



## Supplementation of cassava fiber counteracts high sugar diet-induced metabolic syndromes by maintaining glucose and lipid homeostasis

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### ABSTRACT

Metabolic disorders characterized by different physiological syndromes are affecting modern society, particularly the people who live in urban areas. High sugar diet (HSD) consumption is associated with the development of metabolic diseases such as diabetes and obesity. Dietary fiber has been linked to a variety of health benefits, including obesity prevention, better glucose homeostasis, and control of blood lipid profile. Therefore, we designed this experiment to determine the efficacy of cassava fiber (CF) in preventing the development of diabetes and obesity caused by HSD. Swiss albino male mice were fed with CF in supplementation with or without HSD. In comparison to a high sugar diet group, CF supplementation steadily reduced food intake. Though it was insignificant CF supplementation attenuated the increase in body weight due to HSD consumption. From the intraperitoneal glucose tolerance test (ipGTT), it was revealed that CF supplementation improved glucose tolerance after a glucose (2 g/kg BW) challenge and also showed a significant decrease in area under the curve (AUC). Moreover, CF supplementation remarkably lowered the LDL-cholesterol level of the HSD-fed mice. Overall, our present study demonstrates that consumption of a CF-rich diet helps to maintain glucose homeostasis and prevent the development of metabolic syndromes associated with diabetes and obesity.

**Keywords:** Cassava, dietary fiber, high sugar diet, diabetes, obesity



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## 1 Introduction

Diabetes mellitus and obesity are the most serious health concerns among the prevailing metabolic disorders (Blair, 2016; Kharroubi and Darwish, 2015). High blood glucose levels are a symptom of type 2 diabetes mellitus, which is caused by a combination of peripheral insulin resistance, decreased pancreatic-cell activity, and impaired regulation of hepatic glucose production (Caspard et al., 2017). Obesity develops as a result of excess consumption of nutrients, insuffi-

cient exercise, and other factors that might expedite the accumulation of excess body fat. Excessive calorie intake coupled with inadequate energy expenditure leads to lipid accumulation not just in adipose tissue but also in the liver, muscle, and other internal tissues, resulting in insulin resistance (IR) and metabolic disorders (Chooi et al., 2019). Much of the increased incidence of diabetes and obesity occurs in developing countries which may be due to aging, unhealthy diets, obesity, and a sedentary lifestyle along with malnutrition-related causes. Previous studies have

found that consumption of a high-sugar diet (HSD) accelerates the development of diabetes and obesity (Barrière et al., 2018). Consumption of a variety of types of sugary foods containing refined carbs and simple sugars is preferred by both traditional and modern societies (Fan et al., 2017). Therefore, supplementation of an alternative diet that might counteract the harmful effects of high sugar consumption is considerably needed. Although current management of diabetes and obesity involves exercise and diet modification, drug therapies are typically required as the disease progresses. However, some of the adverse side effects of drug therapies include hypoglycemia, weight gain, and poor postprandial blood glucose (Ng et al., 2014). Therefore, there has been profound progress in research focusing on natural products and their active ingredients having therapeutic potentiality against diabetes and obesity.

Dietary fiber has been shown to have a beneficial effect on the prevention of risk of chronic diseases such as cardiovascular diseases, diabetes mellitus, and obesity (Barber et al., 2020; Lockyer et al., 2016). Dietary fibers can effectively bind with bile acids and also have a role in preventing their reabsorption in the liver, thus inhibiting cholesterol biosynthesis. Dietary fiber, with its vicious and fibrous structure, can help to manage diabetes mellitus and obesity by controlling the release of glucose in the blood with time (Patel et al., 2012). High-fiber diets, particularly soluble fiber, have nutraceutical value in improving carbohydrate metabolism and lowering cholesterol.

Cassava (*Manihot esculenta*) is a major food crop grown in tropical and subtropical climates. It is considered a potentially valuable food resource for developing nations. Cassava roots are a good source of energy while the leaves are high in protein, vitamins, and minerals (Ferraro et al., 2016). Its tuber contains 40% soluble fiber, which is primarily composed of uronic acid, pectin, and glucans (Post et al., 2012). Dietary fiber and starch structures are the main factors of food with a low glycemic index (GI) (Eleazu, 2016). A previous study on the glycemic index of commonly consumed carbohydrate foods found that root/tuber crops have a low glycemic index (Bantle et al., 2008). Reducing the glycemic impact of diet by consuming foods low on the glycemic index has been proven to enhance overall blood glucose control in diabetic patients (Trinidad et al., 2009). Another study revealed that jicama (*Pachyrhizus erosus*), a high-fiber tuber crop, may contribute to lower postprandial blood glucose levels by suppressing  $\alpha$ -glucosidase (Park and Han, 2015). However, the beneficial effect of cassava fiber on the development of metabolic disorders has not been studied yet. Therefore, we have undertaken the present study to examine whether the edible fiber isolated from cassava tuber could prevent the development of diabetes and obesity caused by high sugar diet (HSD) consumption.

