*Food Safety and Health*

WILEY

RESEARCH ARTICLE OPEN ACCESS

# Lipid-Lowering Potential of Food Formulations Based on Culinary-Treated Flours of *Dioscorea bulbifera* (Dana) in Obese and Hyperlipidemic Rats

Fossouo Towa Patrik Florent | Maffo Tazoho Ghislain | Tekou Florian Amel | Kenfack Justine Odelonne | Zokou Ronice | Dangang Bossi Donald Séverin | Womeni Hilaire Macaire

Department of Biochemistry, Faculty of Science, University of Dschang, Dschang, Cameroon

**Correspondence:** Maffo Tazoho Ghislain (maghis2006@yahoo.fr)

**Received:** 28 January 2025 | **Revised:** 29 August 2025 | **Accepted:** 21 October 2025

**Keywords:** boiling | braising | *Dioscorea bulbifera* | lipid-lowering properties

## ABSTRACT

This study aimed to evaluate the lipid-lowering potential of *Dioscorea bulbifera* (Dana) flours subjected to culinary treatments. Two varieties of Dana were boiled and braised and then processed into flours and incorporated at 25% and 50% into the standard diet of rats. Obesity and hyperlipidemia were induced by feeding the animals with a high-calorie diet. Ninety rats were followed for 4 weeks, and lipid and enzyme parameters were assessed. Braising and boiling supplemented in the diet resulted in a reduction in body weight and an increase in food consumption. Supplementation with Dana flours significantly ($p < 0.05$) reduced lipid parameters compared to the control group. The reduction was more pronounced in female than male rats, where values were 76.29 and 70.37 for total cholesterol, 137.15 and 122.18 for triglycerides, and 24.85 and 18.65 mg/dL for LDL-C, respectively, in male and female rats fed with white braised Dana (WBrD) at 25%. However, the increase was observed with HDL-C (32.99 mg/dL male rats fed WBrD 50%) comparatively to the positive control group (17.31 mg/dL male rats). No significant adverse effects on renal or hepatic biomarkers were observed. In conclusion, culinary processing enhances the lipid-lowering potential of Dana, particularly when braised and supplemented at 25%.

## 1 | Introduction

Obesity is a chronic condition resulting from an excessive accumulation of fat that threatens health (Woumbo et al. 2017). Hyperlipidemia is a medical condition characterized by an increase in one or more of the plasma lipids, including triglycerides, cholesterol, cholesterol esters, phospholipids, and/or plasma lipoproteins such as very low-density lipoprotein and low-density lipoprotein along with reduced high-density lipoprotein levels (Mumthaj et al. 2021). There are various risk factors that favor the onset of obesity/hyperlipidemia, namely age, sex, genetic background, physical inactivity, sedentary lifestyle, and poor diet, particularly one rich in fat, smoking, and certain drugs, particularly thiazide diuretics (hydrochlorothiazide), corticoids (dexamethasone), and beta-blockers (metropol) (Nouh et al. 2019; Naser et al. 2021; Abbasi et al. 2024). According to the World Health Organization (WHO) in 2017, approximately 17.9 million people die each year from cardiovascular disease, accounting for 31% of all deaths worldwide, more than 75% of which occur in low- and middle-income countries.

In the fight against obesity and hyperlipidemia, a lot of hypolipidemic drugs are available in the market. The therapeutic drug strategy (statins, fibrates, cholestyramine, ezetimibe, bile acid sequestrants, etc.) has a place of choice but has a number of drawbacks. They are expensive and have side effects such as rhabdomyolysis, myalgia, and steatorrhea (Mumthaj et al. 2021; Nalla et al. 2023). To alleviate these concerns, scientists are increasingly advocating nondrug or natural treatments based on

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the use of functional foods, essential oils, and plant extracts (Konstantinidi and Koutelidakis 2019; Woumbo et al. 2022). Medicinal plants have always been considered a source of healthy life for all people and international trade due to their rich therapeutic benefits and 100% natural characteristics (Nalla et al. 2023). Numerous studies have been carried out in this area on a number of foods such as avocado, soya, olive oil, and fish, which have been shown to have lipid-lowering properties (Woumbo et al. 2017; Chikwendu et al. 2021). This activity is attributed to certain bioactive compounds present in these functional foods, such as polyunsaturated fatty acids, omega-3 and omega-6, polyphenols, flavonoids, saponins, and dietary fibers (Kengne et al. 2020; Chikwendu et al. 2021; Woumbo et al. 2022).

*Dioscorea bulbifera* is a yam grown in Cameroon with therapeutic and nutritional properties and has been the subject of a number of studies designed to demonstrate some of its antioxidant and lipid-lowering properties. The work of Uthirapathy et al. (2021) showed that ethanolic extract of raw *Dioscorea bulbifera* administered to hypercholesterolemic rats lowered LDL cholesterol and triglyceride levels and improved HDL cholesterol. Chinko et al. (2020) evaluated the effects of hydromethanol extracts of *Dioscorea bulbifera* on hyperlipidemia induced by a high-fat diet. They reported that hyperlipidemic rats treated with *Dioscorea bulbifera* extracts had significantly lower levels of total cholesterol, triglycerides, LDL, VLDL, and serum glucose than the control group and higher levels of HDL in treated hyperlipidemic rats. Also, Ikete et al. (2022) reported that *Dioscorea bulbifera's* anti-obesity properties may be attributed to its ability to inhibit serum lipase activity. These activities are generally attributed to the bioactive compounds present in yams, in particular flavonoids, saponins (diosgenin), and fibers (Padhan and Panda 2020; Uthirapathy et al. 2021; Narzary et al. 2025). Some of the mechanisms involve biochemicals such as phenolic compounds that have a benzene ring (C6) and at least one hydroxyl (OH) group, including substituents (glycosides, methyl ethers, esters, etc.) (Albuquerque et al. 2021). These substances have many biological functions, mainly antioxidant and anti-inflammatory effects, and can produce a series of beneficial biological effects on the body such as antibacterial, lipid-lowering, anticancer, cardioprotective, neuroprotective, antidiabetic effects, etc. (Hurtado-Fernández et al. 2010; Sharma et al. 2024; Vishwakarma et al. 2024; Yadav et al. 2024). Concerning fibers, it has been demonstrated that dietary fibers interfere with bile salts reabsorption, probably through a specific binding. These bile salts are natural surface-active molecules playing an important role in lipid digestion, and they are in the largest part reabsorbed within the gastrointestinal tract and sent back to the liver. This fiber binding could influence the emulsifying ability of bile salts and impact on the digestion and transport of lipids, reducing their availability (Surampudi et al. 2016; Guillon and Champ 2000). Also, fibers, for instance, are involved in the repression of digestive enzymes or the prevention of lipids absorption through the intestine wall by increasing the barrier properties of the unstirred layer between BS micelles and intestinal absorptive cells or by forming a local matrix entrapping BS micelles (Surampudi et al. 2016). However, these authors have either worked with extracts or raw flours of *Dioscorea bulbifera*, even though this food is not generally eaten raw and must undergo culinary treatments before consumption, such as boiling, braising, and steaming. These culinary treatments are likely to influence the content of bioactive compounds present in raw Dana tubers, thus modifying their antioxidant and lipid-lowering properties (Achy et al. 2017; Ani et al. 2020). The present study hypothesized that culinary treatments such as boiling and braising may modify the bioactive compound composition of Dana flours, thereby influencing their lipid-lowering effects. The aim of this study was therefore to assess the lipid-lowering potential of *Dioscorea bulbifera* yam flour following culinary treatments, namely boiling and braising, and through supplementation of this flour in the normal albino Wistar rats' diet.

## 2 | Materials and Methods

### 2.1 | Materials

The plant materials used in this study were tubers of two varieties of *Dioscorea bulbifera* identified in the Cameroon National Herbarium under reference number 81853/SRF/CAM. The two Dana varieties were collected from a farmer in Bandjoun, Koung-Khi Department, in January 2023.

The animal material used in this study consisted of albino rats of the Wistar strain bred in the animal house of the Biochemistry Department of the University of Dschang, under a nycthemeral cycle (12 h of light and 12 h of darkness) and fed with water ad libitum in addition to the feed prepared according to the protocol of Telefo et al. (1998), consisting of maize meal (77.8%), soya meal (40%), fish meal (20%), vitamin complex (0.1%), cooking salt (1%), oil (1%), and bone meal (1%).

### 2.2 | Methods

#### 2.2.1 | Flour Preparation

The two Dana varieties were processed using the modified methods described by Umoh and Iwe (2022) and Ani et al. (2020). Samples with a diameter of between 5 and 6 cm were cleaned with tap water, weighed, and then divided into six (06) batches. The batches of raw white Dana (RWD) and raw black Dana (RBD) were peeled, sliced to a thickness of 10 mm, and then oven-dried at 45°C until a constant dry mass was obtained. The resulting pods were then ground using a blender. The batches of white boiled Dana (WBD) and black boiled Dana (BBD) were placed in boiling water and cooked on an Aifa gas hob for 35 min. For the white braised (WBrD) and black braised Dana (BBrD), a low heat was used on a grill at 90°C for 40 min. All treated batches were then sliced into thin 10 mm pieces, dried in an oven at 45°C until a constant dry mass was obtained, and then ground using a blender. These flour samples were then packed in polyethylene bags in a desiccator for later use.

