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Mango doughnuts technology process for innovative prevention of post-harvest loss of mango fruits in Burkina Faso

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The present study involved the processing and testing of two formulations of mango doughnuts. The mango pulp formulations were combined either with maize or rice flour. The dough from both formulations was fried in immersion oil using a gas-fueled fritter and a crepe maker in controlled conditions. Levels of moisture, titrable acidity, total ash, fat, proteins, total sugars and beta-carotene were determined for the dough and for the mango doughnuts by using physicochemical standard methods. Sensory evaluation of the end-products with respect to aroma, color, taste and texture were performed. Results showed that the moisture contents of mango doughnuts obtained using the gas fryer which contained maize (DMMgf) or rice (DMRgf) flour were significantly lower than the same formulations obtained using the crepe maker (DMMcm, DMRcm). The highest fat contents for the DMRgf and DMMgf doughnuts were 25.34 and 29.78%, respectively. The beta-carotene contents of the doughnuts fried with the crepe maker (110.32 and 107.92 µg/100 g) were significantly higher than those doughnut fried with the gas fryer (90.91 and 85.49 µg/100 g). The yellow color of the DMRcm formulation was found to be very attractive by 70% of the tasters. In contrast, the DMMcm sample was found to be fairly attractive by 56.70% of the tasters. This method of processing mangos into doughnuts is convenient, requiring only common household equipment. The product is an innovative way of utilizing and adding value to over-ripe mango fruit, to reduce post-harvest loss and increase food and nutrition security.

Key words: *Mangifera indica***,** mango doughnuts, sensory analysis, nutritional characteristics, Burkina Faso.

INTRODUCTION

In Burkina Faso, mango (*Magifera indica* L.) trees produce about 337,101 metric tons of fruits per year (CEFCOD, 2013). Since mango is a climacteric fruit, post-harvest losses are estimated to be between 30 and 40% (PAFASP, 2011). Different methods of processing mango fruit are practiced in artisanal, small and medium enterprises such as DAFANI in Burkina Faso. Mango fruit products include mango juice, dried mango, jam etc. The most common and widely used form of processing is dried mango (Kanté-Traoré et al, 2017). Dried products are commercialized and consumed around the world. However, the drying process needs specialized equipment such as solar dryers or gas dryers, which are not easily available to individuals. Frying could be an alternative way of processing mango for diversifying mango preservation. An advantage of this process, in relation to sensory appeal for consumers, is that it generates complex products with crisp textures which are also rich in flavors. These characteristics are responsible for the success of fried products around the world (Banks, 1996; Gonzalez., 2007; Mestdagh et al., 2008). Fried products of animal origin are the most common. Fried products of vegetable origin are those based on starchy items such as potatoes (Moreira et al., 1999). Fried products of fruit origin come mainly from plantain bananas; these include "fufu", plantain chips, "alloko", doughnuts as “cracro”, cakes and pancakes made from plantain flour (Eggleston et al., 1991; N’daAdopo, 1993; Rojas-Gonzalez, 2007; Planta Innovation, 2011; Bikoï et al., 2012.; Fongang Fouepe et al., 2016). Several studies describing chip processing, based on local potato varieties are available in several countries such as Nigeria and Côte d'Ivoire (Ogazi, 1987; Onyejegbu and Orolunda, 1995; Diaz et al., 1996; Vitrac and Raoult-Wack, 2002). However, studies of fried products based on mango have not been previously described. The present study looks at an innovative process for transforming mango pulp into doughnuts using local cereal flours. It adds to our knowledge about product diversification for mangos, which may contribute to a reduction in post-harvest losses of this climacteric fruit. Adoption of doughnut production at both the household and commercial level would help reduce the enormous post-harvest losses of mango and contribute to food and nutritional security.

MATERIALS AND METHODS

Plant materials

Fresh mango (*Mangifera indica* L.) of the Keitt variety was purchased from the local fruit market in Ouagadougou, in July 2016. The fruits, at physiological maturity, were kept at room temperature for ripening under natural conditions.

Rice kernels (*Oryza sativa* L.) of the TS2 variety, originating from Taiwan, were obtained. This variety has been introduced to Burkina Faso since 2002 and has been improved upon by the National Institute for Environment and Agricultural Research (INERA). Currently, the TS2 variety is grown in lowlands, either rain-fed or with irrigation. For the purposes of this study, 10 kg of the TS2 variety was purchased at one of the outlets in the city of Ouagadougou.

Maize kernels (*Zea mays*) of the Espoir variety used were from the maize, originating from INERA's varietal selection. Kernels (10 kg) were purchased at the INERA depository in Bobo-Dioulasso.