## 2 Materials and Methods

### 2.1 Preparation of cassava fiber

Edible cassava tubers were collected from local market of Muktagacha Upazila, Mymensingh. After proper washing, collected cassava tubers were peeled and the flesh was cut into small pieces. Then the cassava pieces were dried under the sun. After sun drying, dried pieces of cassava were finely ground by a grinding machine. The ground cassava powder was kept in airtight polythene bags until it was employed for fiber extraction using the techniques previously mentioned with slight modification (Ranganna, 2015). Exactly 120 mL of  $H_2SO_4$  (1.25%) was added to the sample. Then a round-bottomed flask containing cold water was placed on the mouth of the beaker so that it covers the whole space of the mouth of the beaker. The tiny gaps by the sides were sealed with cotton. This round-bottomed flask containing cold water acted as a condenser so that there was no significant loss of  $H_2SO_4$ . The beaker with the flask was placed on the heater to boil the solution for 30 min. Then the content was filtered through the cheese cloth and washed with water several times until it was free from acid as tested by litmus paper. The residue was taken again in a beaker and 120 mL of 1.25% NaOH was added to it and boiled for 30 min following the same technique. Then it was filtered through cheese cloth and washed with water repeatedly until it was free from alkali as tested by litmus paper. The isolated fiber was dried in an oven at 70 °C for 16 hr, and then the fibers were ground to make powder. The fiber powder was immediately stored in a sterilized container and sealed until being used in the experiment.

### 2.2 Diet paradigms

Normal food formulation includes wheat, wheat bran, rice polishing, fish meal, oil cake, gram, pulses, milk, soybean oil, molasses, salt and Embavit (vitamin) at different proportions (Ulla et al., 2017). Three diet paradigms were deployed in this study with supplementation of sucrose (High Sugar Diet) and/or cassava fiber (CF). Types of food were: (i) Normal diet (ND) group: 100% Normal food formulation; (ii) High Sugar Diet (HSD) group: 75% Normal food formulation + 25% Sucrose; and (iii) Cassava Fiber supplemented High Sugar Diet (HSD+CF) group: 50% Normal food formulation + 25% Sucrose + 25% Cassava Fiber. Previous references were used to justify the doses (Li et al., 2016; Santoso et al., 2019). The animals were fed fresh and ad libitum diets that were changed daily to ensure their quality. The treatment was carried out for 24 days following the above-mentioned diet paradigm.

## 2.3 Experimental animals

Six weeks-old Swiss albino male mice were purchased from the Animal Resources Facility of the International Centre for Diarrheal Disease Research, Bangladesh (ICDDR,B), and adapted for 10 days to acclimate them to the new habitat. Animals were kept in a well-ventilated room at  $28 \pm 2$  °C and relative humidity of 70-80% with natural day and light. Normal food and water were available ad libitum before the starting of feeding experiments. Animals were divided into three groups and each group contained at least 4 mice. During the rearing period, the animals were also accustomed to daily handling in order to minimize the stress response that may have arisen in the experiment. All protocols used in this study were approved (AWEEC/BAU/2020\_31) by the Animal Welfare and Experimentation Ethics Committee of Bangladesh Agricultural University guided by the Council for International Organizations of Medical Sciences international guiding principles of biomedical research involving animals.

## 2.4 Measurement of food intake, water intake and body weight

The food and water intake of each mouse were measured daily at 10:00 am for 24 d. The body weight of each mouse was measured with the help of an electric balance (eki300-2n electronic scale, A&D Company Ltd., Korea) 2 times per week up to the end of the experiment.

## 2.5 Intraperitoneal glucose tolerance test (ipGTT)

At the end of the treatment, the intraperitoneal glucose tolerance test (ipGTT) was performed according to the procedure described in a previous report (Maejima et al., 2015). Mice were fasted for around 4 hours after being transferred to clean cages with no food or waste in the hopper or bottom of the cage. Access to drinking water was ensured at all times. A fresh or sterilized scalpel blade was used to score the tip of the tail. The first drop of blood was discarded. On the test strip of the blood glucose meter a small drop of blood ( $<5$   $\mu$ l) was placed. Blood glucose level was measured using a standardized automated blood glucose test meter (Glucolider™ Enhance Blood Glucose Meter, HMD Biomedical Inc., Hsinchu County, Taiwan). A single dose of glucose (2 g/kg BW) was injected intraperitoneally for each mouse. The blood glucose level was recorded for each mouse at 0, 15, 30, 60, and 120 min after ip glucose administration. The area under curve (AUC) data was subsequently calculated from the blood glucose levels in ipGTT.

## 2.6 Blood samples collection and preparation of serum

At the end of the 24-day period, following 18 hours of fasting, blood samples were collected from the Posterior Vena Cava by the method described previously (Hoff, 2000). One by one, the mice were placed in the airtight container containing cotton soaked in chloroform. By making a V-cut, the abdominal cavity of the anesthetized mouse was opened through the skin and abdominal wall, 1 cm posterior to the rib cage. The intestines were shifted over to the left and the liver was pushed forward. The widest part of the posterior vena cava (between the kidneys) was located. A 26 gauge needle and a 1 mL syringe were used. The needle was carefully inserted into the vein and blood was drawn slowly until the vessel wall collapses. The blood was collected in a 1.5 mL Eppendorf tube containing EDTA which acts as an anticoagulant. Then the blood-containing tubes were centrifuged at 4000 rpm for 10 min at 4 °C (Gyrozen 1580R Multi-Purpose High-Speed Refrigerated Centrifuge, Gangnam-gu, Seoul, KOREA). After centrifugation, the supernatant serum without unwanted blood cells was collected in a new tube. Serum samples were stored at  $-20$  °C until lipid profile assay.

## 2.7 Measurement of organ weight

After collecting the blood samples, the internal organs like the liver, heart, and kidney were harvested and trimmed to remove additional tissues. The organs were cleaned in saline solution and placed on a filter paper to remove the saline on the surface. Then the organ weights were measured using a digital balance (eki300-2n electronic scale, A&D Company Ltd., Korea).

