\%$ and $33.87\% \pm 0.31\%$, respectively, similar to those reported for Colombian varieties ($31.9\%-36.6\%$)¹³.

The SAFA content of cacao butter from the African countries are as follows: Ghana, $63.24\% \pm 0.63\%$ ²; Ivory Coast (samples B and D, the sum of palmitic and stearic FAs), $62.1\% \pm 0.1\%$ and $62.9\% \pm 0.35\%$ ¹⁴ and West Africa, $63.8\% \pm 0.0\%$ ¹⁵. The SAFA content from Asian producers are as follows: Indonesia, $63.4\% \pm 0.45\%$ and Malaysia, $62.8\% \pm 0.05\%$ ¹⁴. On the other hand, the SAFA content from South American producers are as follows: Ecuador, $62.28\% \pm 0.57\%$ ² and Brazil (samples I and P), $59.4\% \pm 0.60\%$ and $57.8\% \pm 0.20\%$, respectively¹⁴.

The PUFA content of the Peruvian varieties, CCN 51 and ICS 6 ($3.39\% \pm 0.48\%$ and $3.29\% \pm 0.39\%$, respectively) was higher than that of West Africa ($3.1\% \pm 0.0\%$)¹⁵ and of Ghana and Ecuador ($2.15\% \pm 0.07\%$ and $2.57\% \pm 0.25\%$, respectively)², suggesting a comparative advantage in terms of nutritional value.

The S/U ratios (ratio of saturated FA to unsaturated FA) for CCN 51 and ICS 6 were similar between the two varieties ($p > 0.05$), with the values of 1.78 ± 0.03 and 1.76 ± 0.06 , respectively, whereas the ratios for the varieties found in Ghana and Ecuador is 1.72 ± 0.05 and 1.65 ± 0.04 , respectively² indicating that the SAFA content is higher than the UFA content. Notably, the S/U ratio for the beans found in Ecuador is the lowest of all. Perea et al.¹³ report that a high S/U ratio classifies butter as hard, which is desired by the food industry. In this study, the CCN 51 and ICS 6 varieties obtained remarkably higher S/U values.

The lipid fraction of the "optimal chocolate" was 34.56% (Table 1). In previous reports, Mursu et al.¹⁶ used dark chocolate with 33.00% , Salinas and Bolivar¹⁷ used bar-type chocolate (drinking) with 37.00% fat and Chire et al.¹⁸ used dark chocolate with 36.11% fat. Because the 'optimal chocolate' had a high fat and energy content (34.56%), daily consumption should be regulated to 25 g/dl ². In terms of fat content ($35.11\% \pm 0.03\%$, dry basis), the FA profile of the "optimal chocolate" was determined. While the SAFA content of the "optimal chocolate" was $61.90\% \pm 1.01\%$ that of the chocolate prepared with the cacao beans from Ghana and Ecuador is $66.03\% \pm 2.09\%$ and $63.95\% \pm 1.39\%$, respectively², and that of the bar-type chocolate (drinking) reaches 63.5% ¹⁷. For the "optimal chocolate", the stearic FA content (C18:0) was $33.34\% \pm 1.93\%$ representing one third of the fat content. Stearic FA increases high density lipoprotein cholesterol and serum triglyceride levels in blood². PUFAs were present in high contents in the "optimal chocolate" ($4.36\% \pm 1.01\%$) compared with those in the dark chocolates from Ghana and Ecuador ($1.78\% \pm 0.48\%$ and $2.36\% \pm 0.59\%$, respectively²; 2.45 and 1.85 fold more, respectively).

As per previous studies, dark chocolate traded in Finland has 3.03% linoleic and linolenic FAs¹⁶, bar-type chocolate (drinking) from Venezuela has 3.16% ¹⁷ and the "optimal chocolate" from Peru (this study) had 4.35% . The

S/U ratio is a health indicator for chocolate with standard fat content: the S/U ratio for 'optimal chocolate' reached $1.67\% \pm 0.03\%$, almost similar to that of bar-type chocolate (1.75%)¹⁷. In the study by Torres-Moreno et al.², the S/U ratios for chocolates from Ecuador and Ghana are 1.77 ± 0.01 and 1.94 ± 0.06 , respectively, which increase during cocoa bean processing and chocolate production, with inverse effects on the results of the present study, because the S/U ratios for cacao beans (1.78 ± 0.03 and 1.76 ± 0.06) decreased to obtain the "optimal chocolate" (1.67 ± 0.03).