Braising is a food processing technique that uses the principle of heating to cook the product evenly and improve the digestibility, palatability, and sensory aspects of the food with desirable structural changes to the food matrix. Other benefits of braising include the development of color, aroma, active flavor compounds, and antioxidants. The process can also essentially cook or gelatinize, expand/puff/swell food materials, and convert them into a more pliable, palatable, and attractive form (Sruthi et al. 2021). Steaming is a cooking process that puts food in direct contact with heat, eliminating the phenomenon of osmosis. The water becomes steam at a temperature of 100°C. Steam also ensures even cooking and preserves the qualities of the cooked food. It preserves the flavor of the food and its nutritional value. However, it takes longer than boiling. It is very convenient for tubers, fresh vegetables, rice, and cereals in the form of couscous (Turkmen et al. 2005).

### 2.2.2 | In Vivo Evaluation of Lipid-Lowering Potential

**2.2.2.1 | Experimental Protocol and Induction of Obesity and Hyperlipidemia.** The animals were subdivided into two groups according to their diet: one with a basal diet consisting of maize meal, soya meal, bone meal, fish meal, vitamin complex, cooking salt, and oil (serving as a negative control group) and the other with a high-calorie diet consisting of a basal feed enriched with tallow (20%) and cholesterol (1%) for 12 weeks before the start of the experiment following the protocol described by Al-Okbi et al. (2014). The rats used for the induction of obesity aged 4 weeks with the weight between 65 and 75 g. The onset of obesity and its predict adverse effects on the lipid profile was observed when the rats' BMI ranged between 0.45 and 0.68 g/cm$^2$ according to the works of Novelli et al. 2007.

Ninety (90)-four-month old Wistar albino rats were divided into 15 groups of 3 males and 3 females; each rat was placed in a cage and subjected to a nycthemeral cycle throughout the experimental period. The animals were fed a standard diet and water ad libitum for 1 week to stabilize their metabolism before the onset of obesity and hyperlipidemia induction. Table 1 shows the weights of the ingredients for the preparation of 1000g of high-calorie diet.

**TABLE 1** | Diet composition to make rats obese and hyperlipidemia.

| Ingredients | High-calorie diet (g) |
|---|---|
| Corn flour | 537.2 |
| Soy flour | 158 |
| Fish meal | 79 |
| Bone meal | 7.9 |
| Cooking salt | 6.32 |
| Refined palm oil | 0.79 |
| Vitamin complex | 0.79 |
| Tallow | 200 |
| Cholesterol | 10 |

**2.2.2.2 | Distribution of the Animals and Administration of the Various Formulated Feed Diets.** As for the control groups the negative control group (NCG) received distilled water and the basic food; the positive control group (PCG) received a high-calorie, high-fat food; and finally, a neutral control group (NeCG) received olive oil, recognized as a lipid-lowering agent, combined with the basic food. The test groups were divided into white and black Dana varieties. The different varieties and their culinary forms (boiled and braised) were administered by supplementation at 25% and 50% throughout the treatment. The administration of the different Dana flours and their culinary forms in order to regulate the lipid profile, liver, and kidney damage lasted 4 weeks, and each rat received 50 g of food daily. Briefly, the distribution was as shown in Table 2.

**2.2.2.3 | Assessment of Food Intake and Relative Organ Weight.** During the study, food intake and body mass were measured. Body weight gain was obtained by taking the

**TABLE 2** | Breakdown of animals by type of treatment.

| Groups | Diets |
|---|---|
| PCG | High-calorie feed + 200 mL/kg of distilled water of body weight |
| NCG | Basic feed + 200 mL/kg distilled water of body weight |
| NeCG | Basic feed + 200 mL/kg olive oil |
| RWD 25% | 25% raw white Dana + 75% staple food d |
| RWD 50% | 50% raw white Dana + 50% staple food |
| RBD 25% | 25% raw black Dana + 75% staple food d |
| RBD 50% | 50% raw black Dana + 50% staple food |
| WBD 25% | 25% white boiled Dana + 75% staple food |
| WBD 50% | 50% white boiled Dana + 50% staple food |
| BBD 25% | 25% boiled black Dana + 75% staple food |
| BBD 50% | 50% boiled black Dana + 50% staple food |
| WBrD 25% | 25% white braised Dana + 75% staple food |
| WBrD 50% | 50% white braised Dana + 50% staple food |
| BBrD 25% | 25% black braised Dana + 75% staple food |
| BBrD 50% | 50% black braised Dana + 50% staple food |

Abbreviations: BBD, black boiled Dana; BBrD, black braised Dana; NCG, negative control group; NeCG, Neutral control Group; PCG, positive control group; RBD, raw black Dana; RWD, raw white Dana; WBD, white boiled Dana; WBrD, white braised Dana.

difference between the weight at the end of treatment and the weight at the start of treatment. The quantity of feed consumed by the animals was measured daily by subtracting the mass of feed (in g) found in the cage (mass remaining after 24 h) from that served the previous day (initial mass) using the formula. Feed intake = initial mass (g) − mass remaining (g) after 24 h. The food intakes were then used to determine the daily food intake (DFI) as follows:

$$\text{DFI} = (\text{Quantity of food ingested during the test period (g)})/(\text{Number of days (d)}).$$

At the end of the treatment, the rats were sacrificed, and their blood was collected via cardiac puncture under anesthesia. The vital organs (liver, kidney, and heart) and adipose tissue were isolated, rinsed with physiological water, wrung out, and weighed for assessment of their relative weight using the following formula:

$$\text{Relative weight (\%)} = 100 \times (\text{organ weight/animal weight}).$$

Blood samples collected into dry tubes were let to clot and then centrifuged at 3000 rpm for 15 min, and the supernatants (sera) were collected and stored in eppendorf tubes at −20°C for later analysis.

**2.2.2.4 | Determination of Biochemical Parameters in Rats.** Total cholesterol, HDL cholesterol, and triglycerides were determined by enzymatic colorimetry as described by Trinder (1969) using the Dutch Diagnostics kit. Very low-density lipoprotein (VLDL) cholesterol was estimated from TG ([VLDL] = [TG]/5), and low-density lipoprotein (LDL) cholesterol was estimated using the Friedewald equation ([LDL] = [CT] − ([HDL] + [VLDL] estimated) (Friedewald et al. 1972). These concentrations were expressed in mg/dL. The atherogenic index (AI) was calculated as AI = total blood cholesterol/total blood HDL-C. Urea was determined using the colorimetric method of Fossati and Principe (1982) using a commercial CHRONOLAB kit. The SPINREACT kit was used to determine aspartate aminotransferase (ASAT) and alanine aminotransferase (ALAT) by the method of Thomas (1998) and creatinine by the method of Bartels et al. (1972).

## 2.3 | Statistical Analysis

The results were expressed as means ± standard deviation and an analysis of variance (ANOVA) test was used to compare the mean values of biochemical parameters in rats fed with the different dietary formulations based on dana meal (reference ration and the different test rations). When the means were significantly different, the Fisher test was used to locate the differences at the 5% significance level. The tests were carried out using Minitab 18.1 software, and Microsoft Excel 2013 software was used to display diagrams.

# 3 | Results

## 3.1 | Effects of Consumption of Diets Formulated Based on *Dioscorea bulbifera* Flours on Weight Gain and Daily Food Consumption in Rats

Figure 1a and b shows the effects of formulated foods on weight gained in male and female rats. These figures show that supplementation with 25% and 50% white braised Dana and 25% black boiled dana in male and female rats, and the neutral control (fed olive oil) resulted in a significant ($p < 0.05$) decrease in body weight during treatment compared with the positive control group (PCG). On the other hand, supplementation with 50% boiled Dana meal resulted in a nonsignificant ($p > 0.05$) increase in weight gain compared with the other groups' fed raw and braised Dana of both varieties.

Figure 2a,b represent the food consumption in rats fed with Dana food formulations. The results show an increased daily food consumption in the male rats fed with the Dana-supplemented diet compared with the healthy controls, except for the group fed the 25% white braised dana (35.85 g). For the females, the culinary treatments resulted in an increase in food consumption in the groups fed with the white Dana compared with the positive control group who were sick, and there was no significant difference ($p > 0.05$) within the Dana varieties.

## 3.2 | Effects of Consumption of Diets Formulated With Dana Flours on Relative Organ Weight and Abdominal Fat

The results in Table 3 show that male and female hyperlipidemic rats had higher relative weights than the test groups as a whole. Moreover, rats fed with white and black raw Dana (supplemented at 25%), white braised Dana (supplemented at 25% and 50%), black braised Dana (supplemented at 25%), and the neutral control group (treated with olive oil) had significantly lower relative weights ($p < 0.05$) than the groups fed with white and black boiled Dana (supplemented at 25% and 50%) in all organs (liver, heart, and kidney). In terms of abdominal fat, the groups of rats fed diets of white and black boiled Dana (supplemented at 25% and 50%) and white braised Dana (supplemented at 50%) had higher relative weights, close to those of the hyperlipidemic rats (PCG), which recorded the highest value (6.41 ± 1.78). The neutral control group (NeCG) fed olive oil had the lowest value.