## 2.8 Determination of lipid profile parameters

Lipid profile studies involved analysis of parameters such as total cholesterol (TC) level determined by CHOD-PAP method (Richmond, 1973); triglyceride (TG) level determined by GPO-PAP method (Cole et al., 1997); HDL cholesterol level determined by CHOD-PAP method (Sax, 1975). HumaTex febrile antigen test kit (Human Diagnostic, Wiesbaden, Germany) was used and the absorbance was determined using Humalyzer, Model No-3000 (Human GmbH, Wiesbaden, Germany). Serum LDL cholesterol concentrations were calculated using the Friedewald equation (Friedewald et al., 1972) as follows: LDL cholesterol (mg/dL) = Total cholesterol – HDL cholesterol – (Triglyceride/5)

## 2.9 Statistical analysis

All statistical analyses were performed using Prism 5 (GraphPad Software, CA). All data were displayed as mean  $\pm$  SE. An analysis of variance (ANOVA) followed by Tukey's posthoc test was employed to justify the significant differences among groups of treatment. The  $p < 0.05$  was set as a significant value for all analyses.

## 3 Results

### 3.1 Effect of cassava fiber on daily food intake of mice

We measured the food intake of each mouse until the end of the experiment. At the outset of the experiment, no significant difference was found in daily food intake among the groups (data not shown). However, the supplementation of 25% sucrose and 25% sucrose & 25% cassava fiber into the food influenced the food intake per mouse (Fig. 1). HSD supplementation showed a tendency to increase the food intake than the normal diet (ND) which was reversed by the addition of cassava fiber ( $4.50 \pm 0.65$  g for ND,  $5.00 \pm 0.71$  g for HSD,  $4.25 \pm 1.03$  g for HSD + CF at 4th day of the treatment). Although high sugar diet supplementation tends to increase the food intake as compared to the normal diet, it was not significant. After the 5th day of the treatment, cassava fiber supplementation steadily reduced food intake in comparison to the high-sugar diet group. Though the food intake per mouse was decreased in HSD + CF fed group as compared to the normal diet group, it was statistically insignificant ( $p < 0.05$ ; Fig. 1).

### 3.2 Effect of cassava fiber on daily water intake of mice

There was no significant difference in daily water intake among the groups during the experiment (Fig. 2). However, Supplementation of 25% cassava fiber into the food initially increased the daily water intake per mouse which was comparable to the rest of the experiment ( $5.00 \pm 1.08$  g for ND,  $4.50 \pm 0.65$ g for HSD,  $7.00 \pm 0.71$ g for HSD + CF at 1st day of the treatment). A previous study also showed that water intake was significantly higher in the group fed the fiber-enriched diet than in the Zucker fatty rats fed the standard diet and the lean rats (Sánchez et al., 2010).

### 3.3 Effect of cassava fiber on body weight of mice

We also assessed the body weight of each mouse to determine the role of CF in preventing the development of HSD-induced obesity. The result revealed

that High sugar diet supplementation tends to increase the body weight of the mice though it was statistically insignificant. However, the addition of CF in HSD reversed the increased body weight gain of the mice ( $39.5 \pm 3.48$  g for ND,  $41.75 \pm 2.66$  g for HSD,  $36.00 \pm 3.11$  g for HSD + CF on the 4th day of the treatment) as compared with the HSD group (Fig. 3), but it was not statistically significant ( $p > 0.05$ ). A previous study reported that the body weight gain of the rats fed the soluble cocoa fiber-enriched diet was significantly lower than the body weight gain of the rats fed the regular diet (Sánchez et al., 2010).

### 3.4 Effect of cassava fiber on intraperitoneal glucose tolerance test

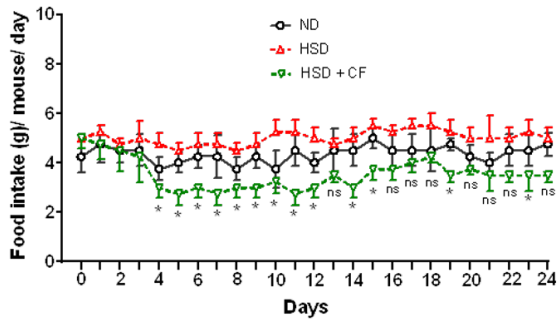
In this present study, we first examined the effectiveness of CF in preventing the development of diabetic symptoms that are caused by HSD. We performed ipGTT at the end of the treatment to assess the blood glucose homeostasis (Fig. 4). High sugar diet supplementation did not induce glucose intolerance though there was a slight increase in the AUC. One of the possible reasons is the short duration (only 24 d) of the HSD treatment. However, the results of GTT also indicated that the CF-supplemented HSD group had lower blood glucose levels than the HSD group almost at all the time points following an injection of 2 g/kg BW glucose (Fig. 4A). Furthermore, the AUC data derived from the GTT graph (Fig. 4B) revealed that the AUC of the CF-supplemented group was significantly lower than the HSD group. Though the AUC of the CF group was lower than the ND group it was statistically insignificant ( $p > 0.05$ ).

