

Research Article

Impact of Cocoa Residues (Shells and Rachis) on the Prevention of High Blood Pressure in Rats

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Abstract

High blood pressure is a key risk factor for cardiovascular disease, making it crucial to identify alternative preventive approaches based on local food resources. This study investigated the potential of a mixture of cocoa shells and husks (by-products of the cocoa industry) to prevent hypertension in Wistar rats with fructose-induced hypertension. Phytochemical analysis of the mixture revealed high levels of total polyphenols (15.87 ± 0.86 g/100 g dry matter) and flavonoids (7.95 ± 0.69 g/100 g dry matter), associated with strong antioxidant ($63.59 \pm 4.7\%$) and anti-inflammatory ($76.26 \pm 0.89\%$) activities. The mixture was also found to be rich in essential minerals, particularly potassium, magnesium and zinc. The use of the cocoa residue mixture (cocoa beans and shells) in the experiment significantly limited the increase in systolic and diastolic blood pressure in rats. These rats remained in good health until the end of the experiment, with systolic blood pressure ranging from 106.33 ± 10.12 mmHg to 113.67 ± 5.67 mmHg and diastolic blood pressure from 83.33 ± 4.04 mmHg to 86 ± 7 mmHg. In contrast, the rats that received only fructose (positive control) developed hypertension, with a systolic blood pressure of 154.33 ± 6.81 mmHg and a diastolic blood pressure of 131.67 ± 9.07 mmHg at the end of the experiment. It also improved haematological, renal, hepatic and lipid parameters, notably by reducing LDL cholesterol, triglycerides and total cholesterol whilst increasing HDL cholesterol. This study suggests that the mixture of cocoa shells and stems shows promising potential as a functional ingredient in the prevention of hypertension.

Keywords

Cocoa Residues, Hypertension Prevention, Oxidative Stress, Functional Food, Wistar Rats

1. Introduction

High blood pressure (HBP) is now a major public health issue due to its prevalence and role in the development of cardiovascular disease. According to the World Health Organization, more than one billion people are affected by it, and nearly 10 million deaths are attributed to HBP each year. In sub-Saharan Africa, the prevalence of HBP is increasing rapidly due to the

combined effects of urbanisation, changing dietary habits, and sedentary lifestyles [1]. In light of this worrying situation, preventing hypertension is a priority, particularly through adopting a healthy lifestyle involving physical activity, a balanced diet, and stress management. Indeed, regular exercise of at least 150 minutes per week has been shown to improve vascular function

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and significantly reduce blood pressure [2], while even modest weight loss, quitting smoking, and reducing alcohol consumption can help to lower blood pressure [3-5]. Of all these proposals, diet plays a central role in prevention. A diet rich in fruit, vegetables, fiber, potassium, magnesium, calcium and antioxidants, combined with reducing salt, saturated fat and sugar intake, has been shown to effectively lower blood pressure [6, 7]. Reducing salt intake to less than 2 g per day and increasing potassium intake promotes sodium elimination and stimulates vasodilation, thereby helping to prevent hypertension [8, 9]. Meanwhile, there is growing interest in natural foods rich in bioactive compounds, such as cocoa. Cocoa (*Theobroma cacao* L.) is recognised in particular for its polyphenol and flavanol content (including epicatechin and catechin), which improves endothelial function, reduces oxidative stress and promotes vasodilation [10, 11]. Several clinical studies have confirmed the blood pressure-lowering effect of consuming flavanol-rich cocoa [12]. However, research in this area has mainly focused on cocoa beans and processed products, such as chocolate. Meanwhile, cocoa residues, including shells, rachis and empty pods, are largely underutilised despite their abundance. These residues contain polyphenols, dietary fiber and minerals such as potassium and magnesium [13], which play an essential role in regulating blood pressure [14]. Using them is part of a circular economy dynamic that is particularly relevant in producing countries such as Côte d'Ivoire, as it offers the possibility of developing accessible functional ingredients while reducing agro-industrial waste. Therefore, it is crucial to explore the nutritional and bioactive potential of these residues. When consumed in powder or herbal tea form, these by-products could help to prevent high blood pressure by acting on oxidative stress, inflammation and blood pressure control simultaneously. The aim of this study is therefore to evaluate the preventive effect of cocoa residue powder on the onset of induced high blood pressure in Wistar rats.