## 3.3 | Effects of Culinary Treatments and Supplementation Applied to Dana on Serum Lipid Profile Markers

The results in Table 4 show that the total cholesterol levels of the untreated hyperlipidemic rats (PCG) were the highest (males: 130.92 mg/dL; females: 119.81 mg/dL). Male rats fed 25% supplemented white braised Dana had the lowest cholesterol concentration (76.29 mg/dL) compared to the other groups. No

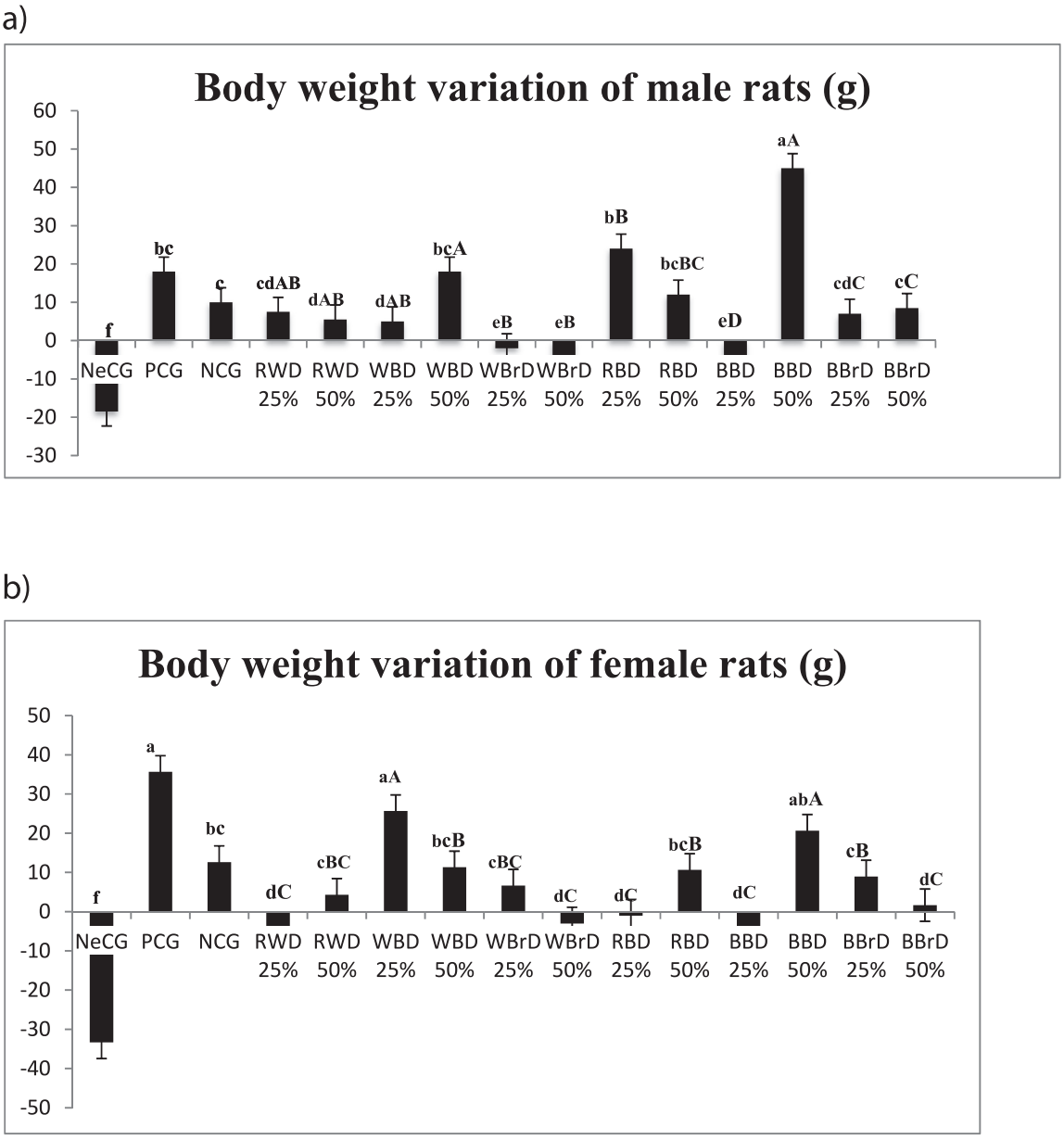



**FIGURE 1** | (a) Body weight variation in male rats after consumption of diets based on *Dioscorea bulbifera* flours. (b) Body weight variation in female rats after consumption of diets based on *D. bulbifera* flours. Means marked with different symbols are significantly different at the 5% probability level. Letters (a–g) on the charts with different letters were significantly different ($p \leq 0.05$) between control and Dana-treated groups; letters (A–C) on the charts with different letters were significantly different ($p \leq 0.05$) for Dana-treated groups. BBD, black boiled Dana; BBrD, black braised Dana; NCG, negative control group; NeCG, Neutral Control Group; PCG, positive control group; RBD, raw black Dana; RWD, raw white Dana; WBD, white boiled Dana; WBrD, white braised Dana.

significant differences ($p > 0.05$) were observed within the different groups of rats fed black and white Dana. With regard to females, the groups fed with the white variety supplemented at 25% (RWD: 75.37 mg/dL, WBD: 71.29 mg/dL; WBrD: 70.37 mg/dL) and the group fed with the black braised Dana supplemented at 25% (70.18 mg/dL) presented a significantly lower cholesterol levels ($p < 0.05$) than the other treated groups. Similarly, the untreated hyperlipidemic rats (PCG) had the highest triglyceride levels (males: 147.64 mg/dL, females: 128.95 mg/dL) and the groups of male rats fed white boiled dana (supplemented at 25% and 50%), white and black raw Dana supplemented at 50%, and black braised Dana (supplemented at 50%) had significantly low levels ($p < 0.05$) and values close to that of the neutral control group receiving olive oil (NeCG). In females, the groups fed with black braised Dana (supplemented at 25% and 50%), raw black (supplemented at 50%), and boiled white (supplemented at 50%) Dana presented significantly low levels ($p < 0.05$) and were close to the values of the neutral and negative control groups. Concerning HDL-C, male rats fed with 50% white braised Dana had the highest HDL concentrations (32.99 mg/dL) than the others in the Dana-fed groups. In females, groups fed with raw white Dana (50%) and braised white and black (50%) Dana presented high HDL concentrations, close to that of the neutral control group (NeCG). As for LDL cholesterol, untreated hyperlipidemic rats presented the highest LDL cholesterol concentrations (88.88 mg/dL), and this value was significantly different and higher than the

