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Muffins fortified with *Dacryodes macrophylla* L. fruit: quality and sensory evaluation

Alvine Sandrine Ndinchout[1], Debapriya Chattopadhyay[2,*], Nyegue Maximilienne Ascension[1], Varinder Kaur[3], Narpinder Singh[3], Moundipa Fewou Paul[1]

[1] University of Yaoundé I, Yaounde, Cameroon

[2] Maharaja Sayajirao University of Baroda, Vadodara, India

[3] Guru Nanak Dev University, Amritsar, India

* e-mail: dpchat6@gmail.com

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Abstract:
Introduction. Due to the increasing demand for natural and functional products, scientists together with industries are conducting research to improve the nutritional quality of food. One of the ways to enhance the functionality of food is to add fruits or vegetables to their formulations. In this study, we attempted to develop muffins fortified with *Dacryodes macrophylla* L. fruit as a value-added ingredient.
Study objects and methods. Our study objects included *D. macrophylla* L. extract and six muffins: three eggless samples and three egg-containing samples. Each group included control and experimental samples. The experimental samples containing 0.5 and 1% of *D. macrophylla* extract instead of wheat flour were evaluated for muffin-making properties. All the samples were analyzed for their physicochemical, antioxidant, and sensory properties, as well as rheological parameters.
Results and discussion. We found that *D. macrophylla* L. reduced the water activity, color values (L^*, a^*, b^*), and firmness of muffins. It had no significant effect on baking loss, height, moisture, cohesiveness, springiness, gumminess or chewiness, but tended to decrease the specific volume of muffins. However, *D. macrophylla* fruit increased the specific gravity, improved rheology properties, and tended to increase adhesiveness and mineral contents. Na and K varied from 5.93 to 7.75 and 2.88 to 7.35 mg/g, respectively. Furthermore, *D. macrophylla* fruit significantly improved the muffins' antioxidant activities. According to sensory evaluation, the muffins made with egg solids and 0.5% of *D. macrophylla* fruit had higher sensory scores than the other experimental samples.
Conclusion. D. macrophylla L. fruit is a good potential ingredient for enriching muffins and developing new functional bakery products. However, further research is needed to improve the color reproduction of muffins and determine the optimal concentration of *D. macrophylla.*

Keywords: *Dacryodes macrophylla* L. fruit, minerals, moisture content, muffins, rheology, sensory, specific gravity, texture analysis, water activity

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INTRODUCTION

The growth in diet-related illnesses such as obesity, cardiovascular diseases, and some types of cancer led the World Health Organization (WHO) and other related organizations to encourage the consumption of fortified food [1]. Fortification is a deliberate addition of essential nutrients to a product to conserve its nutritional quality, enhance its added value, provide it with some functions, as well as to prevent or correct a particular nutritional deficiency in the population [2, 3]. However, one of the essential requirements of fortification is an appropriate food vehicle. Food vehicles should be widely consumed by a large proportion of the population to be able to meet the nutritional needs of the target group [4].

Baked food products are good potential vehicles of micronutrients and bioactive compounds because they are consumed all over the world by children and adults. Muffin is one of the most common bakery

products appreciated by people due to its taste and soft texture. Muffins are ready-to-eat snack food, similar to cupcakes, which are usually eaten at breakfast, as evening snacks, for tea, or at other meals. Muffins are also served as snacks during many celebrations. A special feature of muffins is their porous structure that leads to high volume and spongy texture [5, 6].

In response to the increasing demand for healthy, natural, and functional products, scientists are doing tremendous work in collaboration with industries to improve the nutritional quality of food products. Since fruits and vegetables are rich in natural nutrients, phytochemicals, and phenolic compounds with biological properties, incorporating them in muffins is a good way to fulfill the desires of consumers [7]. Furthermore, natural antioxidants from fruits and vegetables may inhibit lipid peroxidation in food and improve food quality and safety [5].

Dacryodes macrophylla L. is a fruit tree belonging to the *Buseraceae* family that is widespread in Cameroon, Equatorial Guinea, and Gabon. The fruits are commonly consumed directly or used to make natural juices and jelly [8]. *D. macrophylla* has red color that indicates the presence of phenolic compounds (e.g., anthocyanin) and some minerals (e.g., iron).

To the best of our knowledge, there are no available published data on *D. macrophylla* fruits as a potential value-added ingredient of muffins. Nevertheless, in our previous work, we studied the dyeability and bacterial resistance of these fruits on woolen fabric [9]. Ngondi *et al.* also showed that hydroethanolic extract of *D. macrophylla* fruits could have anti-obesity and antioxidant properties [10].

Therefore, we aimed to develop value-added muffins fortified with *D. macrophylla* fruits and to study the impact of that incorporation on the quality and acceptability of muffins. To achieve this aim, we fortified muffins with 1% of *D. macrophylla* fruit. Then, we evaluated their physicochemical properties, rheological parameters, and sensory characteristics. In addition, we determined the antioxidant properties of fortified muffins to assess their functionality.

STUDY OBJECTS AND METHODS

Study objects. We studied two groups of muffins: with egg and without egg. Each group contained a control and experimental samples with 0.5 and 1% of *Dacryodes macrophylla* L. extract instead of wheat flour.

