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Original Article

Fibers from tubers and rhizomes of local plant species in Indonesia as a potent dietary supplement to prevent diet-induced obesity

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Abstract

Various tubers and rhizomes of local plant species in Indonesia have potential as alternative foods and resources of dietary fiber that could counteract metabolic diseases, including obesity, diabetes, and associated health issues. However, studies focusing on the composition and medicinal benefits of extracted fibers from tubers and rhizomes remain limited. Our present study aimed to explore the composition and the beneficial effects of dietary fiber extracted from tubers of achira (*Canna edulis*), Mentawai taro (*Colocasia sp.*), arrowroot (Maranta arundinacea), and jicama (*Pachyrhizus erosus*) to counteract obesity development in mice fed with a fatty diet. Fibers were extracted from tubers and rhizomes, followed by proximate analysis to determine the nutritional and fiber composition. Thereafter, each fiber was tested for its effectiveness in preventing obesity caused by a high-fat diet (HFD) by using mice as the animal model. We revealed that all extracted fibers predominantly consisted of non-starchy carbs with very low fat and protein levels. The extract of achira and jicama consisted of higher total dietary fiber as compared to others. Our experiment on mice demonstrated that supplementation of 25% fiber of achira, Mentawai taro, arrowroot, and jicama in HFD could effectively prevent obesity independent of daily calorie intake. Our findings suggest that the dietary fiber of achira, Mentawai taro, arrowroot, and jicama could be a potent candidate as a supplement to combat HFD-induced obesity.

Keywords: diabetes, diet-induced obesity, daily calorie intake, high-fat diet, metabolic diseases.

Introduction

Various local plant species in Indonesia have high potential as resources for alternative and functional foods, bioactive compounds and dietary fiber [1, 2]. Importantly, the consumption of edible tubers and rhizomes is capable of counteracting metabolic diseases, including obesity, diabetes, and various associated health problems [3, 4]. Such diseases are irrevocably prevalent worldwide including in Indonesia [5, 6]. Unfortunately, until recently, diverse indonesian tuberous plant species remain being neglected. Moreover, the explorations on their medicinal benefits are yet to be established.

In the previous studies using animal models, we have revealed that dietary fiber of jicama (*Pachyrhizus erosus* L., Fabaceae) exerts health-beneficial effects against high-sugar diet-induced hyperglycemia [7], ectopic adiposity [8], and non-alcoholic fatty liver disease (NAFLD) [9]. Another report demonstrated that the fiber of jicama acts as a potent immunomodulator [10]. However, scientific reports concerning the beneficial effects of dietary fiber from other widely distributed tuberous and rhizomes plant species in Indonesia, including achira (*Canna edulis*, Cannaceae), Mentawai taro (*Colocasia sp.*, Araceae), and arrowroot (*Maranta arundinaceae*, Marantaceae) are scarcely available.

Mounting evidence has shown that regular consumption of dietary fiber is essential to sustain metabolic homeostasis against unhealthy diets, including high-fat diets and high-sugar diets [11]. A study using

mice as animal models revealed that dietary fiber supplementation extracted from bamboo shoots effectively improved metabolic profiles, including body weight, fat mass, and plasma lipid profiles against a high-fat diet [12]. Another experiment in piglets also indicated that soluble and insoluble dietary fiber could regulate microbiota composition in the colon and sustain the barrier function of intestinal cells [13]. Thus, dietary fiber plays a crucial role in combating diet-associated metabolic diseases.

This current study aimed to investigate the composition of dietary fiber extracted from tubers of jicama (*P. erosus*), Mentawai taro (Colacasia sp.), and rhizomes of arrowroot (M. *arundinaceae*) and achira (*C. edulis*) and examine their anti-obesity effect against a high-fat diet (HFD) in mice as the animal model.

Material and methods

Sample collection and extraction of fiber

The rhizomes of achira (*C. edulis*) and arrowroot (M. arundinacea) were obtained from the local farmers in Rejang Lebong (Bengkulu Province), while tubers of Mentawai taro were purchased from farmers in Sipora island-Mentawai (West Sumatra Province) and Jicama (*P. erosus*) were obtained from Kuranji-Padang (West Sumatra). All samples were washed with tap water 3–5 times, then peeled and sliced into small sizes. The slices were destructed using a grater until they became porridge-like structures and subsequently subjected to fiber extraction as per the protocol described elsewhere [10]. Briefly, grated samples were soaked in distilled water overnight and the supernatant was subsequently collected and steamed for 30 min at 100°C. Furthermore, the samples were dried at 70°C for 16–17 h, followed by mechanical grinding to obtain the fiber powder.