Preparation of the raw material

Once the purchased mangoes reached gustative maturity, they were sorted, weighed and washed with tap water. They were then wiped, hand-peeled and the seed removed. The pulp obtained was blended using a mixer, weighed, packaged in food bags and stored in the freezer at -20°C.

The maize or rice kernels were washed and dried for 24 h at room temperature at the technopole workshop. Kernels were then ground using a disc mill (Metro Expoters Pvt. LTD, India). The resulting flour was left to cool at room temperature for 10 min and then sieved through a 250µm pore. The flour was then packaged, sealed in food bags and stored in plastic bins in a dry, clean room at room temperature (25°C). The flours were used within one week after initial storage.

Formulation of the mango dough

Formulation of the dough involved measuring the required proportions of raw materials and ingredients, then mixing them to produce the dough for the mango doughnuts. Eight formulations were prepared in two batches. The first batch consisted of mango pulp, wheat or maize flour, sweet potato (orange flesh) or rice flour, and eggs, in proportions of 76:20:4. For the second batch, the same ingredients were used by the proportions 81:15:4. The doughnuts produced from these dough formulations were then subjected to sensory analysis tests. The results of this test showed that the dough formulations that produced doughnuts with the best acceptance were those obtained using mango pulp with maize flour, and mango pulp with rice flour, both containing 4% eggs.Thus, the rest of the study focused on these two formulations as shown in Table 1.

Mango doughnuts processing

The raw material (mango pulp) and ingredients (maize/rice flour and eggs) were mixed in a kneader (Panasonic MK-GB1, China) for 10 min.

The dough obtained was then fried in refined palm oil (Dinor, Sania Cie) using either a gas fryer or a crepe maker (Geepas GPS-1382) according to the diagram summarized in Figure 1. The doughnuts were fried by two methods: i) immersed in a gas fryer at 155°C for 10 min, and ii) using an electric crepe maker at 135°C for 5 min, with a controlled quantity of oil (Figure 1). A sensory evaluation was carried out on the doughnuts with the crepe maker to test the acceptability of this new product by the consumers.

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Table 1. Formulations of mango dough.

Ingredients	Formulation I	Formulation II
	Mango pulp/ Maize flour (MM)	**Mango pulp/ Rice flour (MR)**
Mango pulp (%)	81	81
Maize flour (%)	15	-
Rice flour (%)	-	15
Egg(%)	4	4
Total	**100**	**100**