2. Material and Methods

2.1. Plant and Animal Material

The plant material used consists of cocoa residues, mainly bean shells and cocoa rachis from Azaguie, in Agboville department (Southern Cote d'Ivoire). The cocoa pods were transported to Felix Houphouet-Boigny University's National Center for Floristics in Abidjan, where the beans were removed from the shells. The rachis obtained were fermented for 48 hours. The shells were recovered after the fermented cocoa beans had been dried. The animal material consisted of male *Rattus norvegicus* rats of the Wistar strain, aged 10 to 14 weeks and weighing between 150 and 250 g. The animals were supplied by the breeding unit of the Faculty of Pharmacy and Biological Sciences of Felix Houphouet-Boigny University. The experiments were conducted in the animal facility of the Ecole Normale Supérieure (ENS) in Abidjan-Cocody. The rats were kept under standard conditions: temperature of $22 \pm$

2 °C, 12-hour light/dark cycle, and free access to water and standard feed. The experiments conducted on rats were carried out with the authorization of the National Ethics Committee for Life Sciences and Health.

2.2. Preparation of Cocoa Residue Samples

Cocoa residue powders were obtained from the shells and rachis of cocoa beans. The fresh beans were fermented and dried before being shelled to allow the shells to be recovered. Meanwhile, the rachis underwent 48 hours of fermentation, followed by 96 hours of drying in the shade. The dried shells and rachis were ground using a Moulinex-type grinder to obtain homogeneous powders. These were then mixed at a ratio of 1: 1 (rachis: shells). To prepare the infusions for analysis, 1 g of this mixture was dissolved in 25 ml of tap water and subjected to cold maceration. This preparation corresponds to a concentration of 400 mg/mL.

2.3. Determination of Phytochemical Compounds in Cocoa Residue Powder Mixture

Phenolic compounds were extracted using the method described by Singleton et al. [15]. One gram (1 g) of powder was homogenized in 10 mL of 70% (v/v) methanol, then centrifuged at 1000 rpm for 10 minutes. The pellet was resuspended in 10 mL of the same solvent and centrifuged again under the same conditions. The supernatants were combined in a Falcon tube to obtain the methanolic extract. The total polyphenol content was measured according to Singleton et al. [15]. One milliliter (1 mL) of extract was mixed with 1 mL of Folin-Ciocalteu reagent and allowed to stand for 3 minutes. Next, 1 mL of a 20% (w/v) sodium carbonate solution was added, and the final volume was adjusted to 10 mL with distilled water. After incubation in the dark for 30 minutes, the absorbance was read at 725 nm. Quantification was performed using a calibration curve established with gallic acid (1 mg/mL). Flavonoids were quantified according to Meda et al. [16]. A volume of 0.5 mL of extract was successively mixed with 0.5 mL of distilled water, 0.5 mL of 10% (w/v) aluminum chloride, 0.5 mL of sodium acetate (1 M), and then 2 mL of distilled water. After incubation for 30 minutes at 37 ± 2 °C and protected from light, the absorbance was measured at 415 nm. The concentration was determined using a standard curve made with quercetin (1 mg/mL).

2.4. Determination of Radical Antioxidant and Anti-inflammatory Activities of Cocoa Residue Powders

Radical antioxidant activity was evaluated according to the method of Choi et al. [17] using the stable free radical DPPH (2,2-diphenyl-1-picrylhydrazyl). A volume of 1.5 mL of methanolic extract was mixed with 1 mL of a DPPH solution

(3 mM in methanol). The mixture was incubated in the dark for 30 minutes, then the absorbance was measured at 415 nm using a spectrophotometer. Antioxidant activity was expressed as the percentage inhibition of the DPPH radical, calculated according to following formula:

$$AA(\%) = (DOc - (DOe - DOT)) \times 100/DOc \quad (1)$$

(DOc: Absorbance of the control (1 mL DPPH + 2.5 mL methanol); DOe: Absorbance of the test (1 mL DPPH + 2.5 mL extract); DOT: Absorbance of the blank (1 mL methanol + 2.5 mL extract).

