Measurement of Foaming of Frying Oil and Effect of the Composition of TG on Foaming

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ABSTRACT: We describe a method developed to quantify the amount of foam in frying oils. In this method the foam was quantified by digitizing photographic images that were taken continuously at 1-s intervals; spots showing more than a certain luminance were considered as foam. The ratio of total foaming area to the whole oil surface was integrated to obtain the integration of foam (IF) index as a parameter of the extent of foaming. There was a good correlation between this method and the visual evaluation done by a group of panelists. Furthermore, the foaming tendency correlated with the distribution of TG by M.W. when the IF was plotted against the foam index of TG (FIT), which reflects the M.W. distribution. A correlation was found between the FIT value of oil and foaming on frying, indicating that when the FIT value is small, the oil foams less. Based on the results of this investigation, we have designed a method to obtain edible oils consisting of medium-chain FA that not only are nutritious but also have good cooking properties.

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KEY WORDS: Cooking, frying foam, MCT, MLCT, medium-chain fatty acids, molecular weight, nutrition, photographic images, structured lipid.

Since the discovery by Bloom *et al.* (1) in 1951 that medium-chain FA, unlike long-chain FA, are transported to the liver *via* the portal vein after their absorption in the small intestine, there have been extensive studies on the nutritious effect of FA (2–4). Because of the nutritional advantage of medium-chain FA, they have been used in the medical field as therapeutic agents for improving lipid absorption. It has been confirmed that medium-chain FA are highly stable and possess superior nutritional value compared to long-chain FA, because they are more readily convertible to energy.

However, using these medium-chain FA in cooking oil is problematic. For example, when medium-chain TG oil (MCT) consisting solely of medium-chain FA is used for frying, it smokes; when it is used in combination with long-chain FA, it behaves violently, bubbling over with the consequent risk of fire. To design edible oils having the nutritional value of medium-chain FA, it is necessary to evaluate foaming quantitatively and to determine suitable TG lacking the tendency to foam.

Many authors have investigated the foaming properties of deteriorated oils by focusing on the oxidative polymerization and thermal denaturation of FA, as well as on the effect of polar compounds on the tendency to foam (5–7). Although the relationship between the structure of TG and foaming was also investigated, that study focused on the foaming tendency of deteriorated oils used for frying for long periods of time (8). As yet, only one study has been conducted on the increased foaming tendency caused by the presence of medium-chain FA, and it is limited to the recognition that foaming increases when coconut oil is mixed with other oils (9).

Furthermore, although other researchers have investigated the foaming mechanism when frying (10,11), there are no reports on the relationship between the tendency to foam and the structure of TG, especially among oils consisting of medium-chain FA. Moreover, few studies have been conducted on the foaming phenomenon and the mechanism by which these oils foam.

We have developed a method to quantify foaming. Even though a method to determine the depth of foam in a test tube was reported previously (12), the conditions of that test differ greatly from the frying conditions commonly carried out in the home.

To improve the foaming tendency of oils consisting of medium-chain FA, we quantified the amount of foam under actual frying conditions. We applied an image analysis and digitized the amount of foam produced; data variations were minimized by shortening the exposure interval. Furthermore, using these quantified data, we examined the relationship between the structure of TG consisting of medium-chain FA and their tendency to foam. Based on the results obtained, we designed edible oils having the nutritional value of medium-chain FA with good cooking properties.

EXPERIMENTAL PROCEDURES

Oils. Commercially available edible oils, canola oil (The Nisshin OilliO, Ltd., Yokosuka, Japan), MCT consisting only of medium-chain FA (The Nisshin OilliO, Ltd.), and medium- and long-chain TG oil consisting of 10% medium-chain FA (MLCT10, The Nisshin OilliO, Ltd.) were used. The trial oils, MLCT14 (consisting of 14% medium-chain FA) and MML (consisting of medium- and long-chain FA in a ratio of 2:1 mol), were prepared as reported previously (13). For MLCT14,

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after the ester-exchange reaction between canola oil and MCT catalyzed by lipase, the reactants were successively deacidified, decolorized, and deodorized; MML was prepared by molecular distillation of TG consisting of 2 mol of capric acid and 1 mol of a long-chain FA and fractionated at 90% purity.