In addition, essential FAs (omega 6 and omega 3) produce metabolites that exert positive and negative effects on health and if the omega 6:omega 3 ratio is higher, the product is injurious to health¹⁹. The "optimal chocolate" had 4.35% of omega 6 and omega 3², whereas as chocolate from Ecuador has 2.30% and chocolate from Ghana has 1.80% . Per Mursu et al.¹⁶, chocolate traded in Finland has 1.00% of omega 6 and omega 3. Thus, our results indicate a good presence of essential FAs in the chocolate. Because the ratio of omega 6:omega 3 (Table 2) for "optimal chocolate" was 12.0 ± 1.7 , a daily diet must be supplemented with food products that help attain a ratio of essential FA of 5:1¹⁹. Chocolate from Ecuador has 21.6 , 10.5 ² from Ghana and 9.0 ¹⁶ from Finland. Thus, our results of 12.0 was near the ratio from Ghana. This could be due to the origin or processing factors. Curti et al.²⁰ studied the debittering process of *Lupinus* species and show an omega 6:omega 3 ratio from 10.3 ± 0.3 to 8.8 ± 0.6 . According to Mataix²¹, the FA content in 100 g of food comprising various fruits and nuts, i.e. almonds, peanuts, walnuts and "sacha inchi" seeds²², has omega 6:omega 3 ratios of 37.78 , 36.43 , 5.26 and 0.48 , respectively, indicating that only walnuts possess a balanced value.

We compared three treatments (CCN 51 cacao, ICS 6 cacao and "optimal chocolate") in terms of FA profile. In terms of palmitic FA, we found significant differences among the treatments ($p \leq 0.05$). The "optimal chocolate", which contained 90% of ICS 6 and 10% of CCN 51 cacao, showed similar palmitic FA content as that of ICS 6 cacao fat owing to its higher composition. On the other hand, stearic FA content was similar in all treatments ($p > 0.05$), with $32.77\% \pm 0.35\%$, $33.87\% \pm 0.31\%$ and $33.34\% \pm 1.93\%$ in the CCN 51 cacao, ICS 6 cacao and "optimal chocolate", respectively. Overall, stearic FA content was approximately one third of the total fat content. Oleic FA ($32.30\% \pm 0.00\%$, $32.59\% \pm 0.36\%$ and $32.55\% \pm 0.97\%$, respectively) was the second highest FA and was similar among all treatments ($p > 0.05$), followed by linoleic FA ($2.94\% \pm 0.09\%$, $3.10\% \pm 0.33\%$ and $4.01\% \pm 0.89\%$, respectively), with similar results among all treatments. Lastly, minimal amounts of arachidic and linolenic FAs were found with significant differences ($p \leq 0.05$) among the treatments.

It is recommended to characterize cocoa butter of other varieties and countries and differentiate them by zones. Innovative processes should be developed to improve the nutritional indicators of cocoa lipids.

The SFC of the lipid fractions of the CCN 51 cacao,

ICS 6 cacao and the “optimal chocolate” (Table 3) from 0°C to 40°C with intervals of 5°C showed that the curves decreased and were characteristic of cacao. CCN 51, ICS 6 and the “optimal chocolate”, presented no significant differences in terms of SFC.

Using the same method as used in the present study (IUPAC method 2.150b), Wennermark et al.²³ report the SFC of cacao butter with values of 82% at 10°C, 78% at 20°C, 70% at 25°C, 50% at 30°C and >1% at 35°C. Additionally, they found the differences among the cacao butter contents of different origins (Malaysia, West Africa and Brazil), with Brazilian beans showing the lowest SFC in the temperature range of 10°C-30°C. Chire and Córdova³ reported different SFC values since the cacao butter was a mixture of different cacao beans (50% Ayacucho and 50% Cusco) from the southern part of Peru, with 88.10% at 10°C, 61.10% at 20°C, 17.50% at 25°C, 1.00% at 30°C, 0.30% at 35°C and 0.30% at 37°C. This indicates that the solid fat of cacao butter under study had greater hardness in the temperature range of 0°C-25°C, which further acquired additional heat resistance at 25°C-30°C and, finally, became more waxy at 35°C-40°C than butter from the southern part of the country²⁴.