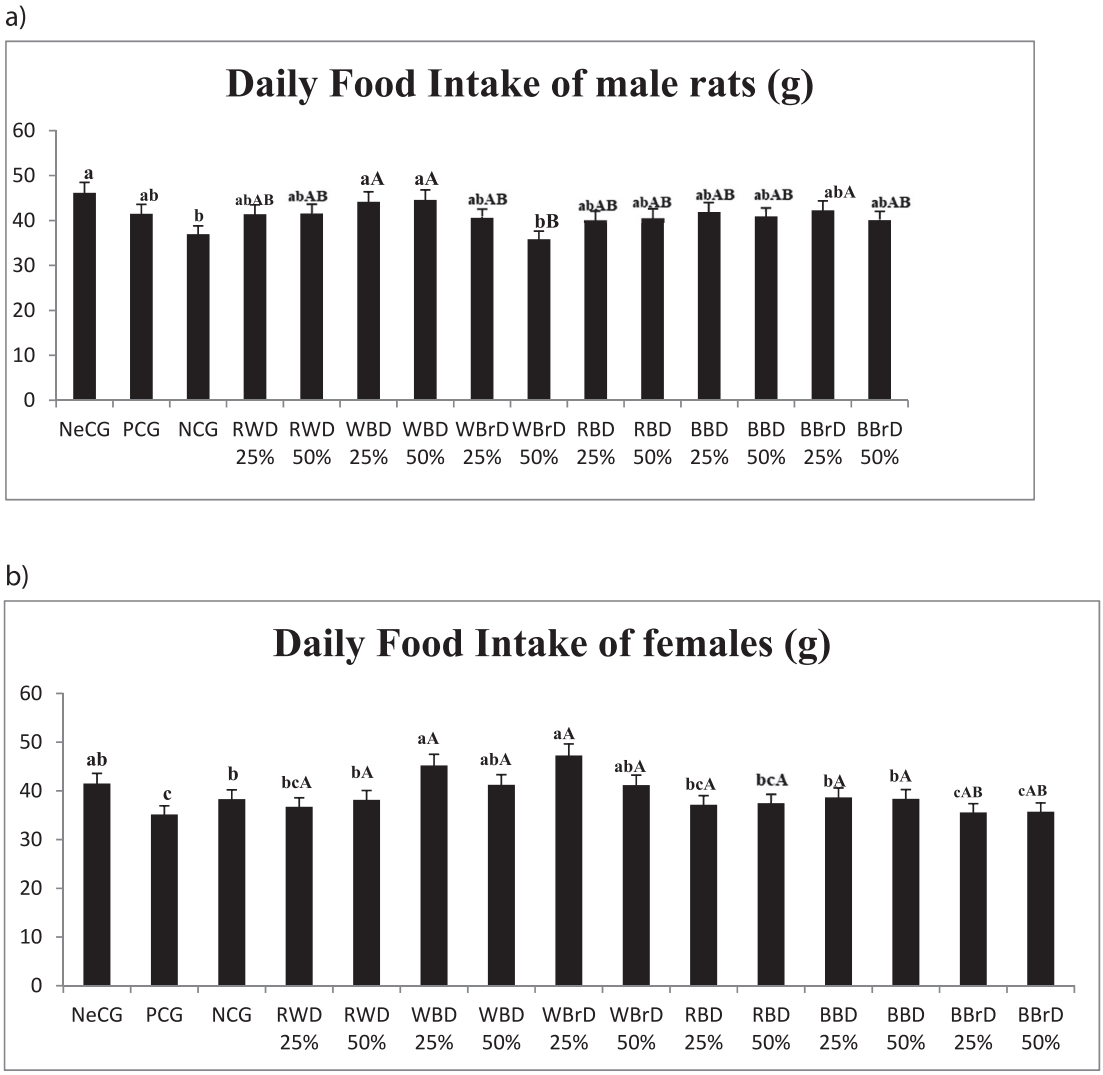



**FIGURE 2** | (a) Daily food intake of male rats during the experiment. (b) Daily food intake of female rats during the experiment. Means marked with different symbols are significantly different at the 5% probability level. Letters (a–g) on the charts with different letters were significantly different ($p \leq 0.05$) between control and Dana-treated groups; letters (A–C) on the charts with different letters were significantly different ($p \leq 0.05$) for Dana-treated groups. BBD, black boiled Dana; BBrD, black braised Dana; NCG, negative control group; NeCG, Neutral Control Group; PCG, positive control group; RBD, raw black Dana; RWD, raw white Dana; WBD, white boiled Dana; WBrD, white braised Dana.

concentrations in male and female rats fed with Dana formulations. The VLDL results show that the groups of rats (males and females) fed with braised Dana (supplemented at 25% and 50%) presented concentrations close to the positive controls values, and boiling significantly affected this parameter. Finally, with the atherogenic index (AI), there was a significant difference ($p < 0.05$) between the groups of male and female rats and also among the different culinary forms and healthy control and neutral control groups (fed olive oil).

### 3.4 | Effects of Different Diets Based on Boiled and Braised Dana Flours on Renal and Hepatic Biomarkers

Table 5 shows that untreated male and female hyperlipidemic rats, respectively, had lower serum creatinine (0.60 IU/L, 0.57 IU/L) and urea (0.15 IU/L, 0.12 IU/L) levels and were significantly different ($p < 0.05$) from the other groups. The AST concentration of male rats fed with 50% raw white Dana (2.15 IU) and 50% raw black Dana (2.21 IU) showed AST concentrations close to those of the control groups (NCG: 2.09 IU; NeCG: 2.32 IU). Female rats fed with boiled Dana had the highest AST levels. With respect to ALT levels, the concentration in male rats fed with raw white Dana supplemented at 50% (40.62 IU/L) and raw black Dana supplemented at 50% (42.48 IU/L) was near to those in the healthy control (34.97 IU/L) and neutral control (44.52 IU/L) groups. Concerning females, there was no significant difference ($p < 0.05$) among the ALT concentration of groups fed with raw white and black Dana (25% and 50% supplementation), braised white Dana (25% and 50% supplementation), and braised black Dana (50% supplementation) compared to the control groups (healthy and neutral controls). The other groups presented higher ALT concentrations than the control group.

**TABLE 3** | Effects of consumption of diets formulated with dana flours on relative organ weights in rats.

| Parameters | Control groups | | | White dana | | | | | | Black dana | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NeCG | PCG | NCG | RWD 25% | RWD 50% | WBD 25% | WBD 50% | WBrD 25% | WBrD 50% | RBD 25% | RBD 50% | BBD 25% | BBD 50% | BBrD 25% | BBrD 50% |
| WHM | $0.45 \pm 0.03^{ab}$ | $0.70 \pm 0.04^{a}$ | $0.31 \pm 0.06^{b}$ | $0.28 \pm 0.01^{bC}$ | $0.27 \pm 0.03^{bC}$ | $0.31 \pm 0.02^{bBC}$ | $0.29 \pm 0.02^{bC}$ | $0.45 \pm 0.10^{abA}$ | $0.40 \pm 0.07^{abAB}$ | $0.39 \pm 0.24^{bBC}$ | $0.31 \pm 0.04^{bBC}$ | $0.64 \pm 0.45^{abA}$ | $0.29 \pm 0.02^{bC}$ | $0.40 \pm 0.03^{bB}$ | $0.29 \pm 0.10^{bC}$ |
| WHF | $0.47 \pm 0.03^{b}$ | $0.68 \pm 0.05^{a}$ | $0.39 \pm 0.06^{bc}$ | $0.42 \pm 0.05^{bA}$ | $0.35 \pm 0.03^{cAB}$ | $0.36 \pm 0.03^{bcAB}$ | $0.38 \pm 0.04^{bcA}$ | $0.44 \pm 0.09^{bA}$ | $0.40 \pm 0.06^{bA}$ | $0.62 \pm 0.36^{aA}$ | $0.33 \pm 0.06^{cB}$ | $0.65 \pm 0.05^{aA}$ | $0.38 \pm 0.04^{bCB}$ | $0.41 \pm 0.04^{bAB}$ | $0.32 \pm 0.20^{cB}$ |
| WKM | $0.81 \pm 0.15^{a}$ | $0.59 \pm 0.11^{c}$ | $0.73 \pm 0.09^{ab}$ | $0.52 \pm 0.10^{cdC}$ | $0.58 \pm 0.02^{cBC}$ | $0.60 \pm 0.02^{bcBC}$ | $0.53 \pm 0.11^{cdC}$ | $0.76 \pm 0.13^{abA}$ | $0.73 \pm 0.10^{abAB}$ | $0.51 \pm 0.06^{dC}$ | $0.59 \pm 0.02^{cBC}$ | $0.76 \pm 0.06^{abA}$ | $0.60 \pm 0.05^{bCBC}$ | $0.69 \pm 0.00^{bcAB}$ | $0.64 \pm 0.13^{bcAB}$ |
| WKF | $0.84 \pm 0.14^{a}$ | $0.63 \pm 0.09^{c}$ | $0.73 \pm 0.09^{bc}$ | $0.74 \pm 0.11^{bcA}$ | $0.76 \pm 0.05^{abA}$ | $0.70 \pm 0.01^{bcA}$ | $0.69 \pm 0.18^{bcAB}$ | $0.75 \pm 0.12^{bcA}$ | $0.73 \pm 0.11^{bcA}$ | $0.81 \pm 0.14^{aA}$ | $0.61 \pm 0.06^{cAB}$ | $0.77 \pm 0.08^{abA}$ | $0.78 \pm 0.11^{abA}$ | $0.70 \pm 0.02^{bcA}$ | $0.71 \pm 0.16^{bcA}$ |
| WLM | $3.40 \pm 0.75^{bc}$ | $2.81 \pm 0.37^{cd}$ | $3.69 \pm 0.14^{bc}$ | $2.80 \pm 0.48^{cdAB}$ | $4.12 \pm 1.51^{abA}$ | $4.44 \pm 2.37^{aA}$ | $3.07 \pm 0.50^{cA}$ | $3.55 \pm 0.55^{bcA}$ | $3.71 \pm 0.83^{bcA}$ | $2.52 \pm 0.69^{dC}$ | $3.06 \pm 0.19^{cBC}$ | $4.04 \pm 0.80^{abA}$ | $3.02 \pm 0.33^{bCBC}$ | $3.38 \pm 0.21^{bCBC}$ | $2.95 \pm 0.24^{bCBC}$ |
| WLF | $3.51 \pm 0.82^{bc}$ | $3.02 \pm 0.30^{c}$ | $3.70 \pm 0.17^{bc}$ | $3.72 \pm 0.91^{bcAB}$ | $5.46 \pm 2.26^{aA}$ | $5.20 \pm 2.70^{aA}$ | $4.00 \pm 0.65^{abA}$ | $3.51 \pm 0.49^{bcAB}$ | $3.70 \pm 0.85^{bcAB}$ | $4.00 \pm 1.09^{abA}$ | $3.18 \pm 0.11^{cAB}$ | $4.08 \pm 0.87^{abA}$ | $3.91 \pm 0.66^{abA}$ | $3.44 \pm 0.19^{bcAB}$ | $3.23 \pm 0.32^{cAB}$ |
| AFM | $1.44 \pm 0.37^{e}$ | $5.89 \pm 1.44^{a}$ | $2.66 \pm 1.32^{d}$ | $2.21 \pm 1.63^{eB}$ | $3.12 \pm 0.79^{cdAB}$ | $3.41 \pm 2.03^{cAB}$ | $5.19 \pm 0.28^{abA}$ | $3.43 \pm 0.95^{cAB}$ | $3.19 \pm 2.69^{cAB}$ | $2.93 \pm 0.65^{dBC}$ | $3.01 \pm 0.87^{cdB}$ | $4.44 \pm 0.91^{bcA}$ | $5.37 \pm 1.04^{abA}$ | $2.67 \pm 1.04^{dC}$ | $5.70 \pm 1.79^{aA}$ |
| AFF | $1.48 \pm 0.37^{d}$ | $6.41 \pm 1.78^{a}$ | $2.78 \pm 1.29^{c}$ | $2.58 \pm 0.84^{cB}$ | $3.88 \pm 1.18^{bAB}$ | $5.08 \pm 2.74^{abA}$ | $4.94 \pm 0.53^{bA}$ | $2.82 \pm 0.99^{bCB}$ | $2.89 \pm 2.55^{bCB}$ | $2.96 \pm 0.90^{bCB}$ | $3.14 \pm 0.91^{bCB}$ | $4.47 \pm 0.86^{bAB}$ | $5.65 \pm 1.99^{abA}$ | $2.58 \pm 0.44^{cBC}$ | $6.22 \pm 1.88^{aA}$ |