### 3.5 Effect of cassava fiber on organ weights of mice

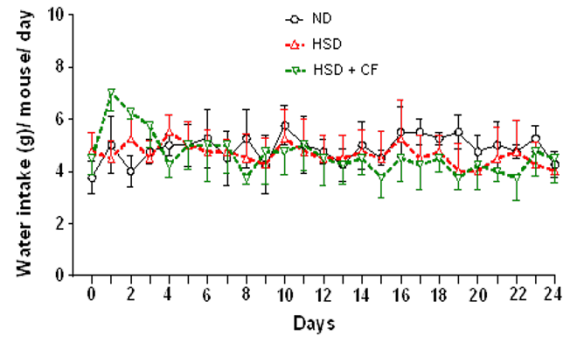
In comparison to the control group, the liver weight showed a tendency to increase ( $p > 0.05$ ) in the HSD mice (Fig. 5). Though the values are insignificant, CF supplementation increased the weight of the liver in the HSD-treated mice ( $2.03 \pm 0.10$  g for ND and  $2.17 \pm 0.13$  g for HSD). CF supplementation for a period of 24 d results in a significant reduction of liver weight in HSD-fed mice. Heart and kidney weights were comparable among the groups at the end of the study.

### 3.6 Effect of Cassava Fiber on blood lipid profile parameters

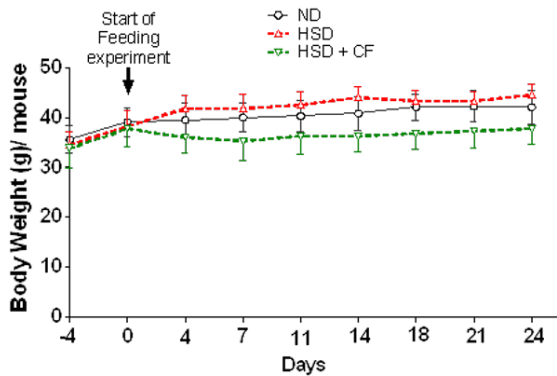
There were no significant differences in serum total cholesterol, triglycerides, or HDL-cholesterol levels among the groups (Fig. 6). Though the HDL-cholesterol in the 25% CF supplemented group was shown to increase, it was statistically insignificant as compared to other groups. In the 25% HSD group, an



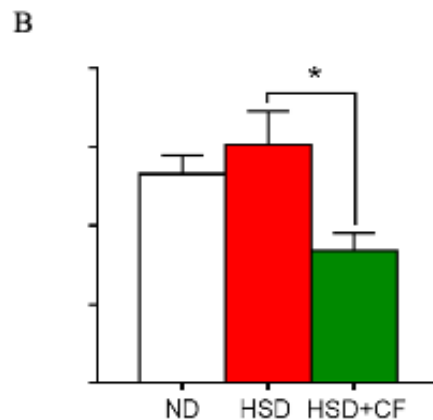
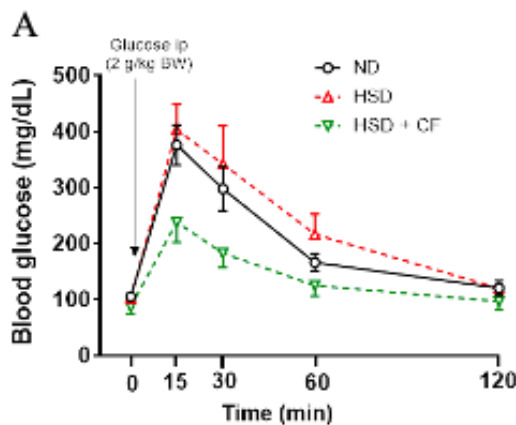
**Figure 1.** CF supplementation attenuated HSD-induced hyperphagia. Mice were allowed ad libitum access to food. Daily average food intake was measured for a period of 24 days. ND: Normal Diet, HSD: High Sugar Diet, CF: Cassava Fiber. \* $p < 0.05$  vs HSD group by one-way ANOVA followed by Tukey’s multiple comparison test. Each point represents mean  $\pm$  SEM.  $n \geq 3$  for each group



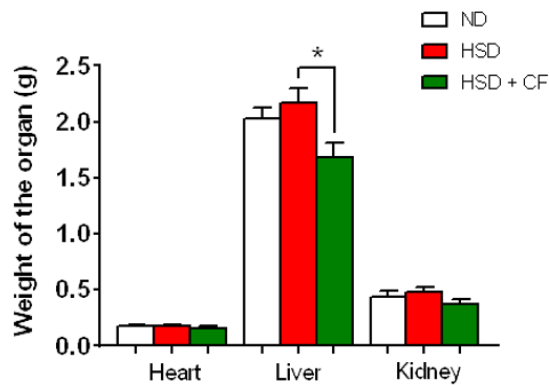
**Figure 2.** CF did not affect daily water intake in HSD-fed mice. Water intake was measured daily during the experimental period. ND: Normal Diet, HSD: High Sugar Diet, CF: Cassava Fiber. Each point represents mean  $\pm$  SEM.  $n \geq 3$  for each group



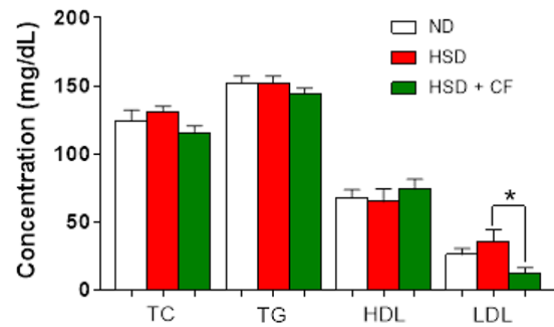
**Figure 3.** CF counteracted the body weight gain in HSD-fed mice. Body weight was measured two times per week until 24 days. ND: Normal Diet, HSD: High Sugar Diet, CF: Cassava Fiber. Each point represents mean  $\pm$  SEM.  $n \geq 3$  for each group