Lipase. The lipase used was Lipase QL (*Alcaligenes* sp.) from Meito Sangyo & Co., Ltd. (Nagoya, Japan).

Materials for frying. Sweet potatoes of the *Beni azuma* species, chicken legs, and pork fillets were used. Light flour from the Nisshin Seifun Group Inc. (Tokyo, Japan), deep-frying flour from the Nisshin Seifun Group Inc., tempura flour from Showa Sangyo Co., Ltd. (Tokyo, Japan), and wheat flour from Frystar Co., Ltd. (Yokohama, Japan) were used.

Frying tests. Frying was conducted as follows. Edible oil was added to the tempura pan [with a 2-L capacity and a 22-cm diameter (KZ-TT2, Epon Co., Ltd., Niigata, Japan); the pan was heated using an electromagnetic cooking appliance (National IH KZ-P8™; Matsushita Electric Industrial Co., Ltd., Osaka, Japan)] to a constant temperature of 180°C. Three kinds of frying techniques commonly used in Japanese cooking were tested, namely, "tempura," "kara-age" (fried chicken), and "tonkatsu" (fried pork cutlet).

(i) Tempura. Ten round slices of sweet potato, about 1 cm thick and 4–5 cm in diameter, were dipped into the batter of the tempura flour (50 g flour mixed with 80 g tap water). Five pieces of sweet potato were fried for 3 min. After removing the fried sweet potato from the pan, another five pieces were fried in the same manner.

(ii) Kara-age. Twelve 20-g chicken legs were covered with 25 g of flour for deep frying. Six chicken legs were then successively fried for 4 min in duplicate.

(iii) Tonkatsu. Ten pork fillets about 1 cm thick and weighing approximately 35 g each were covered with light flour, dipped in beaten egg, and then covered with wheat flour. Each of the fillets of prepared pork was then fried for 4 min in duplicate in a similar manner.

Image analysis. The frying procedure was photographed using a 3-D Digital Fine Scope VC1000™ lens (Omron Corporation, Tokyo, Japan) placed directly above the frying pan. The images were analyzed using Image-Pro Plus™, v. 4.0, image analysis software from Mediacybernetics, Inc. (Carlsbad, CA). For sweet potato frying, 157 frames were taken in total from the beginning to the end, and the first 20 frames were cut off; the remaining 137 frames, numbered 21–157, were used for analysis. Similarly, 190 frames, numbered 21–210, were analyzed for the chicken and pork after deleting the first 20 frames.

As shown in Figure 1, the foaming spot in the image was defined by a fixed luminance criterion, and the ratio of the total foaming area to that of the surface of the frying oil was calculated. Foam showing luminance within an 80–255 range by the Image-Pro Plus was analyzed.

Analysis of the composition of TG. The TG composition of the oils used in the present study was analyzed by GLC using an HP6890™ chromatograph (Agilent, Palo Alto, CA). GLC conditions were as follows: The injector temperature was 370°C; the detector temperature was 370°C; the column temperature rose from 200 to 370°C at a rate of 15°C/min; the split ratio was 50:1; and helium was used as a carrier gas at a flow rate of 6.0 mL/min. A DB-1 column (Agilent) was used after cutting off 5 m in length. The TG composition was determined by the percentage of the peak area.

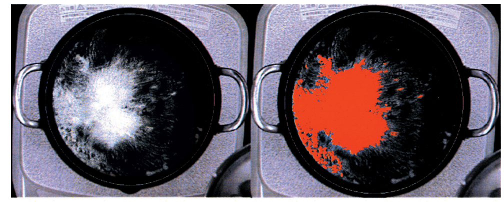

FIG. 1. Example of an image analysis. The foaming spot was defined by a fixed luminance criterion.