*Note:* Means marked with different symbols are significantly different at the 5% probability level. Letters (a–g) in the same row with different letters were significantly different ($p \leq 0.05$) between control and Dana-treated groups; letters (A–C) in the same row with different letters were significantly different ($p \leq 0.05$) for Dana-treated groups.
Abbreviations: AFF, abdominal fat of female rats; AFM, abdominal fat of male rats; BBD, black boiled Dana; BBrD, black braised Dana; NCG, negative control group; NeCG, Neutral Control Group; PCG, positive control group; RBD, raw black Dana; RWD, raw white Dana; WBD, white boiled Dana; WBrD, white braised Dana; WHF, relative weight of the heart of female rats; WHM, relative weight of the heart of male rats; WKF, relative weight of the kidney of female rats; WKM, relative weight of the kidney of male rats; WLF, relative weight of the liver of female rats; WLM, relative weight of the liver of male rats.

## 4 | Discussion

The consumption of a high-fat diet leads to an increase in energy intake, body weight, and consequently increased cell proliferation in adipose tissue, which significantly affects physiology by promoting obesity through hyperphagia. This leads to a change in the composition of plasma lipoproteins, in particular by increasing the portion of cholesterol esters in VLDL and LDL and lowering the plasma level of HDL cholesterol (Nchoutpouen et al. 2020). The objective of this study was to evaluate the effects of the consumption of different food diets formulated with raw, boiled, and braised flours of *Dioscorea bulbifera* (Dana) on the lipid profile of rats made hyperlipidemic. In this work, olive oil was used as a neutral control since its beneficial effects on the lipid profile and on health has already been elucidated. The beneficial effect of the Mediterranean diet, well known as a diet with high olive oil consumption, has been shown to be effective in regulating blood lipid levels and decreasing serum cholesterol, thus preventing cardiovascular diseases, atherosclerosis, and other diseases (Ngakou Takam et al. 2019).

The evaluation of daily food consumption showed that hyperlipidemic male and female rats (positive controls) had the lowest value of food consumption compared to the neutral control (received olive oil) and the other treated groups. There was an increase in the daily food consumption of rats with diets supplemented with Dana flours that had undergone culinary treatments. This result could be explained by the fact that boiling led to the elimination of antinutritional factors (phytates, oxalates, and tannins), promoting good palatability, good digestibility, and intestinal absorption (Sahore 2011; Ayo et al. 2018), thus indicating that culinary forms are more suitable for consumption than raw Dana.

The decrease in weight gain with diet supplemented with 25% and 50% white braised Dana and 25% black boiled Dana, respectively, in male and female rats could be explained by an anorexigenic potential of Dana flours, which would be partly linked to their fiber content and phenolic compounds. Indeed, Fossouo in 2023 showed that culinary treatments applied to *Dioscorea bulbifera*, such as boiling and braising, increased their dietary fiber content. The values of total fiber obtained by the authors were 4.55 ± 0.17, 4.75 ± 0.11, 5.23 ± 0.08, and 7.6 ± 0.13% DM, respectively, for raw black Dana, raw white Dana, boiled Dana, and braised white Dana. Concerning starch, the values decreased after treatment and were 94.23 ± 3.45, 64.79 ± 1.20, 36.44 ± 3.18, and 46.84 ± 4.25% DM, respectively, for raw white Dana, raw black Dana, boiled white Dana, and braised black Dana. The ingestion of foods rich in dietary fiber stimulates the synthesis of anorexigenic compounds such as cholecystokinin and glucagon-like peptide 1 (GLP-1), which are, in fact, satiety factors capable of slowing down the production of orexigenic molecules such as ghrelin (Woumbo et al. 2017). Also, Tucker and Thomas (2009) state in their study that there is a relationship between dietary fiber intake and change in body weight. They observed that over a 20-month period, participants lost an average of 4.4 lbs due to an 8-g increase in dietary fiber per 1000 kcal. This weight loss was primarily due to decreased body fat. It should be recognized that the correlation between dietary fiber and weight

**TABLE 4** | Effects of consumption of culinary forms of dana supplemented to the normal diet on the lipid profile of rats.