Materials. Wheat flour (maida), sugar, baking soda, baking powder, egg, vegetal oil (soybean), and liquid milk (green packet Verka) were purchased from a local supermarket (Amritsar, India). 2,2-diphenyl-1-picrylhydrazyl (DPPH), 6-hydroxy-2,5,7,8-tetramethylchronan-2-carboxylic acid (Trolox), and ascorbic acid were obtained from Sigma-Aldrich Company Ltd. (St Louis, MO, USA). Analytical grade methanol, NaOH, NaCl, HNO_3, H_2SO_4, and $HClO_4$ were provided by Sisco Research Laboratories Ltd. (Mumbai, India). We used such equipment as an orbital shaker (Remi, Mumbai, India), a rotary evaporator (IKA Werke GmbH and Co. KG, Staufen, Germany), and a freeze dryer (Christ Beta 2-8 LD plus, Germany). Freeze-dried *D. macrophylla* L. was used to enhance the antioxidants and color of muffins.

Preparation of *D. macrophylla* extract. The seeds of fresh *D. macrophylla* L. fruit were discarded and the rest of the pulp was dried in a freeze dryer, followed by an extraction with 70% ethanol in an orbital shaker for 2 h at 200 rpm. It was then centrifuged at 4000 g for 10 min at 25°C and the supernatant was collected. The residue was re-extracted and the supernatant was collected and concentrated in a rotary evaporator under reduced pressure at 45°C. The remaining water was eliminated in the freeze dryer and the DME was kept in a fridge at –70°C in sealed plastic containers for the following experiments.

Preparation of muffins. Sugar was first powdered with a mixer and eggs were manually beaten in a bowl with a spoon (just for mixing purposes) for 1 min before weighing. All the ingredients were then weighed to prepare six different muffins (Table 1). Preliminary baking was done to standardize the formulation of muffins and to find the sensorily acceptable concentration of *D. macrophylla* extract.

Then, the required number of eggs was mixed with sugar using an electric hand mixer until creamy. Sunflower oil was added to the creamy mixture, which was continuously mixing, followed by the required amount of liquid milk. After about 4 min of mixing, wheat flour was gradually added to the emulsified gel during continuous stirring in the same direction. Baking powder was the last ingredient to be added to the formulation. The dough was then introduced into greased muffin molds and baked in the preheated oven at 210°C for 8 min. The muffins were allowed to stand for 2 min in the oven and then taken out to cool down for about 30 min at room temperature.

The samples were then kept in sealed plastic food-grade bags at room temperature for further analysis. For eggless muffins, the first step was to mix sugar with oil and the last step was to add baking soda after baking powder. For fortified muffins, *D. macrophylla* extract was dissolved in liquid milk before being added to the mixture (with egg and without egg).

Rheology of dough. Rheological tests of muffin dough were performed with a rheometer (MCR-102, Anton Paar Austria) as reported by Jantider *et al.* [11]. The dough sample was loaded between two parallel plate geometric probes of 40 mm in diameter (PP40) and kept for 5 min (for equilibration). The gap between the plates was 1 mm and the sample was run at 25°C. Stress was set at 0.1 Pa and frequency at 1 rad/s according to the linear viscoelastic region. The measurements of storage modulus (G', solid component) and loss modulus (G'', liquid component) were recorded.

Specific gravity of dough. The specific gravity of each type of muffin dough was determined gravimetrically by dividing the weight of a known

Table 1 Formulation of muffins

Ingredients, g	Eggless muffins			Egg-containing muffins		
	Control	1% DME	0.5% DME	Control	1% DME	0.5% DME
Wheat flour	149	148.5	149.25	150	148.5	149.25
Sugar	85	85	85	85	85	85
Vegetal oil	75	75	75	75	75	75
Milk	75	75	75	75	75	75
Baking powder	5.1	5.1	5.1	5.1	5.1	5.1
Eggs	0	0	0	75	75	75
Baking soda	1	1	1	0	0	0
Dacryodes macrophylla L.extract	0	1.5	0.75	0	1.5	0.75

volume of dough by the weight of an equal volume of water. A standard container was used for measurements [12].

Moisture content. The gravimetric method was used to determine the moisture content in muffin crumb. For this, 2 g of a sample was dried in an air oven at 105°C until no further weight change, using a clean, dry, and pre-weighed aluminum moisture dish. The moisture content was calculated as follows:

$$\text{Moisture content (\%)} = 100 - \frac{(W_1 - W_2)}{W_1} \times 100 \quad (1)$$

where W_1 is the weight of samples before drying; W_2 is the weight of samples after drying (in grams).

Weight loss. The baking loss of muffins was determined in percentage based on the weight of muffin after baking and the weight of muffin dough by using the following formula [13]:

$$\text{Weight loss (\%)} = \frac{(W_d - W_m)}{W_d} \times 100 \quad (2)$$

where W_d is the weight of dough; W_m is the weight of muffin.

Muffin height and diameter. A digital caliper was used to measure the height of muffins (from the highest to the lowest point) and their diameters (mm).

Water activity. The water activity of the samples was measured by placing about 2 g of muffin crumb on a plastic dish of a water activity meter (AquaLab TE, series 3B, version 3.4, Decagon). After calibration with water, values were recorded at 25°C in triplicate.

Muffin volume. The volume of muffins was determined by the millet-seed displacement method as described by Rashida *et al.*, with slight modification [5]. An empty baker was filled with millet seeds and then the seeds were transferred into a container. Then, a muffin was placed in the center of an empty baker and the seeds were loaded back from the container. The remaining seeds were put in a measuring cylinder and their volume (in mL) represented the volume of the muffin. The specific volume was then calculated by dividing the volume recorded by the weight of the muffin (mL/g).