**Figure 4.** CF improved glucose tolerance in HSD-fed mice. (A) A glucose tolerance test (GTT) was performed after an intraperitoneal injection of glucose 2 g/kg BW on the 23rd day of the experiment. (B) The corresponding area under the curve (AUC) of the glucose tolerance test was calculated. ND: Normal Diet, HSD: High Sugar Diet, CF: Cassava Fiber. \* $p < 0.05$  by one-way ANOVA followed by Tukey’s posthoc test. Bars represent mean  $\pm$  SEM.  $n \geq 3$  for each group



**Figure 5.** CF supplementation decreased liver weight significantly. After 24 days of feeding experiment, animals were sacrificed and organs such as Heart, Liver, and Kidney were isolated and weighed. ND: Normal Diet, HSD: High Sugar Diet, CF: Cassava fiber. Bars represent mean  $\pm$  SEM. \* $p < 0.05$  by one-way ANOVA followed by Tukey's posthoc test.  $n \geq 3$  for each group



**Figure 6.** Blood lipid parameters were statistically insignificant among the groups except for LDL. Blood lipid profiles including total cholesterol (TC), Triglycerides (TG), HDL-C, and LDL-C were measured. ND: Normal Diet, HSD: High Sugar Diet, CF: Cassava Fiber. Bars represent mean  $\pm$  SEM. \* $p < 0.05$  by one-way ANOVA followed by Tukey's posthoc test.  $n \geq 3$  for each group

increase in LDL-cholesterol ( $26.10 \pm 4.42$  mg/dL for ND and  $27.28 \pm 10.42$  mg/dL for HSD and  $12.05 \pm 4.24$  mg/dL for HSD + CF) was seen after 24 days of the experiment (Fig. 6) which was significantly reduced by 25% CF supplementation. A previous study showed that HDL-cholesterol level was substantially higher in the soluble cocoa fiber-enriched diet-fed mice in comparison to control mice (Sánchez et al., 2010).

## 4 Discussion

Our current findings demonstrated that the supplementation of CF could effectively preclude the excessive body weight gain induced by HSD. Importantly, the supplementation of CF also exerted a remarkable effect to hamper the increase in food intake due to high sugar diet consumption in mice. Moreover, CF supplementation in the diet also promotes glucose tolerance. The present study showed that the intake of CF-enriched diet is beneficial in the prevention of the key abnormalities known as metabolic syndromes, including obesity, dyslipidemia, and glycemic profile. Reduced food intake is correlated with complex hormonal and neurological pathways that regulate appetite and satiety (Benton and Young, 2017; Santoso et al., 2015). Reduced feed intake simply means a reduction in energy consumption, which is eventually responsible for lowering blood glucose and fat mass (Benton and Young, 2017). The possible mechanism of a substance to prevent the development of diabetes and obesity could be simply due to the reduction of food intake. In support of the

above statement, our findings showed that the quantity of food intake was altered by cassava fiber supplementation. The reduced food intake observed in the mice fed a CF-enriched diet may be due to the effect of satiation that has been activated in these animals. Previous studies reported that dietary fiber-induced reduction in appetite could be a consequence of a mechanical intestinal distention and/or delaying of carbohydrate digestion and glucose absorption. The reduced glycemic and insulin responses may prolong satiety and ultimately reduce energy consumption (Fernandez et al., 1994; Jenkins et al., 2000; Ludwig, 1999; Liu et al., 2003). The low food intake and the improved glucose tolerance obtained in the mice fed a CF-enriched diet would support that these mechanisms would be also involved in the effects of cassava fiber on body weight management.

Consumption of diets containing high sugar may induce excessive body weight gain which accelerates the obesity development in rodents (Torres-Villalobos et al., 2015). Previous researchers found that consuming high-sugar drinks and fast foods regularly increases the risk of obesity and diabetes in adults (Oo et al., 2017; El-Wakkad et al., 2012). Our present finding also demonstrated that the HSD-fed mice exhibited a tendency in body weight gain during 24 days of the treatment, and it was significantly hampered by the 25% CF supplementation in their diet. Despite the fact that the final body weight of HSD-fed mice was higher at the end of treatment, it was statistically comparable to the control group. Another study also supported our findings that mice fed a solid sugar diet for a short duration had no significant differ-

ences in body weight when compared with the control group (Vellers et al., 2017). The above-mentioned results suggested that CF could be one of the non-drug candidates to control obesity, which is a key risk factor for developing type 2 diabetes (Andrikopoulos et al., 2008). High sugar diet consumption is associated with the development of metabolic dysregulations including diabetes and obesity (Barrière et al., 2018; Torres-Villalobos et al., 2015; Lean and Morenga, 2016). In our study, the supplementation of 25% CF notably promoted glucose tolerance. The ability of insulin to maintain glucose homeostasis is indicated by the glucose tolerance test (Andrikopoulos et al., 2008; Lee et al., 2008). A previous study reported that intake of a high sugar diet causes a toxic effect on pancreatic islet  $\beta$  cells which reduce insulin sensitivity and subsequently cause glucose intolerance (Kawahito et al., 2009). Therefore, the improved glucose tolerance by CF supplementation in HSD-fed mice may be due to the preventive mechanism of CF on pancreas damage, especially on islet  $\beta$  cells. However, more research concerning the structural alterations in the pancreas is needed to clarify this speculation. Cassava tuber contains a remarkable amount of phytochemicals like scopoletin, scopolin, esculetin, esculin, linamarin, etc. which have been reported to have beneficial effects against many symptoms and diseases such as cardiovascular and neuromuscular diseases, convulsions, rheumatic pains, asthma, inflammation, hypertension, hyperthyroidism, and hyperglycemia (Blagbrough et al., 2010; Gnonlonfin et al., 2012; Zhang et al., 2021).