The anti-inflammatory activity of cocoa shell and rachis extracts was determined by the protein denaturation inhibition test,

$$\% \text{ inhibition} = (DO_{\text{control}} - DO_{\text{extract}}) \times 100/DO_{\text{control}} \quad (2)$$

2.5. Determination of Mineral and Protein Content

The mineral content was determined using a VARIAN AAS20 air-acetylene flame atomic absorption spectrophotometer, in accordance with the AOAC method [19]. A quantity of 0.3 g of ground sample was weighed into a porcelain crucible and placed in a Prolabo muffle furnace at 650 °C for five hours. After cooling, 5 ml of nitric acid (1 mol/L) was added to the ashes, and the mixture was evaporated in a sand bath. The resulting residue was treated with 5 ml of hydrochloric acid (0.1 mol/L) and returned to the furnace at 400 °C for 30 minutes. The final residue was then dissolved in 10 ml of hydrochloric acid (1 mol/L) and transferred to a 50 ml bottle. The crucible was rinsed twice with 10 ml of the same acid and the bottle was filled to 50 mL with hydrochloric acid. A blank was carried out under the same conditions. The minerals analysed were sodium, potassium, chromium, magnesium and zinc. After mineralisation, standard solutions were prepared for each element according to the reference methods.

The total protein content of the samples was determined using the Kjeldahl method (calculated as N × 6.25), after total nitrogen determination [19]. Organic samples were first digested in the presence of concentrated sulphuric acid. Digestion was carried out by boiling the homogenised sample in acid until a clear solution was obtained. The resulting solution was then made alkaline to convert the ammonium ions (NH₄⁺) into ammonia (NH₃). The released ammonia was distilled and carried in gaseous form to a receiving solution, where it was trapped. The amount of ammonia fixed in the receiving solution is quantified by titration. The total nitrogen content is then calculated from the measured amount of ammonia, allowing the protein content of the sample to be determined.

2.6. Vitamins Determination

Vitamins A, E, and D were analyzed by high-performance

following the method described by Anoop and Bindu [18]. The samples were dried at 50 °C, pulverized into a fine powder, and then extracted by maceration in 70% ethanol for 24 hours. After filtration and vacuum concentration in a rotary evaporator, the extracts were diluted to different concentrations (63–1000 µg/mL). The reaction mixture consisted of 0.45 mL of 5% bovine serum albumin and 0.05 mL of extract, with the pH adjusted to 6.3 using hydrochloric acid (1 N). The tubes were incubated at 37 °C for 20 minutes, then heated to 57 °C for 3 minutes to induce protein denaturation. After cooling, 2.5 mL of phosphate buffer (pH 6.3) was added and the absorbance was measured at 416 nm. Diclofenac sodium was used as a positive control and distilled water as a negative control. The percentage of protein denaturation inhibition was calculated using formula:

liquid chromatography (HPLC) using a Waters system comprising an Alliance 310 automatic injector, an XBridge C18 precolumn (30 × 3.9 mm), an XBridge ODS C18 analytical column (150 × 4.6 mm, 5 µm), an M45 pump, and two fixed UV detectors (254, 280, and 313 nm) mounted in series. The mobile phase used was HPLC methanol, pumped in isocratic mode at 1 mL/min. The standard solutions were prepared from retinol palmitate, tocopherol acetate, and ergocalciferol dissolved in methanol. For sample preparation, 5 g of powder was extracted with 25 mL of hexane under ultrasound for 30 min, then filtered. 5 mL of the filtrate was evaporated in the dark and the residue redissolved in 10 mL of methanol, homogenized by sonication (10 min) and filtered through a hydrophobic membrane. The analyses were performed by injecting 20 µL of each extract; the identification and quantification of the vitamins were obtained by comparing the retention times and peak areas with the standard solutions. Vitamin C was measured using the method described by Pongracz [20]. For extraction, 10 g of sample were homogenized in 40 mL of an acid solution (metaphosphoric acid/acetic acid 2%). The mixture was centrifuged at 3000 rpm for 20 min, then the supernatant was collected and adjusted to 50 mL with boiled and cooled distilled water. A 10 mL aliquot was used for the assay. The vitamin C content was determined by titration with 2,6-dichlorophenol-indophenol until a pale pink color appeared, then calculated using the appropriate formula described by Pongracz [20].