Crude fat. Crude fat of the muffins was estimated gravimetrically on the Soxhlet apparatus [13]. The samples were weighed (W_1) and lipid was extracted with hexane for 6 h at 65°C. The lipid extract was then dried in the oven at 102°C till constant weight. Crude fat was expressed in percentage and calculated as follows:

$$\text{Crude fat (\%)} = \frac{W_2}{W_1} \times 100 \quad (3)$$

where W_1 is the weight of a sample in grams before lipid extraction; W_2 is the weight of the dried lipid extract.

Ash content. Total ash was determined by the incineration method in a muffle furnace. The samples were weighed in porcelain crucibles and incinerated for 1 h at 550 ± 10°C. White ash was cooled and weighed. Ash content was expressed in percentage by using the following formula:

$$\text{Ash (\%)} = \frac{W_2}{W_1} \times 100 \quad (4)$$

where W_1 is the weight of a sample in grams before incineration; W_2 is the weight of the sample after incineration.

Mineral content. ***Preparation of samples.*** The defatted muffins and extracts were digested using a mixture of tri-acid [14]. Three milliliters (3 mL) of tri-acid (HNO_3:H_2SO_4:$HClO_4$ = 5:1:1) was added to 0.5 g of a sample and the mixture was heated at 80°C. After about 2 min, two milliliters (2 mL) of tri-acid was added again under continuous heating until the fume of the mixture became transparent. The digested samples were then cooled at room temperature and the volume was made up to 20 mL with double distilled water. After filtration with Whatman filter paper, the solution was diluted to 100 mL with double distilled water and stored at room temperature as a stock sample solution for mineral estimation.

Calcium. To quantify calcium content, 5 mL of the stock sample solution was diluted to 50 mL with double distilled water. 2 mL of NaOH 1N was added and then a pinch (about 100 mg) of the murexide indicator (a mixture of grind 0.2 g of ammonium purpurate with 100 g of NaCl) to turn the solution pink.

The pink sample solution was then titrated with EDTA solution, 0.01 M (3.723 g of EDTA dissolved in 1000 mL of water) until the pink color turned dark purple. The endpoint of titration was determined by comparing the endpoint color of the sample to the one

obtained with the blank (titration with 50 mL of water). The calcium content (mg/g) was calculated as follows:

$$\text{Calcium content} = \frac{\text{Volume of EDTA used}}{\text{Volume of sample used}} \times 100 \quad (5)$$

Magnesium. To determine the magnesium content, we first estimated the hardness (Ca + Mg) of the samples. For this, 5 mL of the stock solution was diluted to 50 mL with water in a conical flask, followed by the addition of 1 mL of the buffer solution and about 100 mg of the EBT indicator (a mixture of grind 0.40 g of Erichrome with 100 g of NaCl). The wine red color developed and the titration was done with 0.01 M of EDTA. The endpoint was reached by comparing the blue color of the sample solution with the one obtained with the blank (water). Then, magnesium was measured in mg/mL by subtracting the volume of EDTA used to determine hardness to the one used to quantify calcium:

$$\text{Mg} = \frac{(Y - X) \times 400.8}{Vs \times 1{,}645} \quad (6)$$

where Y is the volume of EDTA used to estimate hardness, mL; X is the volume of EDTA used to quantify calcium, mL; and Vs is the volume of a sample, mL. The result was expressed in mg/g of the sample.

Phosphate. The phosphate content was determined spectrophotometrically at 625 nm. Five milliliters (5 mL) of the stock solution was diluted to 50 mL with water and then mixed with 2 mL of ammonium molybdate reagent (prepared by mixing 25 g ammonium molybdate dissolved in 175 mL water and 280 mL H_2SO_4 diluted with 400 mL of water and making the final volume up to 1000 mL with distilled water) and 0.5 ML of stannous chloride (2.5 g $SnCl_2$ dissolved in 100 mL water). The mixture was kept for 15 min and then used to record optical density against the blank on a microplate reader.

Potassium, Sodium and Zinc. These elements were analyzed by atomic absorption spectrometry [15]. KCl, NaCl, and $ZnSO_4$ were used as a standard to quantify K, Na, and Zn, respectively. A serial dilution of each standard was performed to make a calibration curve for each element. Subsequently, the filtrated liquor from mineralization of each sample was diluted with double distilled water and the content of minerals was determined at 766.5 nm for K, 330.2 nm for Na, and 213.9 nm for Zn with an AA 6300 spectrometer (Shimadzu, Tokyo, Japan) against the blank by extrapolation of absorbance on the calibration curve of each element. The final amount (dry weight) was then calculated in mg/g of the sample.

Muffin color. The color of the muffins was determined the next day after preparation by recording the L^*, a^*, and b^* values of crust and crumb. A spectrophotometer with spectra match software was used according to the CIE Lab color scales, where L^* goes in a range of 0 to 100 from dark to light, a^* from green to red, and b^* from blue to yellow. Color values were measured three times at three different points on each muffin and then averaged.

Texture analysis. The texture profile of crumb cubes (12.5 mm^3) from the middle of the muffins was determined using a texture analyzer (Model EZ-SX, Stable microsystems, Shimadzu, UK) equipped with a 5-kg load cell [16]. A double compression test was performed by putting a crumb cube sample in the center of a heavy-duty platform (HD P/90) and subjecting it to compression (50%) with an aluminum 75-mm cylindrical probe (P/75) at 1 mm/s. The texture parameters (firmness, cohesiveness, gumminess, chewiness, and springiness) were calculated based on the texture profile graphic [17].