Maintaining healthy levels of lipids circulating in the bloodstream is important to prevent cardiovascular diseases. In this study, the blood lipid profile parameters such as total cholesterol, triglycerides, and HDL-C in CF treated group are statistically comparable with other groups. Though the previous studies reported that HSD supplementation increases TC, TG, and HDL-C levels in mice, we did not observe remarkable changes in the mentioned parameters. It may be due to the supplementation of HSD for a short period of time. However, the LDL-C was increased in HSD-fed mice which were significantly blunted with CF supplementation. The tendency of the improvement of the lipid profile observed in this study when CF was administered is in agreement with the findings of other experiments in rats and humans using different fibers (Ramos et al., 2008; Anderson et al., 2000). Furthermore, there were no discernible differences in the heart, and kidney weight of the mice. The decreasing trends in the organ weight of CF supplemented mice were likely to correspond with the changes in body weight. Though the present findings corroborate the hypoglycemic and hypolipidemic potentiality of CF but have limitations such as we could not measure the weights of adipose tissues and did not check the effects of CF on the histology of the liver

tissues. Further investigation with prolonged treatment is needed to completely understand the physiological effect of cassava fiber. In mice, cassava fiber could efficiently maintain a normoglycemic condition while also preventing the development of diabetes and obesity caused by HSD.

## 5 Conclusion

Overall, the findings showed that CF affects the parameters that appear to be altered in metabolic syndromes, such as body weight, glycemia, and lipid profile. The development of a new source of natural fiber from an underutilized agricultural commodity like cassava, which is often used in the starch industry, could provide a valuable and inexpensive source of dietary fiber while also allowing more versatile applications in the food industry. Additional studies with CF are required to fully understand the mechanism(s) involved in the modulation of the parameters investigated. In any case, in order to introduce CF as a functional food ingredient for obese and/or metabolic syndrome patients, its efficacy and safety should be determined.

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## Conflict of Interest

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

## References

- Anderson JW, Davidson MH, Blonde L, Brown WV, Howard WJ, Ginsberg H, Allgood LD, Weingand KW. 2000. Long-term cholesterol-lowering effects of psyllium as an adjunct to diet therapy in the treatment of hypercholesterolemia. *The American Journal of Clinical Nutrition* 71:1433–1438. doi: 10.1093/ajcn/71.6.1433.
- Andrikopoulos S, Blair AR, Deluca N, Fam BC, Proietto J. 2008. Evaluating the glucose tolerance test in mice. *American Journal of Physiology-Endocrinology and Metabolism* 295:E1323–E1332. doi: 10.1152/ajpendo.90617.2008.