2.7. Evaluation of the Preventive Anti-hypertensive Effect of Cocoa Residue Powder

The preventive anti-hypertensive effect of a powder consisting of 50% rachis and 50% cocoa shells was studied in fifteen male Wistar rats (aged 10–14 weeks and weighing 150–250 g), which were divided into three groups of five animals. Hypertension was induced by providing the rats with drinking water containing 10% fructose for 30 days. The treated group

received the powder at a dose of 400 mg/kg/day alongside the fructose. The experimental groups included a negative control group (receiving water), a positive control group (receiving fructose) and a treated group (receiving fructose and Shell + Rachis cocoa powder).

Systolic and diastolic blood pressure was measured weekly using the caudal method with a SpaceLabs monitor. Retro-orbital blood samples were taken on days 0 and 30 in EDTA and dry tubes for blood count and biochemical biomarker analysis. These parameters were used to evaluate the impact of the treatment on the pathophysiological alterations associated with fructose-induced hypertension.

2.8. Measurement of Haematological Parameters and Biochemical Markers

Haematological parameters were determined from whole blood collected in EDTA tubes using an automated haematology analyser (Biobase, China). This analysis provided the following counts: white blood cells (WBC), lymphocytes (LYM), intermediate neutrophils (MID) and granulocytes (GR), as well as red blood cell (RBC) concentration, haemoglobin (HGB) level and haematocrit (HCT). The analyser also measured erythrocyte indices, including mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin concentration (MCHC) and red blood cell distribution width (RDW-CV and RDW-SD). Platelet parameters included platelet count (PLT), mean platelet volume (MPV), total platelet volume (TPV), platelet distribution width (PDW) and the P-LCR and P-LCC ratios.

Biochemical markers were analysed using serum obtained by centrifuging blood collected in dry tubes. The assays were performed using a spectrophotometer (Biobase, China) and commercial kits, in accordance with the manufacturers' protocols and after the reagents had been calibrated and quality-controlled. The evaluated parameters included renal markers (urea and creatinine), liver enzymes (ALT and AST), the lipid profile (total cholesterol, LDL, HDL and triglycerides) and

blood glucose. Measurements were performed using colorimetric or kinetic enzymatic methods specific to each kit, with absorbance readings taken at the appropriate wavelengths. Concentrations were obtained automatically from the integrated calibration curves.

2.9. Statistical Analysis

Experiments were repeated three times and the findings were reported as the mean value \pm standard deviation. In order to identify significant variations between the means, a one-factor analysis of variance (ANOVA) was conducted using XLSTAT version 19.0 software. Duncan's test was used at a probability threshold of $\alpha = 0.05$.

3. Results

3.1. Phytochemical Composition and Biological Activities of Cocoa Shell and Rachis Powder

The mixture of cocoa shells and rachis showed a high concentration of bioactive compounds (Table 1). The total polyphenol content reached (15.87 ± 0.86 g/100 g DM) and flavonoids were 7.95 ± 0.69 g/100 g DM. The biological activities associated with these compounds were also significant. The radical antioxidant activity measured by the DPPH method reached $63.59 \pm 4.7\%$, whereas the anti-inflammatory activity assessed through $76.26 \pm 0.89\%$. Regarding mineral composition, the powder contained a high level of 2169 ± 0.33 mg/100g and magnesium 350.7 ± 0.93 mg/100 g. Lower concentrations were observed for sodium (14.56 ± 0.24 mg/100 g), zinc 2.49 ± 0.04 mg/100 g and chromium (10.25 ± 0.04 mg/100 g). Vitamins analysis indicated moderate levels of antioxidant vitamins including vitamin C (4.98 ± 0.65 mg/100 g), vitamin E (0.61 ± 0.00 mg/100 g), vitamin A (0.06 ± 0.00 mg/100 g) and vitamin D (0.02 ± 0.00 mg/100 g).

Table 1. Phytochemical content and biological activities of a mixture of cocoa shell and rachis powder.