Antiradical activity. ***Preparation of extract.*** To prepare the extract, 100 mg of a defatted powdered muffin (muffins defatted with hexane were dried in the oven at 40°C and powdered in a porcelain container) was mixed with 1 mL of 80% methanol in an Eppendorf tube. The extraction was performed in the orbital shaker for 2 h at 25°C followed by centrifugation at 500×g for 15 min. Supernatants were pooled in an empty Eppendorf tube for antiradical analysis.

DPPH assay. Free radical scavenging of the muffin samples was determined according to the method described by Uswa and Rabia, with slight modification [18]. 100 µL of a muffin extract was added to 3.9 mL of the DPPH solution (2.4 mg of DPPH in 100 mL of 80% methanol) and vortexed thoroughly. The mixture was then incubated for 30 min in the dark and the absorbance was read at 515 nm by using a spectrophotometer against 80% methanol as the blank. The control was 3.9 mL of DPPH + 100 µL of the solvent. A calibration curve of trolox was plotted, with the result expressed in µM trolox equivalent/mg of the sample.

Sensory evaluation. The overall acceptability of the fortified muffins was evaluated on the 9-point hedonic scale [19]. Muffin samples were given randomly to a panel of 100 untrained volunteers from Guru Nanak Dev University, Amritsar (India). They were requested to score their appreciation from extremely unpleasant (1) to extremely pleasant (9) based on color, odor, texture, taste, and overall assessment. The panelists were also asked to rinse their mouths with water before tasting each sample.

Data management and statistics. The results were analyzed with Statgraphics Plus program Version 2.1. Data were presented as mean values of triplicate reading ± standard deviation subjected to one-way analysis of variance (ANOVA). Tukey test was used to compare the means, and a significant difference was determined at $P < 0.05$.

RESULTS AND DISCUSSION

Table 2 shows the physical properties of the muffins fortified with *Dacryodes macrophylla* L. We observed that the baking loss in the eggless muffins (9.00–9.56%) was statistically the same but significantly ($P < 0.05$) lower than in the muffins with eggs (11.22–11.67%).

Similarly, the moisture content in the muffins with eggs was higher than in the eggless samples. This might be related to the weaker dough consistency of the muffins with eggs, leading to higher viscosity. When the viscoelasticity of dough is high, air bubbles incorporated during the creaming step of preparation tend to increase and rise to the surface of the muffin, getting lost at the beginning of baking. Moreover, carbon dioxide and vapor pressure produced during baking might escape and increase the baking loss and moisture content. Larger cells also increase baking loss and usually quicken moisture migration during baking [20].

Specific gravity gives general information about air bubbles that are incorporated in the dough during mixing and have a direct effect on the muffin height. Higher specific gravity means less incorporation of air and a lower muffin height. We found the specific gravity values for the eggless muffins (1.12–1.14) to be higher than that for the muffins with eggs (1.03–1.07). Therefore, the height of the eggless muffins was lower (33.97–34.37 mm) that that of the muffins with eggs (41.00–41.40 mm). Table 2 also shows a slightly higher specific gravity, and therefore a lower height, in the samples fortified with the *D. macrophylla* fruit extract. These results might be explained by the presence of eggs which provide the dough with water and protein (an egg contains 74% of water and 12.8% of protein), thereby increasing its viscoelasticity.

Another reason might be the amount of air incorporated in the egg-containing dough compared to the eggless dough. Potential fibers present in *D. macrophylla* fruits might have increased the dough viscosity and consequently decreased air bubbles. Similar results were reported by Rashida *et al.* and Manuel *et al.* who found that using fibers in bakery increased the specific gravity and viscosity of the dough, which might further lead to a lower height and volume of muffins by obstructing air incorporation during mixing [5, 17].

At the same wavelength, the specific volume of the eggless muffins (1.66–1.70 mL/g) was significantly lower than that of the muffins with eggs (2.18–2.36 mL/g). Specific volume indicates the number of air bubbles retained in the final product after baking. The higher specific volume of the muffins with eggs could be explained by higher dough viscoelasticity (due to protein and water from eggs) which might have enhanced the expansion of air bubbles by carbon dioxide and vapor pressure during baking.

Besides, Shevkani and Singh reported that higher dough viscoelasticity ensured air bubbles stability during baking [21]. They also found that the incorporation of proteins in muffin dough increased the specific volume and height of the final products. In our study, however, the specific volume of the muffins with eggs was slightly lower due to the *D. macrophylla* fruits extract.

Similar results were found by Singh *et al.* and Prerna *et al.* who fortified muffins with Jambolan fruit pulp and red capsicum pomace powder, respectively [12, 16]. Our results might be justified by the presence of fibers in *D. macrophylla* fruits which might have inhibited the expansion of muffin by weakening the ability of the gluten matrix to retain carbon dioxide during baking [13].

Water activity (A_w) is an important parameter that enhances the shelf life of dry foods when their value is low. It represents free water in the food and can be defined as a ratio of vapor pressure of the food to the vapor pressure of pure water. The water activity of the eggless muffins (0.81–0.83) was lower than that of the muffins with eggs (0.87–0.90). Consequently, the shelf life of the former samples was higher.