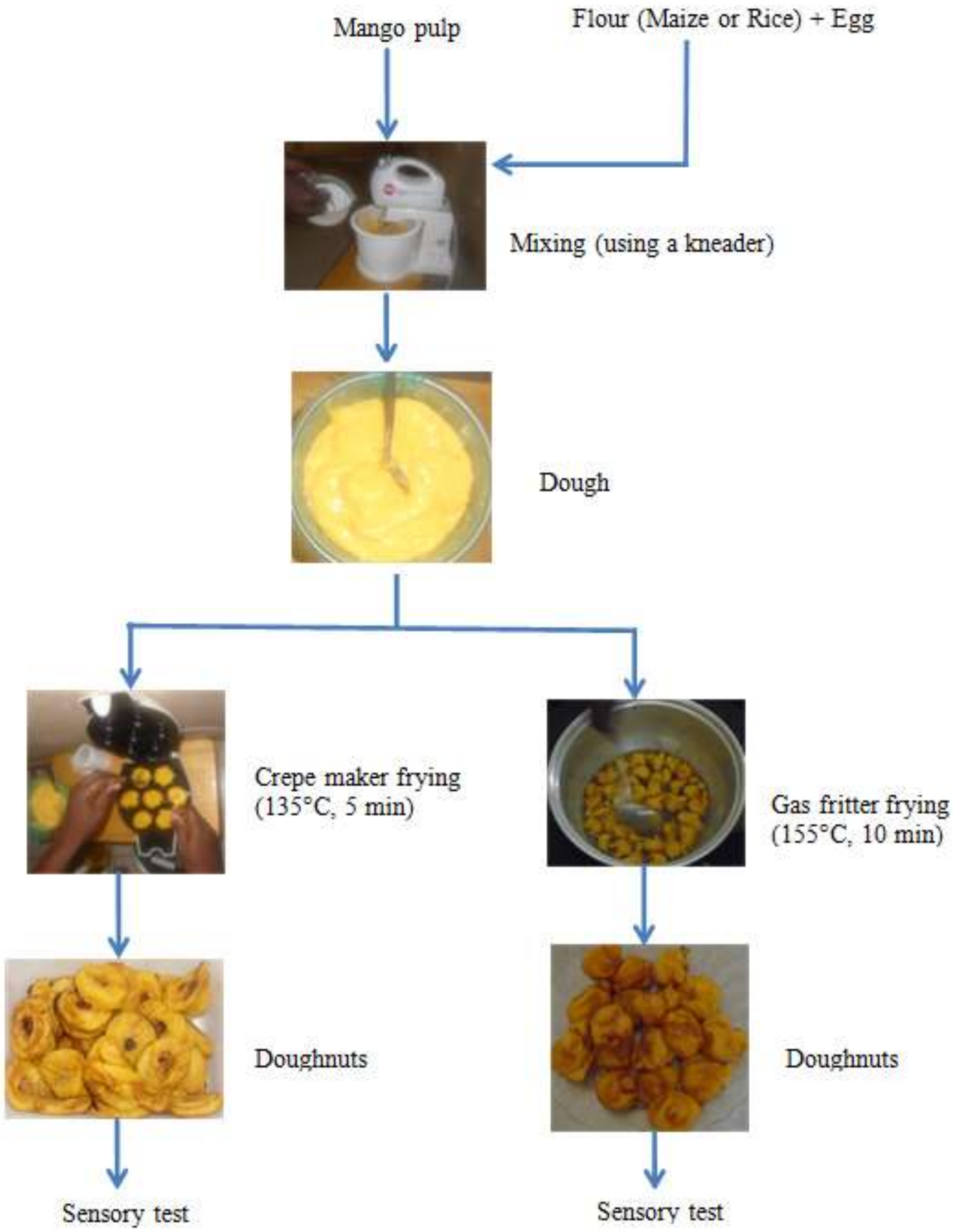

Figure 1. Diagram of mango doughnuts processing.

Doughnuts sampling for analysis

Two samples of each produced dough and mango doughnuts were stored in an airtight bottle in a freezer at -20°C for physico-chemical analysis at a later date.

The sensory evaluation was conducted on freshly-prepared doughnuts, within three hours of preparation.

Physico-chemical analyses

The moisture contents of samples of the different products were determined using to AFNOR standard method.

The titrable acidity expressed as citric acid equivalent was performed by titrating 5 g of mango dough and doughnuts using 0.1 N NaOH as described by AFNOR (1986). The total ash was determined according to the ISO 2171 (2007) method.

The fat was extracted in triplicate with Sohxlet apparatus according to ISO 659 (1998) method. Thereafter, 5 g of dried mango doughnuts were weighed and extracted in n-hexane for 4 h. After extraction, the solvent was evaporated with a Rotavapor. The flask containing the lipids and the traces of the solvent was placed in an oven at 105°C for 1 h, cooled in a desiccator for 30 min and then weighed. The total protein content was determined in triplicate by Kjeldalh method according to the French standard V03-050 (1970) method.

The total sugar content was estimated using a colorimetric method involving acid hydrolysis, intra-molecular dehydration of sugar into furfurals, followed by condensation of the furfural with phenols to obtain colored hemi-acetals or acetals (Montreuil and Spik, 1969).

The β-carotene content of mango doughnuts was determined using the High Performance Liquid Chromatography (HPLC) method as described by Somé et al. (2004). The external standard solution for calibration was prepared by mixing various quantities of pure β-carotene powder weighed into 3 ml of hexane to produce the stock solution. The stock solution was then diluted by 1/10, 1/100 and 1/1000. Optical densities of the eluted compounds were read at 450 nm. The concentration of the solution having an optical density between 0.1 and 0.9 was calculated. From these standard solutions whose concentrations were determined accurately, precise volumes were taken to produce a final solution of 60 pmol/20 µl. The β-carotene in the samples was extracted by successive vortexing of 1 g of finely ground mango doughnut for 2 min with 1 ml of extraction solvent. The solvent was a heterogeneous mixture of hexane, 3M sodium chloride, and ethanol (1/1/1). After vigorous stirring, the mixture was centrifuged at 3000 rpm^{-1} for 5 min at -5°C. This process was repeated three times; thereafter, the hexanic phases were then pooled. The hexane extract (1 ml) was evaporated under a stream of nitrogen while the obtained residue was re-dissolved in 1 ml of acetonitrile. After micro-filtration (0.5 µm), the sample was injected into a LC-18 Supelcosil column (Bellefonte, USA), 25 cm in length and 4.6 in diameter, using a loop of 20 µl. The mobile phase was a mixture of acetonitrile, dichloromethane and methanol in proportions of 7/2/1, respectively. The elution was in an isocratic mode. During elution, the carotenoids were identified by their retention time of 6.22 min ± 0.26, compared to an external standard, using a pump Jasco PU-980 (Tokyo, Japon), a detector Jasco UV 975 (Tokyo, Japon), and online interface with a computer with an operating Software Galaxy work station version 1.9.3.2.