| | Control groups | | | White dana | | | | | | Black dana | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Parameters** | **NeCG** | **PCG** | **NCG** | **RWD 25%** | **RWD 50%** | **WBD 25%** | **WBD 50%** | **WBrD 25%** | **WBrD 50%** | **RBD 25%** | **RBD 50%** | **BBD 25%** | **BBD 50%** | **BBrD 25%** | **BBrD 50%** |
| Male rats | | | | | | | | | | | | | | | |
| TC | 87.40 ± 6.94$^{bc}$ | 130.92 ± 12.93$^{a}$ | 85.18 ± 5.83$^{bc}$ | 87.77 ± 12.28$^{bcA}$ | 86.29 ± 12.52$^{bcA}$ | 77.03 ± 6.90$^{cA}$ | 87.40 ± 12.22$^{bcA}$ | 76.29 ± 12.72$^{cA}$ | 94.25 ± 6.67$^{bcA}$ | 80.92 ± 1.69$^{bCB}$ | 79.62 ± 5.79$^{bCB}$ | 88.88 ± 9.44$^{bcAB}$ | 97.59 ± 3.94$^{bA}$ | 78.51 ± 7.80$^{cB}$ | 81.48 ± 10.91$^{bCB}$ |
| TG | 115.71 ± 5.38$^{ab}$ | 147.64 ± 33.46$^{a}$ | 96.03 ± 5.77$^{b}$ | 141.85 ± 9.53$^{aA}$ | 129 ± 14.05$^{abAB}$ | 124.22 ± 11.52$^{abAB}$ | 116 ± 9.17$^{abB}$ | 137.15 ± 5.73$^{aA}$ | 131.57 ± 8.55$^{aAB}$ | 130.10 ± 16.77$^{aA}$ | 121 ± 3.56$^{abA}$ | 134.80 ± 22.90$^{aA}$ | 133.92 ± 5.50$^{aA}$ | 130.69 ± 11.63$^{aA}$ | 123.05 ± 8.55$^{abA}$ |
| HDL-C | 36.52 ± 2.81$^{b}$ | 17.31 ± 1.70$^{e}$ | 43.47 ± 2.69$^{a}$ | 31.35 ± 3.01$^{bcA}$ | 29.91 ± 1.48$^{abcA}$ | 23.08 ± 4.47$^{deB}$ | 26.49 ± 3.36$^{cdAB}$ | 23.42 ± 3.81$^{deB}$ | 32.99 ± 3.40$^{bcA}$ | 27.75 ± 1.48$^{cdA}$ | 25.66 ± 3.03$^{cdAB}$ | 30.25 ± 2.56$^{abcA}$ | 27.86 ± 3.63$^{cdA}$ | 17.67 ± 0.99$^{eB}$ | 25.85 ± 2.76$^{cdAB}$ |
| LDL-C | 27.74 ± 6.09$^{bc}$ | 88.88 ± 10.51$^{a}$ | 22.5 ± 7.89$^{c}$ | 28.04 ± 8.53$^{bcA}$ | 30.41 ± 6.70$^{bcA}$ | 29.10 ± 4.23$^{bcA}$ | 37.70 ± 10.23$^{bcA}$ | 24.85 ± 6.98$^{cA}$ | 35.24 ± 5.60$^{bcA}$ | 27.15 ± 6.48$^{bcA}$ | 29.58 ± 6.94$^{bcA}$ | 31.67 ± 12.78$^{bcA}$ | 42.94 ± 6.65$^{bA}$ | 34.61 ± 8.47$^{bcA}$ | 31.01 ± 8.25$^{bcA}$ |
| VLDL | 23.14 ± 2.17$^{d}$ | 29.52 ± 9.12$^{a}$ | 19.20 ± 1.23$^{e}$ | 28.37 ± 3.53$^{abA}$ | 25.8 ± 6.17$^{cC}$ | 24.84 ± 0.92$^{dC}$ | 23.2 ± 3.37$^{dD}$ | 27.43 ± 2.61$^{bA}$ | 27.50 ± 4.28$^{bA}$ | 26 ± 6.12$^{cB}$ | 24.2 ± 2.32$^{dC}$ | 26.96 ± 9.01$^{cB}$ | 26.78 ± 2.33$^{cB}$ | 26.13 ± 7.62$^{cB}$ | 24.61 ± 3.38$^{dC}$ |
| AI | 2.39 ± 0.27$^{d}$ | 7.56 ± 3.12$^{a}$ | 1.95 ± 0.12$^{e}$ | 2.80 ± 0.92$^{cdB}$ | 2.88 ± 0.76$^{cdB}$ | 3.33 ± 1.13$^{cB}$ | 3.29 ± 1.08$^{cB}$ | 3.25 ± 1.44$^{cB}$ | 2.85 ± 0.63$^{cdB}$ | 2.91 ± 0.64$^{cdB}$ | 3.10 ± 0.97$^{cB}$ | 2.93 ± 0.72$^{cdB}$ | 3.50 ± 1.77$^{cAB}$ | 4.44 ± 1.96$^{bA}$ | 3.15 ± 1.01$^{cB}$ |
| Female rats | | | | | | | | | | | | | | | |
| TC | 80.11 ± 6.54$^{cd}$ | 119.81 ± 3.61$^{a}$ | 79.62 ± 5.28$^{de}$ | 75.37 ± 5.70$^{efAB}$ | 71.48 ± 5.78$^{efB}$ | 71.29 ± 3.05$^{efB}$ | 80.00 ± 8.06$^{cdAB}$ | 70.37 ± 4.45$^{fB}$ | 85.18 ± 5.48$^{bcA}$ | 86.48 ± 5.25$^{bA}$ | 81.85 ± 3.78$^{cdA}$ | 78.88 ± 3.09$^{deAB}$ | 86.48 ± 6.09$^{bA}$ | 70.18 ± 6.24$^{fB}$ | 76.11 ± 8.94$^{efAB}$ |
| TG | 100.67 ± 9.82$^{de}$ | 128.95 ± 8.46$^{a}$ | 86.96 ± 7.44$^{e}$ | 125.11 ± 5.50$^{aA}$ | 110.13 ± 10.82$^{bcAB}$ | 112.48 ± 8.99$^{bcAB}$ | 105.72 ± 9.69$^{cdB}$ | 122.46 ± 7.83$^{abA}$ | 118.64 ± 6.84$^{abAB}$ | 118.35 ± 8.91$^{abA}$ | 104 ± 12.34$^{cdAB}$ | 117.18 ± 7.68$^{abA}$ | 113.06 ± 11.73$^{bcA}$ | 104.28 ± 9.94$^{cdAB}$ | 100.73 ± 10.13$^{deAB}$ |
| HDL-C | 39.93 ± 4.33$^{b}$ | 18.83 ± 1.43$^{f}$ | 47.41 ± 4.26$^{a}$ | 24.14 ± 3.39$^{deAB}$ | 32.34 ± 7.51$^{cA}$ | 23.46 ± 3.99$^{eB}$ | 27.08 ± 5.71$^{dAB}$ | 27.22 ± 4.39$^{dAB}$ | 29.57 ± 4.10$^{cdAB}$ | 25.09 ± 4.17$^{deA}$ | 21.14 ± 2.62$^{eA}$ | 27.98 ± 4.42$^{dA}$ | 24.79 ± 5.82$^{deA}$ | 22.70 ± 5.07$^{eA}$ | 28.13 ± 2.46$^{cdA}$ |
| LDL-C | 21.03 ± 6.40$^{e}$ | 79.19 ± 1.30$^{a}$ | 14.81 ± 2.53$^{f}$ | 26.20 ± 3.48$^{dAB}$ | 17.10 ± 1.10$^{fB}$ | 25.33 ± 7.71$^{deAB}$ | 31.77 ± 12.57$^{cA}$ | 18.65 ± 4.95$^{fB}$ | 31.88 ± 9.83$^{cA}$ | 37.11 ± 3.16$^{bcA}$ | 39.85 ± 3.24$^{bA}$ | 27.47 ± 2.25$^{dB}$ | 39.09 ± 12.84$^{bA}$ | 26.62 ± 6.10$^{deB}$ | 27.83 ± 12.76$^{dB}$ |
| VLDL | 20.13 ± 4.17$^{c}$ | 25.79 ± 6.51$^{a}$ | 17.39 ± 1.92$^{d}$ | 25.02 ± 3.12$^{aA}$ | 22.02 ± 2.97$^{bB}$ | 22.49 ± 2.15$^{bB}$ | 21.14 ± 2.62$^{bcC}$ | 24.49 ± 3.36$^{abA}$ | 23.72 ± 2.27$^{bAB}$ | 23.67 ± 2.66$^{bAB}$ | 20.8 ± 3.51$^{cC}$ | 23.43 ± 4.19$^{bAB}$ | 22.61 ± 2.01$^{bB}$ | 20.85 ± 3.12$^{cC}$ | 20.14 ± 2.17$^{cC}$ |
| AI | 2.00 ± 0.27$^{c}$ | 6.36 ± 2.97$^{a}$ | 1.67 ± 0.19$^{d}$ | 3.12 ± 0.99$^{bA}$ | 2.21 ± 0.54$^{cB}$ | 3.03 ± 0.92$^{bA}$ | 2.95 ± 0.77$^{bCB}$ | 2.58 ± 0.63$^{cB}$ | 2.88 ± 0.64$^{bCB}$ | 3.44 ± 1.32$^{bA}$ | 3.87 ± 1.46$^{bA}$ | 2.81 ± 0.72$^{cB}$ | 3.48 ± 1.37$^{bA}$ | 3.09 ± 0.79$^{bA}$ | 2.70 ± 0.69$^{cB}$ |

*Note:* Letters (a–g) in the same row with different letters showed significant differences ($p \leq 0.05$) between the control and Dana-treated groups; letters (A–C) in the same row with different letters differed significantly ($p \leq 0.05$) for the Dana-treated groups.

Abbreviations: AI, atheroma index; BBD, black boiled Dana; BBrD, black braised Dana; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; NCG, negative control group; NeCG, Neutral Control Group; PCG, positive control group; RBD, raw black Dana; RWD, raw white Dana; TC, total cholesterol; TG, triglycerides; VLDL, very low density lipoprotein cholesterol; WBD, white boiled Dana; WBrD, white braised Dana.

**TABLE 5** | Effects of the consumption of different diets based on Dana flour on the renal and hepatic functioning of rats.