For cacao butter from Vietnam²⁵, the SFC values range from 83.70% ± 0.20% to 86.40% ± 0.30% at 10°C, 73.30% ± 0.20% to 76.20% ± 0.40% at 20 °C, 63.80% ± 0.20% to 68.90% ± 0.30% at 25°C, 36.70% ± 0.5% to 43.60% ± 0.60% at 30°C and 0.6% ± 0.40% to 1.80% ± 0.30% at 35°C. Their results are similar to those of the present study at temperatures below 20°C (hard butter) and at temperatures between 20°C and 25°C for heat resistant cacao butter. However, the cacao butter from Vietnam acquire lower SFC values at temperatures above 30°C, suggesting that the cacao butter of the varieties under study had waxy residues.

Similarly, for a type of cacao butter from Ghana, Tran et al.²⁵ report a SFC of 85.90% ± 0.20% at 10°C, 74.60% ± 0.20% at 20°C, 65.30% ± 0.30% at 25°C, 40.30% ± 0.50% at 30°C and 0.70% ± 0.20% at 35°C, which are similar to the results of the present study at temperatures of <20°C. However, at temperatures of 25°C, the SFC was higher in our study, confirming the heat resistance of cacao butter. In the ΔS experiment, the SFC values in CCN 51, ICS 6 and the “optimal chocolate” were 65.01%, 65.52% and 65.34%, respectively, which were within the study range reported by Tran et al.²⁵ In the last section of the SFC curve (temperatures of 35°C-40°C), the butter in the present study had waxy residues, more than that of the varieties from Vietnam and Ghana²⁵.

Remarkably, CCN 51, ICS 6 and the “optimal chocolate” presented an inverse relationship between their SFC and temperature ($R^2 = 96.61\%$, 96.81% and 96.55% respectively), which are empirical models based on observation and experimentation²⁶. Data were analysed by simple regression, where the dependent variable was SFC and the independent variable was temperature and the model was double square. The mathematical models for the butter (lipid fraction)

obtained for CCN 51, ICS 6 and the “optimal chocolate” (Figure 1) had negative slopes and were quadratic.

The results showed that the SFC presents a hard cacao butter, resistant to heat and with serosity residues. Therefore, to characterize the SFC of the cacao butter a mathematical model that can confirm the quality of the cacao butter is recommended. For example, for the products with cocoa butter replacers or substitutes, the SFC should be different.

CONCLUSIONS

The FA profiles of the Peruvian cacao varieties CCN 51 and ICS 6 from the district of Uchiza (Peru) showed nutritional potential in terms of PUFA content ($3.39\% \pm 0.48\%$ and $3.29\% \pm 0.39\%$, respectively) that was higher than that of the African varieties. Thus, the Peruvian varieties provide a greater nutritional contribution to the “optimal chocolate” blend processed with 70% cacao and cacao bean mixes (10% CCN 51 and 90% ICS 6). The PUFA content of the “optimal chocolate” was $4.36\% \pm 1.01\%$, a level significantly higher than that of other chocolate producers in the world and those recognized in Ecuador. Similarly, the ‘S/U ratios’ calculated for CCN 51 cacao, ICS 6 cacao and the “optimal chocolate” were $1.78\% \pm 0.03\%$, $1.76\% \pm 0.06\%$ and $1.67\% \pm 0.03\%$, respectively. The n6:n3 ratio for the “optimal chocolate” was 12.0 ± 1.7 , thus differentiating it from those obtained from African cacao.

The high SFC at low 10°C and medium 20°C temperatures is characteristic of hard cacao butter, and a significantly high SFC at high temperatures (35°C and 40°C) is considered beneficial for the distribution of products in tropical areas because it imparts heat resistance. The SFC in terms of temperature had a negative slope formed a quadratic equation.

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