RESULTS AND DISCUSSION

Figure 2 shows the results of the image analysis of the photographs taken while frying sweet potato slices in canola oil. Foaming rapidly increased immediately after the slices were dipped into the frying oil, and thereafter decreased over time. Data obtained immediately after the beginning of frying were variable; therefore, we used frames 21–157 for analysis, rejecting the first 20 frames. To reduce variability, the foaming tests were carried out in duplicate for sweet potato, chicken, and pork, and the mean value of each test was integrated. The integration of foam (IF) index was used as a parameter reflecting the overall amount of foam; this index was obtained by integrating the mean values of all three tests.

Frying tests were carried out six times in canola oil, and the variance in the IF values was examined. As shown in Table 1, the CV of the IF values, which reflects the amount of foam in the canola oil during frying, was small (3.5%). Furthermore, the CV of the IF value of MLCT10 was 3.6% and that of MLCT14 was 2.6%. Thus, IF is a reproducible, reliable parameter. Since the IF value reflects the integrated foaming tendency of oil used according to three typical frying techniques (tempura, kara-age, or tonkatsu), it might be acceptable as a practical parameter to assess the amount of foam produced in frying.

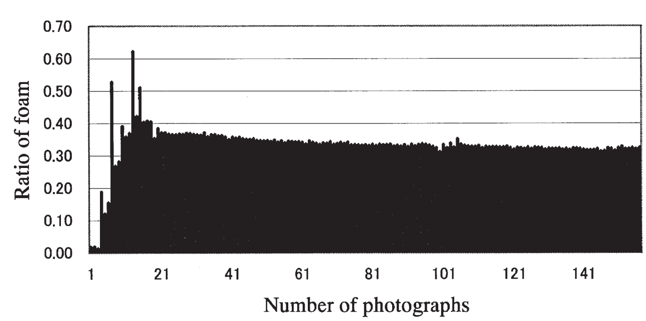

FIG. 2. Results of the image analysis of sweet potato slices fried in canola oil.

TABLE 1
Variation in the Integration of Foam (IF) Values of Canola Oil

Trial number	IF value
1	302
2	285
3	282
4	307
5	299
6	287
Average	293.7
SD	10.3
CV	3.5

The increased foaming tendency of the deteriorated edible oils, as well as the state of foaming, is recognizable by visual observation during home frying in most cases. Results using the IF values were compared with those of visual evaluation by a group of panelists. For the evaluation by panelists, five different edible oils were selected, and the amount of foaming on frying was checked by 21 trained panelists who had been participating in oil research. Foaming was evaluated on a scale of 1 to 10 points (1 = no foam; 10 = overflows), and the mean values were compared with the IF values. Canola oil; a mixed oil consisting of a 9:1 mixture of canola oil and MCT, the latter of which was composed of medium-chain FA; MLCT10; MLCT14; and MML were used in these experiments. The results are shown in Figure 3. A positive correlation was found between the results of the visual evaluation and IF values at IF values above 290, but for the oils with less tendency to foam, the IF values did not decrease to values less than 290, despite the differences detected by visual inspection. This could be because, in the image analysis of foaming by luminance, the frying objects (sweet potato, chicken, and pork) were indistinguishable from the foam (Fig. 1). Therefore, in the oils with less tendency to foam, the results of visual inspection were inconsistent with the IF values. Namely, in the image analysis, the foam over the frying object was not counted, giving a constant image regardless of the actual amount of foam over the frying object, and the method was meaningful only when the foam was spread around the frying object. Oils consisting of medium-chain FA tended to boil over around the entire frying object. This is a dangerous property, because it may cause bubbling over and/or fire. Therefore, it is important to investigate oils with an IF value greater than 290, those which correlated significantly with the results of visual evaluation.