| | Control groups | | | White Dana | | | | | | Black Dana | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Parameters** | **NeCG** | **PCG** | **NCG** | **RWD 25%** | **RWD 50%** | **WBD 25%** | **WBD 50%** | **WBrD 25%** | **WBrD 50%** | **RBD 25%** | **RBD 50%** | **BBD 25%** | **BBD 50%** | **BBrD 25%** | **BBrD 50%** |
| Male | | | | | | | | | | | | | | | |
| ALT | 44.52 ± 0.87$^{f}$ | 110.87 ± 2.61$^{a}$ | 34.97 ± 5.94$^{g}$ | 44.23 ± 2.66$^{fA}$ | 40.62 ± 2.48$^{fgA}$ | 66.34 ± 3.49$^{cdA}$ | 59.36 ± 8.73$^{deA}$ | 45.97 ± 2.66$^{fA}$ | 43.77 ± 1.49$^{fA}$ | 46.56 ± 6.13$^{fC}$ | 42.48 ± 4.39$^{fgC}$ | 74.49 ± 8.25$^{bA}$ | 67.51 ± 2.02$^{bcAB}$ | 58.2 ± 3.63$^{eB}$ | 47.72 ± 5.04$^{fC}$ |
| AST | 2.32 ± 1.00$^{b}$ | 4.71 ± 3.56$^{a}$ | 2.09 ± 0.17$^{b}$ | 2.44 ± 0.30$^{bB}$ | 2.15 ± 0.66$^{bC}$ | 2.66 ± 0.30$^{abB}$ | 3.03 ± 0.07$^{abB}$ | 2.77 ± 0.01$^{abB}$ | 2.58 ± 0.11$^{bB}$ | 2.64 ± 0.05$^{bB}$ | 2.21 ± 0.40$^{bC}$ | 2.39 ± 0.82$^{bB}$ | 3.31 ± 1.36$^{abAB}$ | 2.96 ± 0.17$^{abB}$ | 2.62 ± 0.16$^{bB}$ |
| Urea | 0.31 ± 0.01$^{ab}$ | 0.15 ± 0.10$^{c}$ | 0.35 ± 0.06$^{a}$ | 0.26 ± 0.08$^{abcA}$ | 0.21 ± 0.07$^{bcA}$ | 0.29 ± 0.02$^{abA}$ | 0.24 ± 0.06$^{bcA}$ | 0.27 ± 0.01$^{abA}$ | 0.22 ± 0.01$^{bcA}$ | 0.25 ± 0.04$^{abcAB}$ | 0.20 ± 0.07$^{bCB}$ | 0.30 ± 0.04$^{abA}$ | 0.20 ± 0.05$^{bCB}$ | 0.26 ± 0.02$^{abAB}$ | 0.21 ± 0.04$^{bcAB}$ |
| Creatinine | 1.23 ± 0.50$^{a}$ | 0.60 ± 0.05$^{b}$ | 1.30 ± 0.76$^{a}$ | 0.73 ± 0.14$^{abA}$ | 0.60 ± 0.23$^{bA}$ | 1.01 ± 0.19$^{abA}$ | 0.98 ± 0.30$^{abA}$ | 0.85 ± 0.25$^{abA}$ | 0.79 ± 0.10$^{abA}$ | 0.75 ± 0.09$^{abA}$ | 0.73 ± 0.14$^{abA}$ | 1.07 ± 0.14$^{abA}$ | 1.04 ± 0.32$^{abA}$ | 0.95 ± 0.16$^{abA}$ | 0.95 ± 0.19$^{abA}$ |
| Female | | | | | | | | | | | | | | | |
| ALT | 38.12 ± 10.41$^{ef}$ | 102.14 ± 6.11$^{a}$ | 31.48 ± 5.99$^{f}$ | 41.32 ± 5.33$^{cdB}$ | 38.30 ± 6.15$^{deB}$ | 60.52 ± 13.22$^{bA}$ | 57.61 ± 9.23$^{bcA}$ | 40.74 ± 11.22$^{cdB}$ | 39.40 ± 3.72$^{deB}$ | 40.97 ± 5.80$^{cdB}$ | 37.83 ± 3.63$^{fB}$ | 68.09 ± 20.95$^{bA}$ | 55.87 ± 9.23$^{cdAB}$ | 54.88 ± 0.89$^{cdAB}$ | 40.74 ± 17.13$^{deB}$ |
| AST | 2.03 ± 1.33$^{b}$ | 4.19 ± 3.9$^{a}$ | 1.97 ± 0.26$^{b}$ | 2.26 ± 0.17$^{abAB}$ | 2.03 ± 0.86$^{bB}$ | 2.37 ± 0.70$^{abAB}$ | 2.71 ± 0.57$^{abAB}$ | 2.36 ± 0.70$^{abAB}$ | 2.18 ± 0.81$^{abAB}$ | 2.47 ± 0.33$^{abAB}$ | 2.09 ± 0.60$^{abB}$ | 2.72 ± 1.40$^{abAB}$ | 2.91 ± 1.13$^{abAB}$ | 2.50 ± 0.50$^{abAB}$ | 2.21 ± 0.28$^{abB}$ |
| Urea | 0.28 ± 0.04$^{ab}$ | 0.12 ± 0.02$^{f}$ | 0.32 ± 0.04$^{a}$ | 0.24 ± 0.04$^{cdA}$ | 0.21 ± 0.01$^{deA}$ | 0.28 ± 0.00$^{abA}$ | 0.23 ± 0.07$^{cdA}$ | 0.26 ± 0.00$^{cA}$ | 0.21 ± 0.07$^{deA}$ | 0.23 ± 0.04$^{cdAB}$ | 0.20 ± 0.02$^{deAB}$ | 0.29 ± 0.01$^{abA}$ | 0.19 ± 0.04$^{efB}$ | 0.25 ± 0.00$^{cAB}$ | 0.20 ± 0.03$^{deAB}$ |
| Creatinine | 1.02 ± 0.1$^{a}$ | 0.57 ± 0.0$^{e}$ | 1.24 ± 0.50$^{a}$ | 0.71 ± 0.05$^{cdAB}$ | 0.57 ± 0.1$^{eB}$ | 0.98 ± 0.30$^{abA}$ | 0.92 ± 0.10$^{abcA}$ | 0.82 ± 0.19$^{bcA}$ | 0.73 ± 0.23$^{cdAB}$ | 0.73 ± 0.08$^{cdAB}$ | 0.69 ± 0.05$^{deB}$ | 0.95 ± 0.19$^{abA}$ | 0.92 ± 0.29$^{abcA}$ | 0.85 ± 0.25$^{bcA}$ | 0.79 ± 0.10$^{cAB}$ |

*Note:* Means assigned different symbols are significantly different at the 5% probability level. Letters (a–g) in the same row with different letters showed significant differences ($p \leq 0.05$) between the control and Dana-treated groups; letters (A–C) in the same row with different letters differed significantly ($p \leq 0.05$) for the Dana-treated groups.

Abbreviations: ALT, alanine amino transferase; AST, aspartate amino transferase; BBD, black boiled Dana; BBrD, black braised Dana; NCG, negative control group; NeCG, Neutral Control Group; PCG, positive control group; RBD, raw black Dana; RWD, raw white Dana; WBB, white boiled Dana; WBrD, white braised Dana.

change was independent of many other potential factors including age, baseline fiber and fat intakes, activity level, and baseline energy intake.

HDL cholesterol controls lipid metabolism by removing free cholesterol from peripheral cells, esterifying it, and transporting it to the liver for degradation, which is why it is commonly referred to as "good cholesterol" (Gautier et al. 2011). The increase in serum HDL cholesterol levels in rats fed diets supplemented with Dana flour could be explained by the fact that HDL are indeed cardioprotective molecules since they allow the efflux of cholesterol to the liver for elimination (Gautier et al. 2011; Nchoutpouen et al. 2020). These results are in line with those of Uthirapathy et al. (2021), who observed a correction in serum HDL cholesterol levels in rats subjected to gavage of ethanolic extract of *Dioscorea bulbifera* due to their high flavonoid content. Consumption of 25% supplemented raw white Dana and 25% supplemented braised white Dana resulted in a decrease in LDL cholesterol concentrations, respectively (28.04 mg/dL; 24.85 mg/dL), as in female rats fed with 50% supplemented raw white Dana (17.10 mg/dL) and 25% supplemented braised white Dana (18.65 mg/dL). This decrease observed in these groups could be due to the inhibition of hepatic cholesterol synthesis by phenolic compounds, in particular, flavonoids, present in flours of different culinary forms (Nguekouo et al. 2018) and the fiber content of flours (Woumbo et al. 2017). Fossouo (2023) found that the content of phenolic compounds in *Dioscorea bulbi*fera (Dana) flours was of the order of 124.78 mg EAG/g (boiled white Dana) and 35.89 mg EAG/g (boiled black Dana) for hydroethanolic extracts. The work of Ani et al. (2020) reported that fibers cause a decrease in total cholesterol and LDL cholesterol. The reduction in cholesterol levels is likely due to an increase in bile acid synthesis. Andersson et al. (2002) found that oat bran doubled the serum concentration of 7α-hydroxy-4-cholesten-3-one (α-HC), which is a metabolite in the synthesis of bile acids that is oxidized from 7α-hydroxycholesterol. The reduction in serum triglyceride levels may be owing to a decreased absorption of fat from the small intestine. Uthirapathy et al. (2021) reported that flavonoids present in *Dioscorea bulbifera* extracts are powerful antioxidants and inhibitors of hydroxy-methyl-glutarylcoenzyme A reductase, the main enzyme in cholesterol synthesis. Fossouo (2023) demonstrated in their study that culinary treatment influences the content of flavonoids. They observed that the content of flavonoids in *Dioscorea bulbifera* extracts varied from 6.59 ± 0.77 to 115.34 ± 8.54 depending on culinary treatment and the nature of extracts (aqueous, ethanolic, and hydroethanolic). Therefore, *Dioscorea bulbifera* could be an important matrix for lipid-lowering effects. The total cholesterol/HDL ratio represents the atherogenic index (AI), and in this work, this index was higher in untreated hyperlipidemic rats (7.56 ± 3.12 in males and 6.36 ± 2.97 in females) than the groups that received Dana-based diets. Indeed, in the clinical interpretation of these parameters, the total cholesterol/HDL ratio must be between 2.5 and 3 (Njinkoue et al. 2017). This ratio (AI) being much higher than 3 could confirm the establishment and evolution of the dyslipidemic and arteriosclerotic process (Njinkoue et al. 2017). In the context of this work, there was a significant decrease in the atherogenic index observed in the groups that received the raw white Dana (supplements at 25% and 50%), raw black Dana supplemented at 25%, braised white Dana supplemented at 50%, and boiled black Dana supplemented at 25% compared to the positive control. These results could therefore mean that the culinary forms of the white and black varieties improve the lipid profile parameters. These results are in line with those of Chiu et al. 2018 who enumerated major popular nutraceutical/functional food ingredients with hypocholesterolemic or hypolipidemic activities such as plant sterols/stanols, red yeast, rice, green tea catechins (e.g., epigallocat echin gallate; EGCG), curcumin, berberine, garlic, spirulina, fish oil (omega-3-fatty acids—docosahexaenoic acid; DHA and eicosapentaenoic acid; EPA), soybean (protein), pre- and probiotics, and soluble fibers as well as other minor lipid-lowering nutraceuticals/functional foods like grape seed polyphenol (resveratrol), quercetin (onion), royal jelly (honey), and prune. The mechanisms of action are the following: functional foods can interfere in micelle formation, inhibit the bile acid reabsorption (diminish the cholesterol pool), inhibit HMG Co-A reductase and the activity of ACAT and gastric lipase, inhibit NPC1L1 transporter expression, upregulate hepatic LDL-R production, enhance hepatic lipase activity, increase the expression of LPL and fatty acid oxidation enzymes, upregulate the BSH enzyme (decrease bile acid reabsorption), and modulate cholesterol synthesis (HMG Co-A reductase inhibitor) and the expression of the VLDL receptor (Chiu et al. 2018).