In contrast, Table 2 shows a slight decrease in water activity of the egg-containing muffins fortified with the *D. macrophylla* fruit extract. It might be attributed to fibers in *D. macrophylla* fruits absorbing more water and thereby reducing unbound water in muffins.

Moisture, fat, and ash contents (Table 2) in the control muffins with eggs (25.33, 18.61, and 1.27) were significantly higher than those in the control eggless samples (19.17, 16.82, and 1.07). Higher moisture might be attributed to egg yolk phospholipids acting as emulsifiers and thereby holding moisture in emulsified form.

Table 2 Physical properties of muffins with *Dacryodes macrophylla* extract

Physical properties	Eggless muffins			Egg-containing muffins		
	Control	1% DME	0.5% DME	Control	1% DME	0.5% DME
Baking loss, %	9.00 ± 0.33^a	9.56 ± 0.48^a	9.11 ± 0.11^a	11.67 ± 0.19^b	11.22 ± 0.11^b	11.56 ± 0.29^b
Specific gravity	1.12 ± 0.00^c	1.14 ± 0.00^d	1.13 ± 0.00^d	1.03 ± 0.00^a	1.07 ± 0.00^b	1.06 ± 0.00^b
Specific volume, mL/g	1.70 ± 0.03^a	1.66 ± 0.01^a	1.69 ± 0.02^a	2.36 ± 0.01^d	2.18 ± 0.01^b	2.27 ± 0.01^c
Water activity	0.83 ± 0.00^a	0.81 ± 0.00^a	0.82 ± 0.00^a	0.90 ± 0.00^c	0.87 ± 0.00^b	0.89 ± 0.00^c
Moisture, %	19.17 ± 1.64^a	19.67 ± 0.73^a	19.33 ± 0.88^a	25.33 ± 0.44^b	26.00 ± 1.04^b	25.50 ± 0.76^b
Crude fat, %	16.82 ± 0.13^a	16.84 ± 0.46^a	16.82 ± 0.22^a	18.61 ± 0.34^b	18.63 ± 0.24^b	18.63 ± 0.31^b
Height, mm	34.37 ± 0.50^a	33.97 ± 0.30^a	34.23 ± 0.27^a	41.40 ± 0.35^b	41.00 ± 0.21^b	41.33 ± 0.33^b

Values are mean ± standard deviation of triplicate experiments. The values carrying the same letter on the same row are not statistically significant ($P \geq 0.05$)

Table 3 Mineral and ash contents of muffins fortified with *Dacryodes macrophylla* extract

Component	Eggless muffins			Egg-containing muffins		
	Control	1% DME	0.5% DME	Control	1% DME	0.5% DME
Ca, mg/g	3.58 ± 0.53^{a}	5.18 ± 0.53^{ab}	4.38 ± 0.27^{a}	4.11 ± 0.53^{a}	6.79 ± 0.53^{b}	5.72 ± 0.27^{ab}
Mg, mg/g	2.27 ± 0.32^{a}	2.92 ± 0.56^{a}	2.76 ± 0.32^{a}	2.60 ± 0.32^{a}	3.90 ± 0.56^{a}	3.73 ± 0.43^{a}
P, mg/g	0.66 ± 0.13^{a}	0.87 ± 0.01^{abc}	0.83 ± 0.02^{ab}	1.00 ± 0.02^{bc}	1.11 ± 0.02^{c}	1.05 ± 0.02^{bc}
Na, mg/g	5.03 ± 0.03^{a}	7.19 ± 0.01^{d}	5.82 ± 0.02^{b}	5.93 ± 0.06^{b}	7.75 ± 0.01^{e}	6.75 ± 0.02^{c}
K, mg/g	1.52 ± 0.02^{a}	3.61 ± 0.01^{d}	2.40 ± 003^{b}	2.88 ± 0.11^{c}	5.36 ± 0.03^{f}	3.87 ± 0.05^{e}
Zn, $\times 10^2$ mg/g	0.39 ± 0.03^{a}	1.53 ± 0.08^{bc}	1.13 ± 0.09^{b}	1.67 ± 0.31^{c}	3.36 ± 0.06^{e}	2.45 ± 0.21^{d}
Ash, %	1.07 ± 0.07^{a}	1.12 ± 0.06^{ab}	1.11 ± 0.06^{ab}	1.27 ± 0.03^{ab}	1.34 ± 0.03^{b}	1.29 ± 0.05^{ab}

Values are mean ± standard deviation of triplicate experiments. The values carrying the same letter on the same row are not statistically significant ($P \geq 0.05$)

Similarly, the increment of fat and ash in the control muffins with eggs may be due to the inherent presence of fat and minerals in the egg. The incorporation of *D. macrophylla* did not have any significant effect on moisture or fat, although it slightly increased the ash content. These results might be due to lower fat and ash contents in *D. macrophylla*.

Furthermore, the mineral content (Table 3) in the control muffins with eggs was higher than that in the control eggless muffins, particularly phosphorus, sodium, potassium, and zinc, which showed a significant difference. This result was expected because of the inherent presence of minerals in the egg. Also, both samples clearly illustrated the enhancement of minerals in the muffin fortified with the *D. macrophylla* extract, thereby showing this extract as a rich source of minerals.

Our results were in line with those found by Sheetal *et al.*, who reported increased mineral contents in muffins fortified with dried Moringa Oleifera [1].

The rheology parameters of muffin dough s are presented in Table 4 as G', G'', and tan δ, where G' (storage modulus) represents dough elasticity meaning a solid-like behavior, G'' (loss modulus) represents dough viscosity meaning a liquid-like behavior, and tan δ (ratio of G'' over G') tends to zero for solids and to infinity for liquids.