Analysis of nutrition and fiber

Analysis of protein, fat, carbs, fibers and moisture was performed by following the protocols as described elsewhere [14]. Briefly, the protein concentration was measured by the Kjeldahl method (AOAC 988.05), fat by acid hydrolysis method (AOAC 950.54), and starch by an enzymatic method ((AOAC 979.10). The fiber concentration was measured by using an enzymatic-gravimetric method (AOAC 991.43) and moisture by vacuum drying method (AOAC 934.01).

Experimental diet treatment on animals

Our study used 24 adult male mice (2 months old with 25–27 g body weight; Deutschland, Denken, and Yonken/DDY strain) purchased from Balai Veteriner Baso-Bukittinggi (West Sumatra). Before the experiment, animals were reared for 7 days in the room (temperature 26–27°C; humidity 65; light-dark cycle 12 h light and 12 h dark). During this period, mice were fed ad libitum with a standard rodent diet (RATBIO; Citra Ina Feedmill Jakarta, Indonesia) and a tap water drink.

Figure 1: Fresh tubers and rhyzomes (upper panels) and the extracted fiber (lower panels) of achira (*C. edulis*), Mentawai taro (*Colocasia sp.*), arrowroot (M. *arundinacea*) and jicama (*P. erosus*).

Every mouse was kept in a single cage (one animal per cage). The research protocols, including animal use and handling in this research, have been approved by The Research Ethics Committee of Medical Faculty, Andalas University (No. 528/UN.16.2/KEP-FK/2021).

At the end of acclimation, animals were randomly divided into six groups as follows (a) ND: fed with a normal diet, (b) HFD: fed with a high-fatty diet, (c) HFD + *Canna*: fed with a high-fat diet supplemented with 25% *Canna edulis* fiber, (d) HFD + *Colocasia*: fed with a high-fat diet supplemented with 25% *Colocasia sp.* Fiber, (e) HFD + *Maranta*: fed with a high-fat diet supplemented with 25% *Maranta arundinacea* fiber, and (f) HFD + *Pachyrhizus*: fed with a high-fat diet supplemented with 25% *Pachyrhizus erosus* fiber. The diet treatments were carried out continuously for eight weeks. The food was served ad libitum and changed daily to sustain the quality and hygiene.

Food intake and calorie intake measurement

The food intake was measured at the latest week of treatment for seven days continuously. Accordingly, calorie intake was subsequently calculated based on the nutritional content of the food consumed by the animals. Fractions of calorie intake composing carbohydrates, protein, and fat were determined based on the composition of each diet, such as 4 kcal/g, 4 kcal/g, and 9 kcal/g, respectively [15].

Body weight measurement

The body weight of mice was recorded biweekly during eight weeks of treatment. The measurements were performed at 09:00–10:00 in the morning using a sensitive digital balance. Bodyweight change was calculated based on the data of initial and final body weight