Sensory evaluation

A sensory test was carried out on the mango doughnuts produced by frying in the crepe maker. It involved the evaluation of the sensory profile according to the ISO 11035 (1994) method. This evaluation tested sensory attributes such as color, aroma, taste, texture in the mouth, and texture by feeling between the fingers. The test was performed in two sessions during two days by 30 panelists from the Departments of Institute of Applied Sciences and Technologies CNRST, Burkina Faso. Participants had minimum education. The panelists consisted of 13 men and 17 women distributed into the three age groups as follows: 15 - 30 years: 40%, 31 - 40 years: 46.70%, over 40 years: 13.30%. The doughnut samples of each formulation were randomly placed onto plates with a three-digit code (Cochran and Cox, 1957), and were served to each panelist. Panelists were isolated to avoid inter-communication during evaluation.

Statistical analysis

All physico-chemical data were generated in triplicate. ANOVA, following Newman-Keuls test (SNK) was performed using XLSTAT (2014) to analyze and compare the physic-chemical parameters. The data from the organoleptic evaluation were analyzed by SPSS 20.

RESULTS AND DISCUSSION

Sensory evaluation of mango doughnuts

Results of the sensory tests of the mango doughnuts are shown in Figures 2 to 6. The yellow color of the doughnuts samples (mango pulp + rice flour + egg) was found to be very attractive by 70% of the panelists. On the other hand, the yellow color of doughnut samples DMMcm (mango pulp + maize flour + eggs) was perceived moderately attractive by 57% of the panelists (Figure 2).

The mango flavour was judged to be weakly intense for the DMMcm doughnut by 67% of the panelists compared with 40% for the DMRcm doughnut (Figure 3).

Concerning the texture, DMMcm was judged to be moderately soft by 48% of the panelists and weakly by 52% of them. DMRcm was judged to be very soft by 74% and moderately soft by 22% of the panelists (Figure 4).

The texture in the mouth was judged to be moderately oily by 45% and of low oiliness by 41% of the panelists for DMMcm, whereas DMRcm was found to be very oily by 31% and moderately oily by 52% of the panelists (Figure 5). These results corroborate those of physic-chemical analysis where the fat content of DMMcm and DMRcm were 13.09 and 15.87% respectively.

Regarding the acid taste, 78% of the panelists found the mango doughnut obtained with maize flour (DMMcm) to be weakly acidic. The DMRcm was judged to be moderately acidic by 56% and weakly acidic by 41% of the panelists (Figure 6). The results of the sensory test of DMMcm and DMRcm with regard to acid taste also confirm those of the physico-chemical analysis whose acidity was low, leading to a less acid taste. In summary,

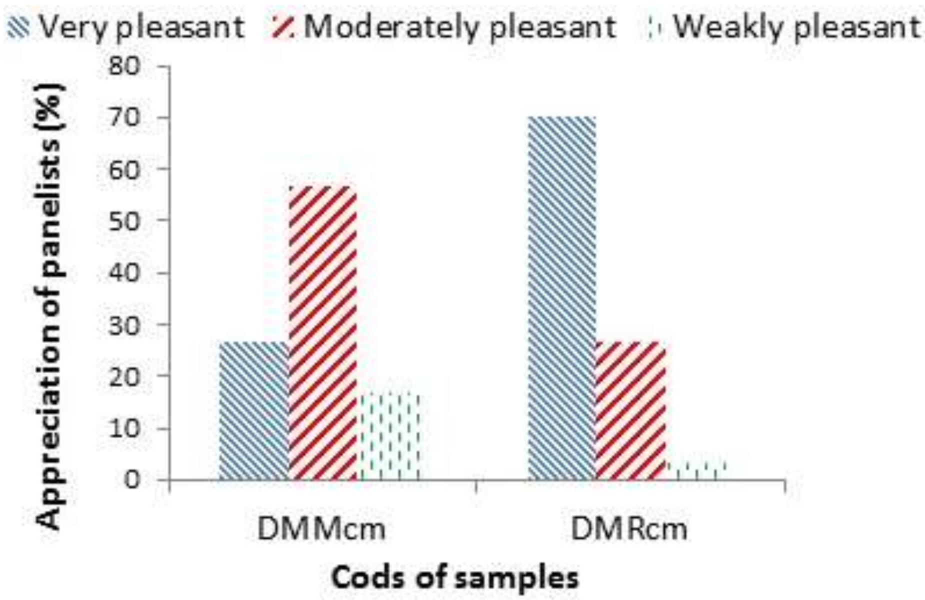

Figure 2. Appreciation of the yellow color of mango doughnuts; Where, DMMcm = Mango doughnut obtained with dough (Mango pulp + Maize flour) fried in crepe make and DMRcm = Mango doughnut obtained with dough (Mango pulp + Rice flour) fried in crepe maker.