- Bantle JP, Wylie-Rosett J, Albright AL, Apovian CM, Clark NG, et al. 2008. Nutrition recommendations and interventions for diabetes. *Diabetes Care* 31:S61–S78. doi: [10.2337/dc08-s061](https://doi.org/10.2337/dc08-s061).
- Barber TM, Kabisch S, Pfeiffer AF, Weickert MO. 2020. The health benefits of dietary fibre. *Nutrients* 12:3209. doi: [10.3390/nu12103209](https://doi.org/10.3390/nu12103209).
- Barrière DA, Noll C, Roussy G, Lizotte F, Kessai A, Kirby K, Belleville K, Beaudet N, Longpré JM, Carpentier AC, Geraldès P, Sarret P. 2018. Combination of high-fat/high-fructose diet and low-dose streptozotocin to model long-term type-2 diabetes complications. *Scientific Reports* 8:424. doi: [10.1038/s41598-017-18896-5](https://doi.org/10.1038/s41598-017-18896-5).
- Benton D, Young HA. 2017. Reducing calorie intake may not help you lose body weight. *Perspectives on Psychological Science* 12:703–714. doi: [10.1177/1745691617690878](https://doi.org/10.1177/1745691617690878).
- Blagbrough IS, Bayoumi SA, Rowan MG, Beeching JR. 2010. Cassava: An appraisal of its phytochemistry and its biotechnological prospects. *Phytochemistry* 71:1940–1951. doi: [10.1016/j.phytochem.2010.09.001](https://doi.org/10.1016/j.phytochem.2010.09.001).
- Blair M. 2016. Diabetes mellitus review. *Urologic nursing* 36. doi: [10.7257/1053-816X.2016.36.1.27](https://doi.org/10.7257/1053-816X.2016.36.1.27).
- Casparid H, Jabbour S, Hammar N, Fenici P, Sheehan JJ, Kosiborod M. 2017. Recent trends in the prevalence of type 2 diabetes and the association with abdominal obesity lead to growing health disparities in the USA: An analysis of the NHANES surveys from 1999 to 2014. *Diabetes, Obesity and Metabolism* 20:667–671. doi: [10.1111/dom.13143](https://doi.org/10.1111/dom.13143).
- Chooi YC, Ding C, Magkos F. 2019. The epidemiology of obesity. *Metabolism* 92:6–10. doi: <https://doi.org/10.1016/j.metabol.2018.09.005>. Obesity: the 21st century epidemic.
- Cole T, Klotzsch S, Namara M. 1997. Measurement of triglyceride concentration. In: Rifai N, Warnick G, Dominićzak M, (Eds), *Handbook of Lipoprotein Testing*. AACC Press, Washington.
- El-Wakkad A, Hassan NE, El-Zayat SR, Sibaii H, El-Masry S. 2012. Multiple markers of diabetes in relation to abdominal obesity in obese Egyptian adolescent girls. *International Journal of Pharmacy and Pharmaceutical Sciences* 4:276–81.
- Eleazu CO. 2016. The concept of low glycemic index and glycemic load foods as panacea for type 2 diabetes mellitus: prospects, challenges and solutions. *African Health Sciences* 16:468. doi: [10.4314/ahs.v16i2.15](https://doi.org/10.4314/ahs.v16i2.15).
- Fan JG, Kim SU, Wong VWS. 2017. New trends on obesity and NAFLD in Asia. *Journal of Hepatology* 67:862–873. doi: [10.1016/j.jhep.2017.06.003](https://doi.org/10.1016/j.jhep.2017.06.003).
- Fernandez ML, Sun DM, Tosca MA, McNamara DJ. 1994. Citrus pectin and cholesterol interact to regulate hepatic cholesterol homeostasis and lipoprotein metabolism: A dose-response study in guinea pigs. *The American Journal of Clinical Nutrition* 59:869–878. doi: [10.1093/ajcn/59.4.869](https://doi.org/10.1093/ajcn/59.4.869).
- Ferraro V, Piccirillo C, Tomlins K, Pintado ME. 2016. Cassava (*Manihot esculenta* Crantz) and yam (*Dioscorea* spp.) crops and their derived foodstuffs: safety, security and nutritional value. *Critical Reviews in Food Science and Nutrition* 56:2714–2727. doi: [10.1080/10408398.2014.922045](https://doi.org/10.1080/10408398.2014.922045).
- Friedewald WT, Levy RI, Fredrickson DS. 1972. Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. *Clinical Chemistry* 18:499–502. doi: [10.1093/clinchem/18.6.499](https://doi.org/10.1093/clinchem/18.6.499).
- Gnonlonfin GJB, Sanni A, Brimer L. 2012. Review scopoletin – a coumarin phytoalexin with medicinal properties. *Critical Reviews in Plant Sciences* 31:47–56. doi: [10.1080/07352689.2011.616039](https://doi.org/10.1080/07352689.2011.616039).
- Hoff J. 2000. Methods of Blood Collection in the Mouse. *Laboratory Animals* 29:47–53.
- Jenkins DJ, Kendall CW, Axelsen M, Augustin LS, Vuksan V. 2000. Viscous and nonviscous fibres, nonabsorbable and low glycaemic index carbohydrates, blood lipids and coronary heart disease. *Current Opinion in Lipidology* 11:49–56. doi: [10.1097/00041433-200002000-00008](https://doi.org/10.1097/00041433-200002000-00008).
- Kawahito S, Kitahata H, Oshita S. 2009. Problems associated with glucose toxicity: Role of hyperglycemia-induced oxidative stress. *World Journal of Gastroenterology* 15:4137. doi: [10.3748/wjg.15.4137](https://doi.org/10.3748/wjg.15.4137).
- Kharroubi AT, Darwish HM. 2015. Diabetes mellitus: The epidemic of the century. *World Journal of Diabetes* 6:850–867. doi: [10.4239/wjd.v6.i6.850](https://doi.org/10.4239/wjd.v6.i6.850).
- Lean MEJ, Morenga LT. 2016. Sugar and type 2 diabetes. *British Medical Bulletin* 120:43–53. doi: [10.1093/bmb/ldw037](https://doi.org/10.1093/bmb/ldw037).
- Lee S, Muniyappa R, Yan X, Chen H, Yue LQ, Hong EG, Kim JK, Quon MJ. 2008. Comparison between surrogate indexes of insulin sensitivity and resistance and hyperinsulinemic euglycemic clamp estimates in