This study also highlights sex differences in the response of hyperlipidemia rats to *Dioscorea bulbifera* meal supplementation. Female rats generally showed more reductions in total cholesterol (WBrD 25%: 70.37 mg/dL) and triglycerides (WBD 25%: 105.72 mg/dL) when fed with braised and boiled Dana flour than male rats (WBrD 25%: 76.29 mg/dL) and triglycerides (WBD 25%: 116 mg/dL). Females tended to show greater improvement in HDL-C concentrations (WBrD 25%: 27.22 mg/dL) than male rats (WBrD 25%: 23.42 mg/dL). These trends were observed generally in all groups and could be attributed to hormonal and metabolic differences between the sexes. It is known that estrogen stimulates the expression of the hepatic LDL receptor and lipoprotein lipase activity and promotes the elimination of LDL and triglycerides but increases HDL levels (Gautier et al. 2011; Persson et al. 2012). In addition, females generally have a greater ability to resist during induction of obesity by a high-fat diet. This could be due to hormonal adaptations and specific interactions with the gut microbiota (Stapleton et al. 2024). Male rats are often more favorable in accumulating visceral fat, and this may explain the more pronounced reduction in triglycerides and cholesterol after supplementation. In addition, several studies have shown differential expression of genes involved in lipid metabolism depending on sex. For example, males activate β-oxidation pathways (PPAR-α, CPT1L) to a greater extent, while females favor the synthesis and transport of triglycerides and VLDL (Schmidt et al. 2012; Bideyan et al. 2021; Mahinda 2024).

It is known that elevated serum levels of certain metabolic enzymes (AST and ALT) and substances (urea and creatinine) are indicators of liver and kidney deterioration. The liver is the central organ involved in the body's metabolic processes and is affected by complications of lipid disorders (Tekou et al. 2018). By measuring the levels of these enzymes in this work, we

intended to verify whether raw and processed (boiled and braised) *Dioscorea bulbifera* (Dana) flours protect or have the ability to reduce the effects of complications of hyperlipidemia in the liver and the kidney, given that an increase in the activities of these enzymes causes damage to these organs (Nguekouo et al. 2018). In this study, rats fed with boiled black and white Dana supplemented with 25% presented the highest levels of AST. All groups presented higher concentrations of ALT levels than the control except for rats fed with raw white Dana 50% (40.62 IU/L) and raw black Dana 50% (42.48 IU/L), whose values were close to those of the negative control groups (34.97 IU/L). The high levels of AST and ALT could be due to an accumulation of fat in the liver of the animals during the induction of hyperlipidemia, leading to cell damage and release of these transaminases (Kouadio et al. 2022). The relative weight of the organ provides information on its hypertrophy or atrophy. Thus, an increase or decrease in the relative weight of the organs indicates organ dysfunction (Amresh et al. 2008). In this work, there was a significant increase in the relative liver weight (WL) of male rats in the groups fed with 25% supplemented white boiled Dana (WBD) and 50% supplemented black boiled Dana (BBD) and a decrease in abdominal fat in some groups, namely the group of rats, which consumed 25% supplemented white boiled Dana and 50% supplemented black boiled Dana. This may be due to an accumulation of fat in the rats' livers.

Liver enzymes (ASAT and ALAT) also showed different profiles depending on sex. Males rat supplemented with raw Dana (RWD 50%: 2.15 IU) had values closer to the negative controls (NCG: 2.09 IU), suggesting better restoration of liver function. Females maintained slightly higher levels in boiled forms, which could reflect more pronounced cytochrome P450 activity or less hepatic lipid accumulation due to estrogenic protection (Qiu et al. 2023; Lee and Jung 2023). With regard to renal function, creatinine levels were slightly higher in males, which is to be expected given their greater muscle mass (Yim et al. 2023). However, there were not significant differences concerning urea and creatinine levels in both sexes after treatment, reflecting the overall protective effect of Dana. These results are in line with the observations of Pessoa et al. (2015), who showed that diet supplemented by *Dioscorea bulbifera* flours improved the lipid profile and reduced hepatic and renal oxidative stress in diabetic rats.

Functional foods and their bioactive compounds show promise in the management of obesity and hyperlipidemia through a variety of mechanisms. Plant foods containing flavonoids, polysaccharides, and polyphenols can inhibit lipid biosynthesis, promote lipid metabolism, and regulate intestinal microbiota (Gong et al. 2020). Cereals, vegetables, fruit, and pulses have anti-obesity effects by inhibiting enzymes such as α-amylase and α-glucosidase, stimulating thermogenesis and modulating the intestinal microbiota (Oladimeji and Adebo 2024). Although functional foods have potential in obesity management, further clinical and epidemiological studies are needed to fully understand their effects and mechanisms. They noted that *Dioscorea bulbifera* (Dana) has been the subject of several in vitro and in vivo studies in animals but not really in humans. Given the many properties of this plant, it would be possible to carry out studies on humans in order to establish dietary recommendations in terms of dietary fiber, phenolic compounds, etc.

In summary, these results highlight that the lipid-lowering and organ-protective effects of *Dioscorea bulbifera* flour are not uniform between the sexes. Interactions between bioactive food compounds, particularly saponins, flavonoids, and fiber, and sex hormones such as estrogen and testosterone may partly explain these differences. In addition, culinary treatments (boiling and braising) appear to modulate these sex-specific effects by altering the profile and bioavailability of bioactive compounds. These results indicate that in the further investigation, it will be important to take in account larger sample sizes, hormones, and transcriptomic analyses to fully elucidate the sex-specific pathways involved in the lipid-lowering action of *Dioscorea bulbifera*.

## 5 | Conclusion

Culinary application and administration of different food diets in rats based on Dana flours led to an increase in daily food consumption in groups fed with boiled Dana flours and to a reduction in weight gain in groups fed with braised Dana flours. The test groups showed a significant reduction in triglyceride, total cholesterol, and LDL cholesterol and an increase in HDL cholesterol levels. These levels were close to those of rats in the neutral control group of olive oil, thus reflecting the hypolipidemic effect of Dana flours. The consumption of the different test diets led to significant differences in serum enzyme concentrations (AST and ALT) compared with the control groups. Overall, the results of this work therefore indicate that a diet made from 25% of Dana white variety, and braised Dana improves the lipid profile of rats made obese and hyperlipidemic rats, in both sexes, with a minimal risk of deterioration of the liver and kidneys. In future investigations, the duration of the study will have to be extended to study the real long-term physiologic effects of the plant. Also, the targeted formulation of snacks, in particular biscuits made from treated *Dioscorea bulbifera* (Dana) flour, will enable an in-depth assessment of the regulatory mechanism in gastrointestinal tract.

### Author Contributions

**Fossouo Towa Patrik Florent:** data curation, formal analysis, funding acquisition, investigation, methodology, resources, software, validation, visualization, writing – original draft. **Maffo Tazoho Ghislain:** conceptualization, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, visualization, writing – original ddraft. **Tekou Florian Amel:** formal analysis, funding acquisition, investigation, methodology, resources, validation, visualization, writing – original draft. **Kenfack Justine Odelonne:** formal analysis, investigation, funding acquisition, methodology, resources, validation, visualization, writing – review and editing. **Zokou Ronice:** formal analysis, funding acquisition, methodology, resources, validation, visualization, writing – original draft. **Dangang Bossi Donald Séverin:** formal analysis, funding acquisition, methodology, resources, supervision, validation, writing – review and editing. **Womeni Hilaire Macaire:** funding acquisition, methodology, project administration, resources, supervision, validation, writing – review and editing.

### Funding

The authors have nothing to report.

## Conflicts of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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