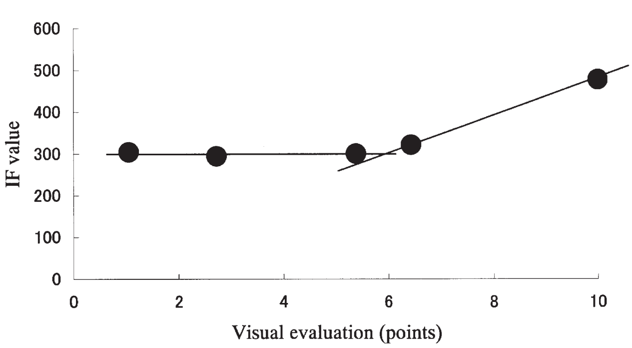

FIG. 3. Correlation between the results of visual evaluation and integration of foam (IF) values. For the visual evaluation by a group of panelists, a scale of 1–10 points was used (1 = no foam; 10 = overflows).

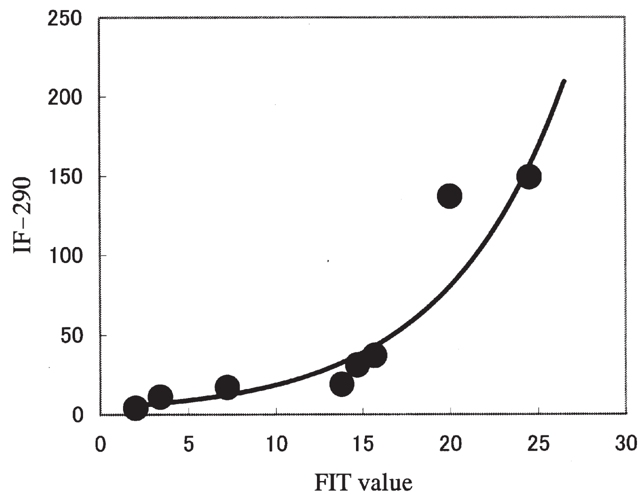

FIG. 4. Correlation between the foam index of TG (FIT) values and the IF values. For abbreviation see Figure 3.

Next, we examined the relationship between the foaming property of oils consisting of medium-chain FA and their structure. While frying in MCT, smoking occurred but no foam was observed. However, when MCT was mixed with canola oil, violent foaming occurred during frying. Based on these facts, we considered that the coexistence of TG of different M.W. might lead to foaming. Namely, the violent foaming observed when frying with edible oils consisting of medium-chain FA could be attributed to the M.W. distribution of the TG in the oil. Considering these points, the foam index of TG (FIT) value, defined as an index of the distribution of TG by M.W., could be determined as follows:

$$\mathrm{FIT} = \Sigma\,[|\mathrm{RM} - \mathrm{ARM}| \times (\mathrm{mol\%})/100]$$
$$\mathrm{RM} = [(\mathrm{M.W.} - 470)/(976 - 470)] \times 100 \qquad [1]$$

where RM, ARM, and M.W. represent the relative M.W., the average relative M.W., and the M.W., respectively. In this evaluation 470 is the M.W. of tricapryloylglycerol and 976 is the M.W. of triarachidonylglycerol. We examined the correlation between the FIT and IF values. Eight different kinds of oils were prepared by mixing MCT with canola oil or by ester-exchange reactions, and the corresponding IF values of these oils were determined by the image analysis method. The results are shown in Figure 4, where the IF value was deducted from 290, as the blank value of the frying object, and then plotted against the FIT value. A correlation was found between the FIT value of the oil and foaming on frying, indicating that when the FIT value is small, the oil foams less. Moreover, it is important that the FIT value of TG be lower than 15 because the foaming tendency increased exponentially when the FIT value was greater than 15, with a consequent rise in fire caused by bubbling over during frying. Thus, it is expected that frying oils with good properties can be obtained by constructing TG with an FIT value lower than 15, even if they contain medium-chain FA. Based on this theory, edible oils having the nutritional value of medium-chain FA and favorable cooking properties can be produced.

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