	Parameters	Shell + Rachis cocoa
Phytochemical compounds	Total polyphenols (g/100g DM)	15.87 ± 0.86
	Flavonoids (g/100g DM)	7.95 ± 0.69
	Radical antioxidant activity (%)	63.59 ± 4.7
	Anti-inflammatory activity (%)	76.26 ± 0.89
Minerals (mg/100g dry matter)	Magnesium	350.7 ± 0.93
	Sodium	14.56 ± 0.24
	Potassium	2169.4 ± 0.33
	Zinc	2.49 ± 0.04

	Parameters	Shell + Rachis cocoa
Vitamins (mg/100g dry matter)	Chromium	10.25 ± 0.04
	Vitamin C	4.98 ± 0.65
	Vitamin A	0.06 ± 0.00
	Vitamin E	0.61 ± 0.02
	Vitamin D	0.02 ± 0.00

Values are means standard deviations of triplicate measurements.

3.2. Effect of Cocoa Shell and Rachis Mixture on Blood Pressure

Before the experiment began, there was no significant difference in blood pressure between the groups (Table 2). However, after treatment (30 days), rats receiving fructose alone

showed a marked increase in blood pressure, with systolic pressure rising from 108.67 ± 3.21 mmHg to 154.33 ± 6.81 mmHg and diastolic pressure from 87 ± 5.29 mmHg to 131.67 ± 9.07 mmHg. Rats treated with the cocoa shell and rachis mixture exhibited significantly lower blood pressure values compared with the fructose group. The systolic pressure reached 113.67 ± 5.67 mmHg and the diastolic pressure 86 ± 7 mmHg, remaining close to those of the negative control group.

Table 2. Changes in blood pressure during the experiment.

Groups (Treatments)	Blood pressure before experiment (mmHg)		Blood pressure after experiment (mmHg)	
	Systole	Diastole	Systole	Diastole
Negative control (Water)	107 ± 7.81b	83.67 ± 1.59a	105 ± 3.61 b	82.67 ± 11.59 a
Positive control (Water + fructose)	108.67 ± 3.21b	87 ± 5.29a	154.33 ± 6.81c	131.67 ± 9.07c
Test (Water + fructose + shell and rachis cocoa)	106.33 ± 10.12 b	83.33 ± 4.04 a	113.67 ± 5.67 b	86 ± 7 a

Values are means standard deviations of triplicate measurements. Values with similar superscript alphabet letter along the column are significantly different at $P < 0.05$.

3.3. Effect of Cocoa Shell and Rachis Powder on Haematological Parameters in Wistar Rats

The positive control group showed a significant increase in red blood cells count and platelets number compared with the negative control (Table 3). Red blood cells increased from $6.5 \pm 4.85 \times 10^6/\mu\text{L}$ in the control negative group to

$22.83 \pm 5.23 \times 10^6/\mu\text{L}$ in the control positive group. Platelet count also increased from $328.3 \pm 172.78 \times 10^3/\mu\text{L}$ to $522 \pm 181.02 \times 10^3/\mu\text{L}$. Lymphocytes content decreased from 80.27 ± 10.5% to 57.4 ± 5.02% respectively in negative control and positive control groups. The same time, treatment with cocoa residue powder partially restored these parameters. Red blood cell count decreased to $16.23 \pm 1.10 \times 10^6/\mu\text{L}$, platelet count $326 \pm 22.5 \times 10^3/\mu\text{L}$ and lymphocyte content increased to 64.33 ± 2.10%.

Table 3. Effect of cocoa shell and rachis powder on haematological parameters in Wistar rats.

Parameters	Negative control (Water)	Positive control (Water + fructose)	Test (Water + fructose + shell and rachis cocoa)
Red blood cells ($10^6/\mu\text{L}$)	6.5 ± 4.85a	22.83 ± 5.23b	16.23 ± 1.10b

Parameters	Negative control (Water)	Positive control (Water + fructose)	Test (Water + fructose + shell and rachis cocoa)
White blood cells (10 ³ μ L)	110.8 \pm 10.09a	115.23 \pm 1.08a	114.8 \pm 0.53a
Platelets (10 ³ μ L)	328.3 \pm 172.78a	522 \pm 181.02b	326 \pm 22.5a
Lymphocytes (%)	80.27 \pm 10.5b	57.4 \pm 5.02a	64.33 \pm 2.10ab

Values are means standard deviations of triplicate measurements. Values with similar superscript alphabet letter along the line are significantly different at $P < 0.05$.