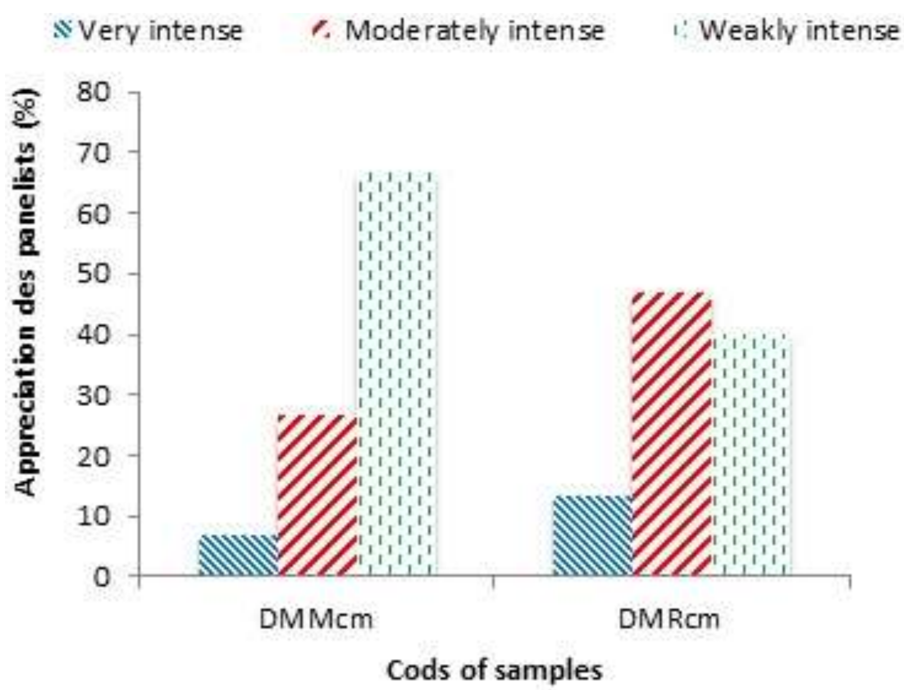

Figure 3. Appreciation of the flavor of mango doughnuts; Where, DMMcm = Mango doughnut obtained with dough (Mango pulp + Maize flour) fried in crepe make and DMRcm = mango doughnut obtained with dough (Mango pulp + Rice flour) fried in crepe maker.

both doughnut formulations were very appreciated by the panelists.

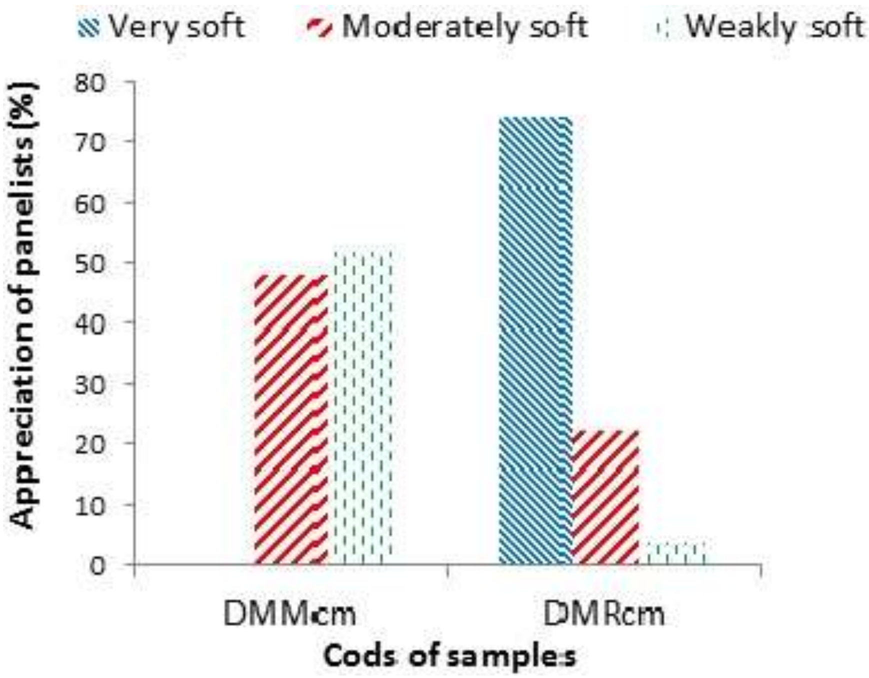

Figure 4. Appreciation of the texture on fingers of mango doughnuts; Where, DMMcm = Mango doughnut obtained with dough (Mango pulp + Maize flour) fried in crepe make and DMRcm = Mango doughnut obtained with dough (Mango pulp + Rice flour) fried in crepe maker.