We observed that the storage modulus of all doughs was greater than the loss modulus, indicating a typical elastic dough behavior required for good quality muffins. Besides, Nazanin and Mostafa reported that the viscosity of cake dough should be optimum to hold air bubbles in the final product, since too low dough viscosity inhibits air incorporation and too high dough viscosity inhibits expansion of air bubbles [22].

In our study, the control muffin with egg exhibited the highest tang δ, indicating very soft gel dough. As can be seen in Table 4, the moduli of the eggless doughs were lower than the moduli of the doughs made with eggs. This was due to the functional role of an egg as a good emulsifier increasing dough viscoelasticity.

The moduli G' and G'' increased both for the eggless and egg-containing muffins fortified with 1% *D. macrophylla* This might be attributed to the capacity of potential fibers in *D. macrophylla* to absorb water in the dough, thereby lowering the free water level available to facilitate the movement of particles in the matrix. The direct consequence of this process was higher dough viscoelasticity. This finding was also supported by Jantinder *et al.* and Felicidad *et al.* who found that adding proteins and Jambolan fruit pulp increased muffin dough viscosity and viscoelasticity, respectively [16, 23].

The color of bakery products is one of the most important parameters that influences consumers' purchasing choices. Crumb color highly depends on the formulation ingredients, as well as the duration and temperature of baking, whereas crust color depends on caramelization and Maillard reactions.

The color data for our muffins are given in Table 5 as L^*, a^*, b^* and DE corresponding to lightness, redness, yellowness, and different color. We observed that the L^* and a^* values of crumb and crust color for the control muffins with egg were slightly lower than those for the control eggless muffins but the difference

Table 4 Rheology parameters of muffins with 1% of *Dacryodes macrophylla* extract

Rheology parameters	Eggless muffins			Egg-containing muffins		
	Control	1% DME	0.5% DME	Control	1% DME	0.5% DME
G'	103.90 ± 9.38^{a}	120.90 ± 9.39^{a}	–	664.00 ± 22.62^{b}	804.00 ± 23.13^{c}	–
G''	41.00 ± 3.56^{a}	42.29 ± 3.13^{a}	–	286.11 ± 7.47^{b}	299.9 ± 8.02^{b}	–
Tang delta	0.39 ± 0.03^{a}	0.35 ± 0.031^{a}	–	0.43 ± 0.01^{b}	0.37 ± 0.01^{a}	–

Values are mean ± standard deviation of triplicate experiments

Table 5 Color parameters of muffins with 1% of *Dacryodes macrophylla* extract

Color data	Color parameters	Eggless muffins			Egg-containing muffins		
		Control	1% DME	0.5% DME	Control	1% DME	0.5% DME
Crust	*L**	47.67 ± 0.58^{b}	38.17 ± 1.43^{a}	–	46.85 ± 0.40^{b}	34.74 ± 1.32^{a}	–
	*a**	3.80 ± 0.27^{d}	2.16 ± 0.09^{c}	–	0.95 ± 0.03^{b}	–0.17 ± 0.03^{a}	–
	*b**	22.38 ± 0.15^{b}	19.01 ± 0.49^{a}	–	28.55 ± 0.25^{c}	21.76 ± 0.32^{b}	–
	DE	46.56 ± 1.18^{a}	52.24 ± 0.13^{b}	–	47.70 ± 1.50^{a}	50.70 ± 0.63^{b}	–
Crumb	*L**	69.31 ± 1.13^{c}	46.70 ± 0.30^{b}	–	52.36 ± 1.75^{b}	36.21 ± 2.59^{a}	–
	*a**	10.33 ± 0.51^{c}	6.73 ± 0.58^{b}	–	6.16 ± 0.27^{b}	0.90 ± 0.13^{a}	–
	*b**	29.52 ± 0.21^{c}	23.49 ± 0.49^{b}	–	38.51 ± 0.16^{d}	18.03 ± 0.89^{a}	–
	DE	40.40 ± 2.72^{a}	57.40 ± 1.80^{c}	–	46.22 ± 0.07^{b}	69.62 ± 0.97^{d}	–

Values are mean ± standard deviation of triplicate experiments. The values carrying the same letter on the same row are not statistically significant ($P \geq 0.05$)

was not significant ($P \geq 0.05$). However, the *b** value of the control muffins with egg was higher than that of the control eggless muffins. This result could be due to egg protein enhancing the Maillard reaction by providing amino acid which may have reacted with sugars to generate dark-brown substances, thereby reducing the lightness of the final product, as well as redness [21, 22]. However, high yellowness might be attributed to the yellow part of the egg which might have impaired the color of the muffin dough. Moreover, incorporating the *D. macrophylla* extract decreased the *L**, *a**, *b** and DE values of the muffins (crumb and crust). This might be due to the pigments and polyphenol interacting with other constituents of the dough to impart greenness, thereby darkening the muffin's color. These results were in line with those reported by Rashida *et al*. and Marina *et al*. who noticed a reduction in the *L**, *a**, and *b** values with increased amounts of wheatgrass powder and avocado puree in muffin dough, respectively [5, 24].

Since the eggless and egg-containing muffins with 0.5% DME were heterogeneous, they were not included in the color analyses.