3.4. Impact of Cocoa Shell and Rachis Powder on Renal, Hepatic and Lipid Parameters

Fructose administration significantly increased renal biomarkers in rats (Table 4). Urea levels increased from 38.8 \pm 0.06 g/mL to 118.8 \pm 0.91 g/mL in positive control, while creatinine increased from 11.45 \pm 0.11 to 17 \pm 1.31 g/mL. Similarly, hepatic parameters were affected, with ALT increasing

from 27.49 \pm 0.52 g/mL to 58.39 \pm 00 g/ml and bilirubin from 40.91 \pm 0.57 g/mL to 48.88 \pm 0.35 g/ml. The lipid profile was also altered. The positive control (fructose group) showed increased levels of LDL, total cholesterol and triglycerides, while HDL decreased. Administration of the cocoa shell and rachis powder improved these parameters. Urea and creatinine values returned close to normal levels, liver enzyme activities decreased, LDL and triglycerides were reduced and HDL levels increased compared with the fructose group.

Table 4. Impact of cocoa shell and rachis powder on renal, hepatic and lipid parameters in Wistar rats.

	Parameters	Negative control (Water)	Positive control (Water + fructose)	Test (Water + fructose + shell and rachis cocoa)
Renal parameters (g/mL)	Urea	38,8 \pm 0,06a	118,8 \pm 0,91 b	37,88 \pm 0,48 a
	Creatinine	11,45 \pm 0,11a	17 \pm 1,31 b	13,29 \pm 0,09 a
Liver parameters (g/mL)	Bilirubin	40,91 \pm 0,57 a	48,88 \pm 0,35 c	47,51 \pm 0,1 b
	ALT	27,49 \pm 0,52 a	58,39 \pm 00 c	34,65 \pm 00 b
	AST	0,37 \pm 00 a	0,56 \pm 0,01 a	0,21 \pm 0,1 a
	LDL	0,18 \pm 0,02 a	0,35 \pm 0,06 a	0,19 \pm 0,03 a
Lipid parameters (g/mL)	HDL	4,90 \pm 0,56 b	2,54 \pm 0,82 a	4,1 \pm 0,48 ab
	Cholesterol	8,5 \pm 0,8 a	15,62 \pm 1,33 b	9,6 \pm 0,88 a
	Triglycerides	17,06 \pm 1,04 a	63,7 \pm 2,45 c	21,9 \pm 1,58 b

Values are means standard deviations of triplicate measurements. Values with similar superscript alphabet letter along the line are significantly different at $P < 0.05$.

4. Discussion

The present study provides compelling evidence that cocoa shell and rachis, typically discarded during cocoa processing, possess significant bioactive potential for cardiovascular health management. This study demonstrates that cocoa shells and rachis contain a high concentration of bioactive compounds with potential health benefits. The high levels of polyphenols and flavonoids observed are consistent with previous studies reporting that cocoa by-products are rich sources

of antioxidant compounds [13]. These molecules are known to neutralize free radicals and reduce oxidative stress, which plays a central role in the development of hypertension. The strong antioxidant and anti-inflammatory activities observed in this study may contribute to the protective effects of cocoa residues. Polyphenols have been reported to inhibit inflammatory signaling pathways and reduce the production pro-inflammatory cytokines involved in cardiovascular diseases [21]. This phytochemical richness translates into high radical antioxidant activity (63.59%) and significant anti-inflammatory activity (76.26%). These activities confirm the ability of cocoa