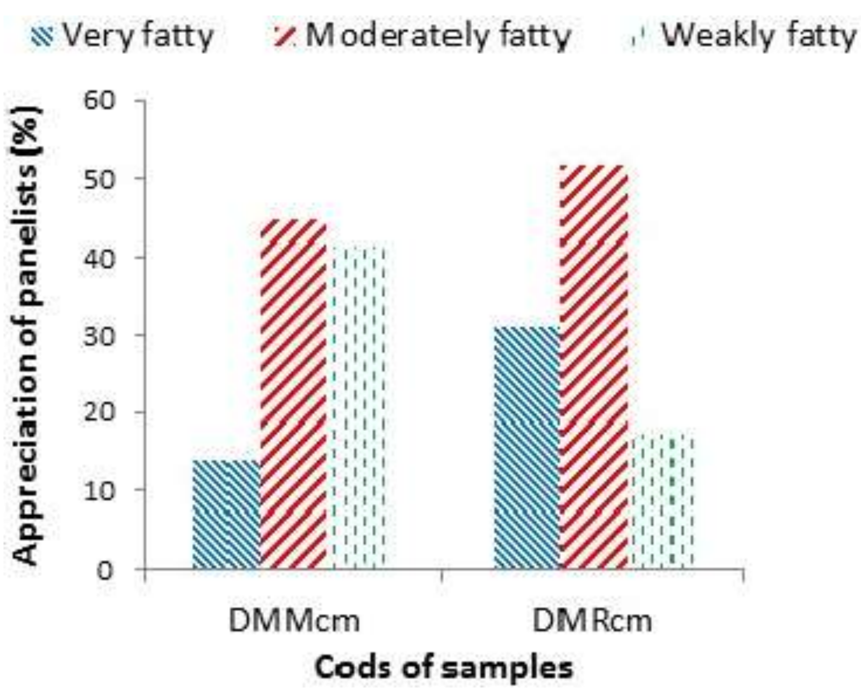

Figure 5. Appreciation of the texture in mouth of mango doughnuts; Where, DMMcm = Mango doughnut obtained with dough (Mango pulp + Maize flour) fried in crepe make and DMRcm = mango doughnut obtained with dough (Mango pulp + Rice flour) fried in crepe maker.

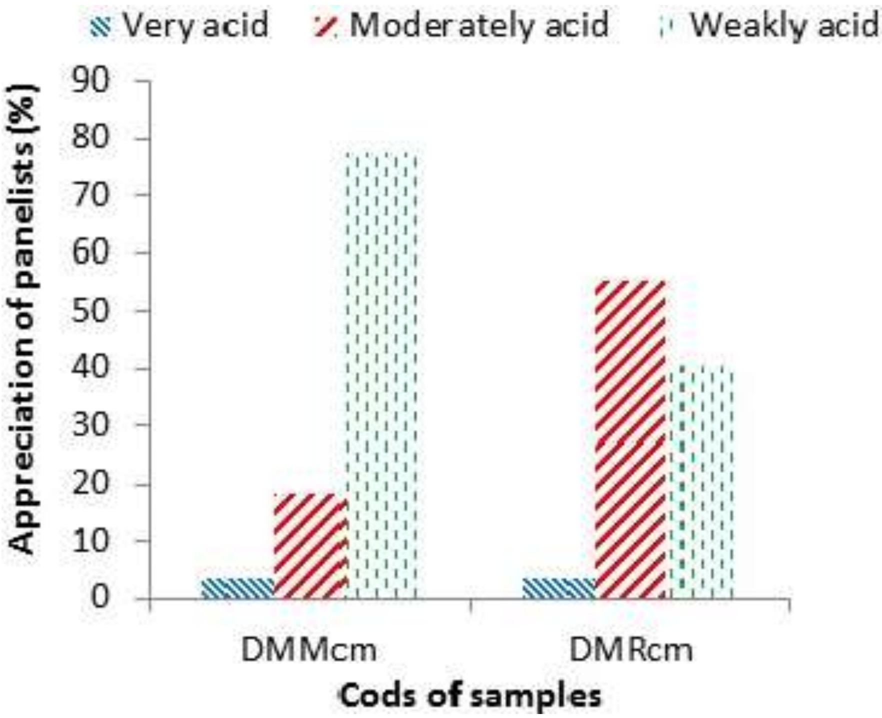

Figure 6. Appreciation of the acid taste of mango doughnuts; Where, DMMcm = Mango doughnut obtained with dough (Mango pulp + Maize flour) fried in crepe make and DMRcm = Mango doughnut obtained with dough (Mango pulp + Rice flour) fried in crepe maker.