- mice. *American Journal of Physiology-Endocrinology and Metabolism* 294:E261–E270. doi: 10.1152/ajpendo.00676.2007.
- Li X, Guo J, Ji K, Zhang P. 2016. Bamboo shoot fiber prevents obesity in mice by modulating the gut microbiota. *Scientific Reports* 6:32953. doi: 10.1038/srep32953.
- Liu S, Willett WC, Manson JE, Hu FB, Rosner B, Colditz G. 2003. Relation between changes in intakes of dietary fiber and grain products and changes in weight and development of obesity among middle-aged women. *The American Journal of Clinical Nutrition* 78:920–927. doi: 10.1093/ajcn/78.5.920.
- Lockyer S, Spiro A, Stanner S. 2016. Dietary fibre and the prevention of chronic disease—should health professionals be doing more to raise awareness? *Nutrition bulletin* 41:214–231. doi: 10.1111/nbu.12212.
- Ludwig DS. 1999. Dietary fiber, weight gain, and cardiovascular disease risk factors in young adults. *JAMA* 282:1539. doi: 10.1001/jama.282.16.1539.
- Maejima Y, Rita RS, Santoso P, Aoyama M, Hiraoka Y, Nishimori K, Gantulga D, Shimomura K, Yada T. 2015. Nasal oxytocin administration reduces food intake without affecting locomotor activity and glycemia with c-Fos induction in limited brain areas. *Neuroendocrinology* 101:35–44. doi: 10.1159/000371636.
- Ng M, Fleming T, et al. 2014. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet* 384:766–781. doi: 10.1016/s0140-6736(14)60460-8.
- Oo SS, Rao USM, Zin T. 2017. Prevalence and factors associated with obesity among adult at the Kampung Kolam, East Coast Malaysian Peninsula- A cross sectional study. *International Journal of Pharmacy and Pharmaceutical Sciences* 9:273–281. doi: 10.22159/ijpps.2017v9i3.16888.
- Park CJ, Han JS. 2015. Hypoglycemic effect of jicama (*Pachyrhizus erosus*) extract on streptozotocin-induced diabetic mice. *Preventive Nutrition and Food Science* 20:88–93. doi: 10.3746/pnf.2015.20.2.88.
- Patel DK, Prasad SK, Kumar R, Hemalatha S. 2012. An overview on antidiabetic medicinal plants having insulin mimetic property. *Asian Pacific Journal of Tropical Biomedicine* 2:320–330. doi: 10.1016/s2221-1691(12)60032-x.
- Post RE, Mainous AG, King DE, Simpson KN. 2012. Dietary Fiber for the Treatment of Type 2 Diabetes Mellitus: A Meta-Analysis. *The Journal of the American Board of Family Medicine* 25:16–23. doi: 10.3122/jabfm.2012.01.110148.
- Ramos S, Moulay L, Granado-Serrano AB, Vilanova O, Muguera B, Goya L, Bravo L. 2008. Hypolipidemic effect in cholesterol-fed rats of a soluble fiber-rich product obtained from cocoa husks. *Journal of Agricultural and Food Chemistry* 56:6985–6993. doi: 10.1021/jf8009816.
- Ranganna S. 2015. *Handbook of Analysis and Quality Control for fruit and Vegetable Products* (2nd edition). Tata McGraw-Hill Education.
- Richmond W. 1973. Preparation and properties of a cholesterol oxidase from *Nocardia* sp. and its application to the enzymatic assay of total cholesterol in serum. *Clinical Chemistry* 19:1350–1356. doi: 10.1093/clinchem/19.12.1350.
- Sánchez D, Moulay L, Muguera B, Quiñones M, Miguel M, Aleixandre A. 2010. Effect of a soluble cocoa fiber-enriched diet in Zucker fatty rats. *Journal of Medicinal Food* 13:621–628. doi: 10.1089/jmf.2009.0127.
- Santoso P, Amelia A, Rahayu R. 2019. Jicama (*Pachyrhizus erosus*) fiber prevents excessive blood glucose and body weight increase without affecting food intake in mice fed with high-sugar diet. *Journal of Advanced Veterinary and Animal Research* 6:222. doi: 10.5455/javar.2019.f336.
- Santoso P, Maejima Y, Kumamoto K, Takenoshita S, Shimomura K. 2015. Central action of ELA-BELA reduces food intake and activates arginine vasopressin and corticotropin-releasing hormone neurons in the hypothalamic paraventricular nucleus. *NeuroReport* 26:820–826. doi: 10.1097/wnr.0000000000000431.
- Sax SM. 1975. *Clinical chemistry – principles and technics*, 2nd ed. r. j. henry, j. w. winkelmann, and d. c. cannon, (eds). harper row, publishers, new york. *Clinical Chemistry* 21:273–274. doi: 10.1093/clinchem/21.2.273a.
- Torres-Villalobos G, Hamdan-Pérez N, Tovar AR, Ordaz-Nava G, Martínez-Benítez B, Torre-Villalvazo I, Morán-Ramos S, Díaz-Villaseñor A, Noriega LG, Hiriart M, Medina-Santillán R, del Carmen Castillo-Hernandez M, Méndez-Sánchez N, Uribe M, Torres N. 2015. Combined high-fat diet and sustained high sucrose consumption promotes NAFLD in a murine model. *Annals of Hepatology* 14:540–546. doi: 10.1016/s1665-2681(19)31176-7.

- Trinidad TP, Mallillin AC, Loyola AS, Sagum RS, Encabo RR. 2009. The potential health benefits of legumes as a good source of dietary fibre. *British Journal of Nutrition* 103:569–574. doi: [10.1017/s0007114509992157](https://doi.org/10.1017/s0007114509992157).
- Ulla A, Alam MA, Sikder B, Sumi FA, Rahman MM, Habib ZF, Mohammed MK, Subhan N, Hossain H, Reza HM. 2017. Supplementation of *Syzygium cumini* seed powder prevented obesity, glucose intolerance, hyperlipidemia and oxidative stress in high carbohydrate high fat diet induced obese rats. *BMC Complementary and Alternative Medicine* 17:289. doi: [10.1186/s12906-017-1799-8](https://doi.org/10.1186/s12906-017-1799-8).
- Vellers HL, Letsinger AC, Walker NR, Granados JZ, Lightfoot JT. 2017. High fat high sugar diet reduces voluntary wheel running in mice independent of sex hormone involvement. *Frontiers in Physiology* 8:628. doi: [10.3389/fphys.2017.00628](https://doi.org/10.3389/fphys.2017.00628).
- Zhang L, Xie Q, Li X. 2021. Esculetin: A review of its pharmacology and pharmacokinetics. *Phytotherapy Research* 36:279–298. doi: [10.1002/ptr.7311](https://doi.org/10.1002/ptr.7311).



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