residues to neutralise free radicals and inhibit inflammatory processes. Recent studies have demonstrated that cocoa polyphenols can inhibit NF- κ B activation and reduce pro-inflammatory cytokine production, which are key mechanisms in the pathophysiology of hypertension [22]. The results suggest that the cocoa shell and rachis mixture could have a preventive effect by acting on the molecular causes of hypertension rather than solely its consequences. In terms of minerals, cocoa residue powder is particularly rich in potassium (2,169.4 mg/100 g) and magnesium (350.7 mg/100 g). This high mineral content gives cocoa residue additional value. These minerals play a role in vasodilation and the regulation of electrolyte balance and sodium sensitivity, which are all key mechanisms in blood pressure control [23, 24]. Although antioxidant vitamins (C and E) are present in moderate amounts in the residues, they could nevertheless enhance their protective effect. The natural combination of these minerals, vitamins and phenolic compounds could give cocoa residues a synergistic effect as part of a nutritional approach [25]. The mineral composition of the cocoa residue powder may also explain part of the antihypertensive effect observed. Potassium and magnesium are essential minerals involved in vascular tone regulation and electrolyte balance. High potassium intake promotes sodium excretion and contributes to vasodilation, which can help reduce blood pressure. This effect is thought to be due to the combined action of polyphenols and minerals, which promote the bioavailability of nitric oxide and reduce vascular stiffness [26, 27]. This result is particularly interesting as it highlights the potential of inexpensive, locally sourced resources derived from agricultural waste for preventing high blood pressure.

The prevention of blood pressure elevation observed in treated rats suggests that cocoa residues may improve vascular function. This effect could be associated with enhanced nitric oxide bioavailability and reduced vascular stiffness, mechanisms commonly associated with cocoa flavonoids. Furthermore, the normalization of haematological parameters in treated animals suggests a reduction in inflammatory and oxidative stress conditions induced by fructose consumption. Similar immunomodulatory effects of cocoa polyphenols have been reported in previous studies [28, 29]. The improvement of renal and hepatic biomarkers also indicates a protective effect of cocoa residues against organ damage associated with metabolic disorders. The increase in urea, creatinine and liver enzymes observed in the positive control group confirms the harmful impact of fructose on target organs of hypertension, particularly the kidneys and liver. In animals receiving cocoa residue powder, renal and hepatic values were significantly improved, approaching those of the negative control group. This could suggest a nephroprotective and hepatoprotective effect. These effects may be related to reduced oxidative stress and inhibited lipid peroxidation in tissues, mechanisms which have been extensively documented for cocoa polyphenols [30].

In terms of the lipid profile, the positive group shows an increase in LDL, total cholesterol and triglycerides, alongside a decrease in HDL. Concurrent administration of cocoa residue

powder significantly improves the lipid profile, characterized by decreased LDL, triglycerides and total cholesterol, and increased HDL. Recent studies suggest that cocoa flavonoids influence the expression of enzymes involved in lipogenesis and encourage cholesterol elimination [31].

These effects may be related to the antioxidant properties of cocoa polyphenols, which reduce lipid peroxidation and oxidative injury in tissues. Finally, the favorable changes observed in the lipid profile support the cardioprotective potential of cocoa residues. Polyphenols have been shown to regulate lipid metabolism by inhibiting lipogenesis and enhancing cholesterol elimination. Overall, these findings highlight the potential of cocoa shells and rachis as valuable functional ingredients for preventing hypertension and associated metabolic disorders while promoting the sustainable valorization of cocoa by-products.

5. Conclusion

This study highlights the antihypertensive preventive potential of the cocoa shell and husk mixture, thereby adding value to the abundant by-products of the cocoa industry. The mixture contains a high quantity of bioactive compounds, particularly polyphenols and flavonoids, which have high antioxidant and anti-inflammatory activity. This gives the mixture major potential for a cardiovascular protective effect. In rats with fructose-induced hypertension, supplementation with cocoa shells and husks significantly limited increases in both systolic and diastolic blood pressure. This haemodynamic improvement was accompanied by normalisation of haematological, renal and hepatic parameters, as well as an improvement in the lipid profile characterised by a decrease in LDL cholesterol, triglycerides and total cholesterol, and an increase in HDL cholesterol. These effects suggest a synergistic role for phenolic compounds and essential minerals, particularly potassium and magnesium, in modulating oxidative stress, inflammation, and vascular function. The cocoa husk mixture appears to be a promising candidate for developing functional foods for preventing high blood pressure while contributing to the sustainable use of agro-industrial by-products.

Abbreviations

LDL	Low Density Lipoproteins
HDL	High Density Lipoprotein
HBP	High Blood Pressure
EDTA	Ethylene Diamine Tetraacetic Acid

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Author Contributions

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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