Nutritional characteristics

The biochemical characteristics (moisture, tritrable acidity, total ash, fat, total sugars, proteins) of the dough and the mango doughnuts are displayed in Table 2. It can be seen that dough from formulation I, composed of mango pulp, maize flour and egg (DMM), and dough from formulation II, composed of the mango pulp, rice flour, and egg (DMR), contained the same level of moisture (68.68% ± 0.07). The moisture levels of the doughnuts prepared by crepe maker (DMMcm or DMRcm), and those prepared by gas fryer (DMMgf or DMRgf) ranged from 52.60 to 55.12% and 44.06 to 49.90%, respectively. Thus, the moisture content was significantly higher ($p<0.0001$) in doughnuts made with crepe maker than those made with gas fryer. The decrease in moisture content observed in the doughnut samples compared with dough is not surprising as this has also been reported by Shaker (2014) in potato strips, where the water contents drops from 77.25 to 30.51% after frying. This decrease of the water content is due to water evaporation from the heat of frying. Under the effect of heating, the water evaporates from the doughnuts and oil is subjected to endosmosis (Oroszvari et al., 2005). Indeed, frying is a result of dehydration under heat conditions in a hydrophobic environment resulting in a decrease of water content (Courtois et al., 2012).

The fat contents of the dough made with maize flour (DMM) or rice flour (DMR) were 12 and 13%, respectively. After frying, the fat contents in the doughnuts rose to 29.78 and 25.34% for the gas-fried (DMMgf) and crepe maker (DMRgf), respectively. Moreira et al. (1999) also found that the fat content of doughnuts was in the order of 20 - 25%. On the other hand, fat content of the mango doughnuts fried with the gas fryer (DMMgf, DMRgf) were slightly higher than these values. Other findings show that the oil absorbed in fried products increases with the quantity of water lost during frying (Rossell, 2001; Bouchon, 2009; Thanatuksorn et al., 2010; Galoburda et al., 2013). The endosmosis of oil is due to filling the spaces left by the evaporated water. This observation is confirmed in the present study because the samples having the highest fat content (29.78 and 25.34%) had the lowest moisture content (44.06 and 49.90%). However, the samples fried with crepe maker (DMMcm and DMRcm) had slightly elevated levels of fat (13.09 and 15.87%), respectively. It can be seen that the level of fat is higher in mango doughnuts obtained with the gas fryer than those obtained with the crepe maker, where the endosmosis of oil is limited. The

Table 2. Proximate composition of dough and doughnuts (% DM).

Samples (cods)	Moisture (%)	Titrable Acidity (%DM)	Total ash (%DM)	Fat (%DM)	Total sugar (%DM)	Proteins (% DM)	Energetic value (Kcal.100 g^{-1})
Dough							
Mango pulp + Maize flour + Egg (DMM)	68.68 ± 0.07^a	9.78 ± 0.00^b	1.15 ± 0.02^a	12.05 ± 0.04^d	61.99 ± 0.03^a	5.86 ± 0.13^b	357.86 ± 3.19^d
Mango pulp + Rice flour + Egg (DMR)	68.65 ± 0.01^a	10.48 ± 0.01^a	0.91 ± 0.01^b	13.12± 0.12^c	59.63^c ± 0.07^b	6.09 ± 0.02^a	366.44 ± 3.81^c
Doughnuts							
Mango pulp + Maize flour + Egg (DMMcm)	52.60± 0.04^c	4.62 ± 0.01^d	0.95 ± 0.05^b	13.09 ± 0.14^c	59.31 ± 0.05^c	5.53± 0.01^d	300.97 ± 3.16^f
Mango pulp + Maize flour + Egg (DMMgf)	44.06 ± 0.04^e	4.30 ± 0.00^f	0.85 ± 0.01^c	29.78 ± 0.15^a	40.37 ± 0.08^f	5.69± 0.02^c	422.26 ± 0.79^b
Mango pulp + Rice flour + Egg (DMRcm)	55.12 ±0.05^b	7.80 ± 0.00^c	0.84 ± 0.01^c	15.87 ± 0.05^e	58.85 ± 0.12^d	6.04 ± 0.07^a	328.21 ± 1.30^e
Mango pulp + Maize flour + Egg (DMRgf)	49.90 ± 0.03^d	4.38 ± 0.00^e	0.73 ± 0.03^d	25.34 ± 0.17^b	48.37 ± 0.04^e	5.96 ± 0.00^a	433.28 ± 6.96^a

Different letters a, b, c, d, e and f in the same row indicate statistically significant differences.