The textural parameters of the muffins are presented in Table 6. We found that the eggless muffin (4.68) was firmer than the muffin with egg (3.65). This was expected because an egg is a good emulsifier that acts as a plasticizer by increasing dough viscoelasticity and thereby reducing muffin firmness.

We also noticed that muffin firmness showed an opposite trend to the specific volume. This was in line with Nazaninet and Mostafa who concluded that softness was improved by both a higher cake volume and the anti-firming effect of the emulsifiers [22]. Furthermore, we found that firmness decreased with the incorporation of *D. macrophylla* This result was consistent with Prerna *et al*. who reported a decrease in muffin hardness with an increase in capsicum pomace [12]. Chewiness corresponds to the amount of energy required to disintegrate food for swallowing. Chewiness and gumminess of muffins follow the same trend as hardness since both parameters are dependent on firmness [17]. Springiness is a desirable property indicative of muffin elasticity, since it measures the extent of recovery between the first and the second compression. In our study, the springiness values were generally higher (0.68–1.97) than those obtained by Shevkani and Singh who added different protein isolates to muffins (0.64–0.85) [21].

The higher springiness of the control muffin with egg (1.97), compared to the control eggless sample (1.27), might be due to egg protein aggregation that improved the quality of muffins. However, this textural parameter decreased with the incorporation of *D. macrophylla* Prerna *et al*. also reported a decrease in springiness with the incorporation of capsicum pomace [12].

Cohesiveness is the ability of a material to stick to itself. It measures the internal resistance of food

Table 6 Texture parameters of muffins under study

Texture parameters	Eggless muffins			Egg-containing muffins		
	Control	1% DME	0.5% DME	Control	1% DME	0.5% DME
Hardness	4.68 ± 1.57^{c}	2.96 ± 0.55^{a}	3.03 ± 0.14^{a}	3.65 ± 0.32^{b}	2.61 ± 0.20^{a}	3.01 ± 0.05^{a}
Adhesiveness, mJ	0.007 ±0.003^{a}	0.008 ± 0.002^{a}	0.006 ±0.002^{a}	0.022 ± 0.002^{b}	0.031 ± 0.004^{bc}	0.023 ± 0.005^{b}
Cohesiveness	0.17 ± 0.011^{a}	0.16 ± 0.01^{a}	0.17 ± 0.01^{a}	0.29 ± 0.04^{b}	0.23 ± 0.01^{ab}	0.24 ± 0.01^{ab}
Springiness, mm	1.27 ± 0.11^{ab}	0.68 ± 0.04^{a}	0.75 ± 0.24^{a}	1.97 ± 0.45^{b}	1.02 ± 0.14^{ab}	0.84 ± 0.14^{a}
Gumminess, N	1.35 ± 0.33^{b}	0.63 ± 0.06^{ab}	0.71 ± 0.06^{ab}	1.05 ± 0.21^{ab}	0.48 ± 0.09^{a}	0.52 ± 0.03^{a}
Chewiness, mJ	3.02 ± 1.14^{b}	0.54 ± 0.15^{a}	0.74 ± 0.15^{ab}	1.38 ± 0.40^{ab}	0.35 ± 0.01^{a}	0.40 ± 0.17^{a}

Values are mean ± standard deviation of triplicate experiments

Table 7 DPPH assay: Antiradical activity of muffins with *Dacryodes macrophylla* extract

Radical Scavenging Activity	Eggless muffins			Egg-containing muffins		
	Control	1% DME	0.5% DME	Control	1% DME	0.5% DME
DPPH, µM troloxeq/mg	3.90 ± 0.52^{a}	6.84 ± 0.93^{bc}	5.06 ± 0.19^{abc}	4.57 ± 0.26^{ab}	7.85 ± 0.96^{c}	6.22 ± 0.30^{abc}

Values are mean ± standard deviation of triplicate experiments

Table 8 Sensory indicators of muffins under study

Sample	Color	Odor	Texture	Taste	Overall acceptability
			Eggless muffins		
Control	7.9 ± 0.1^{cd}	7.7 ± 0.1^{c}	7.4 ± 0.1^{c}	7.7 ± 0.1^{cd}	7.7 ± 0.1^{c}
1% DME	6.6 ± 0.1^{b}	7.1 ± 0.1^{b}	6.6 ± 0.1^{a}	7.2 ± 0.1^{c}	6.9 ± 0.1^{b}
0.5% DME	7.1 ± 0.1^{c}	6.9 ± 1.0^{b}	6.8 ± 0.1^{ab}	6.4 ± 0.1^{b}	6.6 ± 0.1^{b}
			Egg-containing muffins		
Control	7.9 ± 0.1^{cd}	7.6 ± 0.1^{c}	8.2 ± 0.1^{d}	7.8 ± 0.1^{d}	7.9 ± 0.1^{c}
1% DME	6.1 ± 0.1^{a}	6.3 ± 0.1^{a}	7.1 ± 0.1^{bc}	4.6 ± 0.2^{a}	5.3 ± 0.1^{a}
0.5% DME	7.5 ± 0.1^{c}	7.6 ± 0.1^{c}	8.0 ± 0.1^{d}	7.8 ± 0.1^{d}	7.7 ± 0.1^{c}

Values are mean ± standard deviation of triplicate experiments. Values carrying the same letter in the same column are not statistically significant ($P \geq 0.05$)

structure under some compression. We found the cohesiveness value of the control muffin with egg to be significantly higher (0.29) than that of the control eggless muffin (0.17). This result might be attributed to the egg protein network along with starch gel that might have impacted the muffin crumb texture [21].