fat contents of the mango doughnuts fried with the crepe maker were relatively low. Total sugar content of the dough samples (DMM, DMR) were 59.63 and 62% respectively. After processing of dough into doughnuts (DMMcm, DMRcm, DMMgf, DMRgf), total sugars ranged from 40.37 to 58.85%. Sugar levels obtained were all significantly different (Table 2). The decrease in total sugar contents in the doughnut samples could be explained by caramelization of sugar and Maillard reactions which reduce sugars and amino acids during frying (Moyano et al., 2002). These reactions, which are responsible for the color, flavor and texture characteristics of the fried products, also produce compounds such as heterocyclic amines and acrylamides (Biego et al., 2009). Heterocyclic amines and acrylamides developed at temperatures between 100 and 200°C are suspected to be carcinogenic compounds (Friedman, 2003; Berlitz et al., 2004; Taubert et al., 2004; Pedreschi et al., 2004; Biego et al., 2009). However, deep frying at temperatures below 200°C may considerably limit their formation (Saguy and Dana, 2003). Since our doughnuts were fried at 155 and 135°C with a maximum time of 10 min, it could be assessed that the formation of these products would be limited.

The protein content of the dough samples ranged from 5.86 to 6.09% whereas that of the mango doughnuts ranged from 5.53 to 6.04%. A slight decrease in protein contents was observed in the doughnuts (DMMcm, DMMgf, DMRcm and DMRgf). Since the decrease in protein levels is not very significant, we could say that the frying temperature of the mango doughnut did not have a destructive effect on proteins or at least on total nitrogen. Nevertheless, protein digestibility may be affected by the process. Gonzalez (2007) reported that proteins are denatured into carboxylic groups under the effect of heat. It enters also in Maillard reactions with sugar to give new products such as acrylamide.

The average β carotene contents of the dough (DMM, DMR) ranged from 172.46 to 195.85 µg.100 g^{-1} DM, respectively (Table 3). Results show that β-carotene contents in the dough made from maize flour (DMM) was higher than those made from rice flour (DMR). β-carotene content in the mango doughnuts ranged from 85.49 to 110.32 µg.100 g^{-1} DM. The decrease in β-carotene content was observed after frying, and the mango doughnuts produced with the gas fryer had the lowest beta carotene level (85.49 and 90.91 µg.100 g^{-1}). Higher losses were recorded in mango doughnuts produced with the gas fryer (50.44 and 50.68%) compared with those produced with the crepe maker (37.43 and 43.68%). The decrease in the β carotene content observed in the mango doughnuts obtained with crepe maker and gas fryer was likely due to the isomerization reactions exposed by carotenoids during frying. These isomers then entered into complex reactions to form new products such as flavors (Villota and Hawkes, 1992; Belitz et al., 2004).

Conclusion

Mango pulp can be used to produce good quality doughnuts for human consumption. Appreciation of the doughnuts, as indicated by the panelists,

Table 3. Beta carotene contents and energetic value of mango doughnuts.

Samples (cods)	β-carotene (µg.100 g^{-1} DM)	β-carotene loss rate (%)
Dough		
Mango pulp + Maize flour (DMM)	195.85 ± 3.48[a]	-
Mango pulp + Rice flour (DMR)	172.46 ±1.30[b]	-
Doughnuts		
Mango pulp + Maize flour (DMMcm)	110.32± 5.07[c]	43.68
Mango pulp + Maize flour (DMMgf)	90.91 ± 17.81[d]	53.68
Mango pulp + Rice flour (DMRcm)	107.92 ± 4.59[c]	37.43
Mango pulp + Rice flour (DMRgf)	85.49 ± 3.21[d]	50.44

Different letters a, b, c, d, e and f in the same row indicate statistically significant differences.

suggests that they could be easily accepted by families, restaurants and street food vendors. The use of the crepe maker reduced the fat content of final products compared to frying in oil. Processing with the crepe maker also gave doughnuts with higher beta-carotene content. Adopting the formulation of mango doughnuts would help diversify mango consumption and improve growers'/processors' incomes. This product could be interesting for the food processing actors. This would not only reduce the post-harvest loss of mango, but also increase food and nutrition security in mango producing countries.

Abbreviations

DMM = dough consisting of mango pulp + maize flour +egg,
DMR = dough consisting of mango pulp + rice flour +egg,
DMMcm = Doughnuts (mango pulp + maize flour +egg) obtained by frying in the crepe maker
DMRcm = Doughnuts (mango pulp + rice flour +egg) obtained by frying in the crepe maker,
DMMgf = Doughnuts (mango pulp + maize flour +egg) obtained by frying in the gas fryer
DMRgf = Doughnuts (mango pulp + rice flour +egg) obtained by frying in the gas fryer

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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