Nevertheless, there was no significant difference in cohesiveness and adhesiveness values in the muffins fortified with *D. macrophylla*. Our results were in agreement with those found by Maria *et al.* who reported no significant differences in cohesiveness values among fiber-enriched bake products (squash seed flour) [20].

Overall, hardness, chewiness, gumminess, and springiness decreased with the incorporation of *D. macrophylla*, whereas cohesiveness and adhesiveness did not show any significant difference. However, the muffins with egg had lower hardness, chewiness, and gumminess and higher springiness, cohesiveness, and adhesiveness compared to the eggless muffins.

The total phenolic content assay determines both bound and unbound phenolics, while the radical scavenging activity assay measures free antioxidants. Thus, the latter is more efficient at preventing the reactive oxygen species from attacking lipoproteins, polyunsaturated fatty acids, DNA, amino acids, and sugars because it describes the capacity of an antioxidant in both food and biological systems [25].

Therefore, we used DPPH, a stable free radical, to evaluate the antioxidant capacity of our fortified muffins (Table 7). We found that the DPPH inhibition values for both eggless muffins and those with eggs increased significantly with the incorporation of *D. macrophylla* fruit. This result may be attributed to antioxidant compounds in *D. macrophylla* fruit increasing the DPPH activity.

Our results were consistent with those found by other authors who reported better DPPH activity with higher levels of Jambolan fruit pulp in the gluten-free muffins [11, 16].

The results of sensory evaluation of the muffin samples are presented in Table 8. The overall acceptability ranged from 5.3 to 7.9, meaning that the muffins were considered slightly or moderately pleasant according to the 9-point scale, except for the sample scoring 5.3 (neither unpleasant, nor pleasant).

The egg-containing muffins with 1% of DME recorded the lowest score (5.3) and was considered not acceptable because its acceptance index (59%) was lower than 70% (Table 9). This low score resulted from the sample's taste, which also had the lowest score. Most panelists considered its taste unpleasant, indicating bitterness after swallowing.

In contrast, the control egg-containing muffins received the highest overall acceptability score (7.9) and the highest acceptance index (87.88%). However, we found no significant difference with the control eggless muffin or the egg-containing muffin with 0.5% DME.

Table 9 Acceptance index and acceptability among muffin samples

Sample	Acceptance index, %	Acceptability, %	
		Like	Dislike
	Eggless muffins		
Control	86.00	101 (100.0)	0 (0.0)
1% DME	77.11	89 (88.12)	12 (11.88)
0.5% DME	73.33	83 (82.18)	18 (17.82)
	Egg-containing muffins		
Control	87.88	101 (100.0)	0 (0.0)
1% DME	59.22	44 (43.56)	57 (56.44)
0.5% DME	85.55	98 (97.03)	3 (2.97)

A product is acceptable when its acceptance index is greater than 70%

Table 10 Ranking of muffin samples

Sample	Eggless muffins			Egg-containing muffins		
	Control	1% DME	0.5% DME	Control	1% DME	0.5% DME
Rank	2.4 ± 0.1^{b}	4.2 ± 0.1^{c}	4.6 ± 0.1^{d}	1.9 ± 0.1^{a}	5.8 ± 0.1^{e}	2.1 ± 0.1^{ab}

Values are mean ± standard deviation of triplicate experiments. Values carrying the same letter in the same row are not statistically significant ($P \geq 0.05$)

The highest score of the control egg-containing muffin might be attributed to its texture, which was rated highest (8.2). Its appreciation by the panelists was in agreement with its springiness and specific volume (1.97 and 2.36, respectively), also scored highest.

The incorporation of *D. macrophylla* fruits tended to lower the average acceptance scores both for the eggless muffins and for those with eggs. The same trends were observed by Abdessalem *et al.* who introduced date fiber concentrate in muffins [13]. In our work, the egg-containing muffins with 0.5% DME had the best rank among the samples and received the same rank as the controls (both with and without egg). This means that the panelists preferred the muffins with *D. macrophylla* extract to the eggless control muffins.

CONCLUSION

Our results revealed that the incorporation of *Dacryodes macrophylla* L. fruit decreased water activity, the *L**, *a**, and *b** values, as well as the firmness of the muffins, whereas no prominent difference was observed in their baking loss, height, moisture, fat, cohesiveness, springiness, gumminess, or chewiness.

In contrast, *D. macrophylla* increased specific gravity, changed rheology, and tended to increase adhesiveness, antioxidant activity, and mineral contents (particularly Na and K) of the muffins. Another interesting result was that the panelists statistically accepted the muffins with 0.5% of DME, scoring them in the same range as the control ones.

Therefore, *D. macrophylla* fruit is a good potential ingredient to develop new bakery products rich in minerals and antioxidants but further investigations need to be done to improve the color acceptance of muffins and to determine the optimal concentration of *D. macrophylla*.

CONTRIBUTION

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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ORCID IDs
Alvine Sandrine Ndinchout https://orcid.org/0000-0002-5474-5687
Debapriya P. Chattopadhyay https://orcid.org/0000-0002-7563-9293
Nyegue Maximilienne Ascension https://orcid.org/0000-0002-9642-9930
Varinder Kaur https://orcid.org/0000-0001-7284-0701
Narpinder Singh https://orcid.org/0000-0002-9683-7846
Moundipa Fewou Paul https://orcid.org/0000-0002-2694-5569