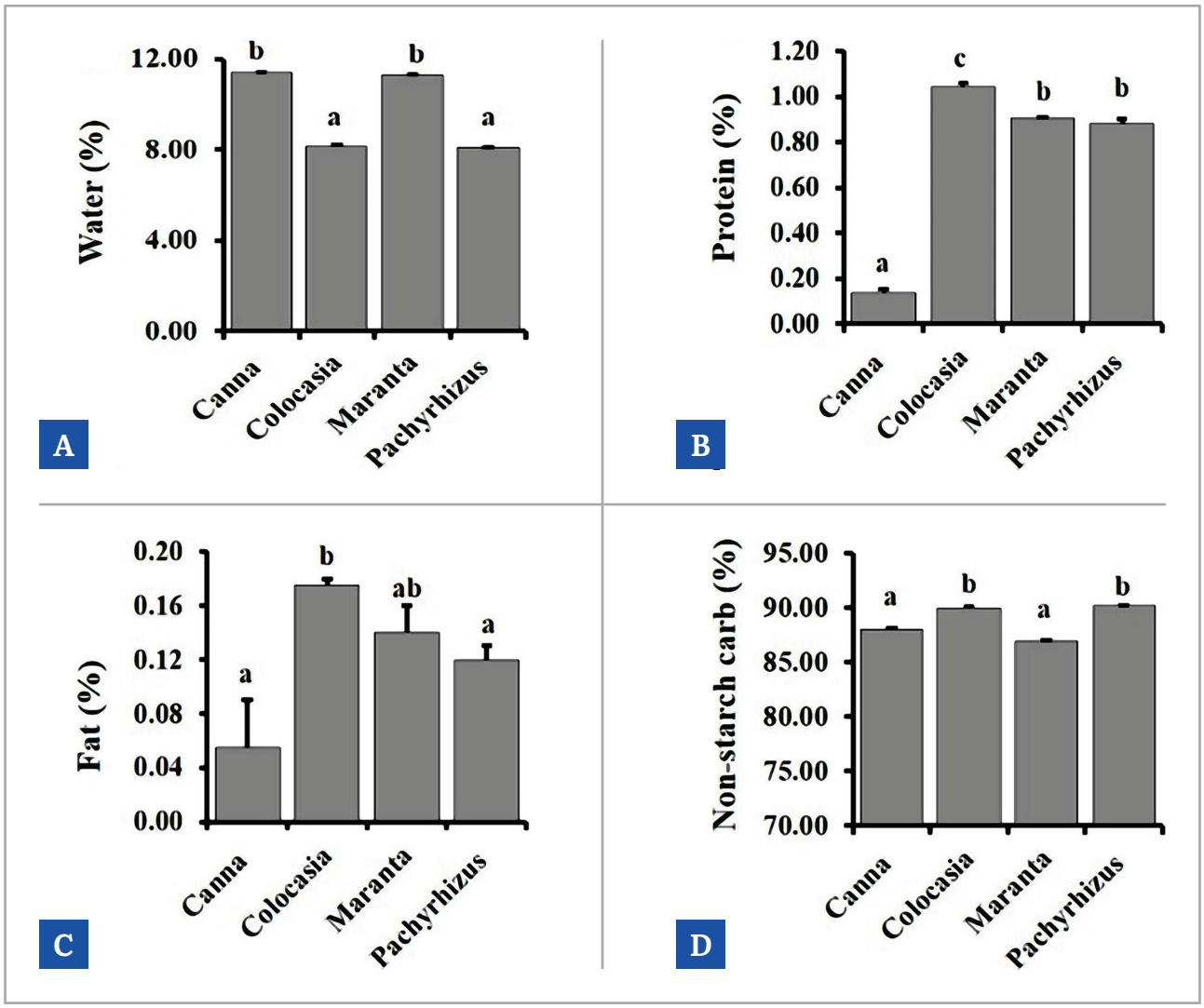

Figure 2: Water and nutrient content of extracted fibers. A – water content; B – protein content; C – fat content; D – non-starchy carbs.

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presented in grams, percentages, and fold changes. Resistance of body weight gain to calorie intake (both total and fat-calorie intake) was determined by dividing the energy consumption by body weight gain (%).

Statistical analysis

Data are presented as mean±SD. An analysis of Variance (ANOVA) and subsequent DNMRT with $p<0.05$ was generated to justify the significant value of difference among groups. The statistical analysis was performed by using SPSS ver. 26.

Results

Composition of fiber extract

Fiber extraction from the tubers of achira, Mentawai taro, arrowroot, and jicama was successfully conducted to obtain the fiber (Figure 1). Furthermore, the proximate analysis revealed that the fiber of achira (*Canna*) and arrowroot (*Maranta*) contained higher water content as compared with Mentawai taro (*Colocasia*) and jicama (*Pachyrhizus*) ($P<0.05$; Figure 2A). Moreover, the protein and fat were detected in lower concentrations for all types of extracted fiber (Figure 2BC), with the lowest one found in the *Canna* fiber extract. Importantly, the concentration of non-starchy carbs was highly detected in all samples (Figure 2D), indicating the effectivity of fiber extraction.

Further analysis of fiber samples also revealed that each species of tuberous plant consisted of different components of fiber. Total dietary fiber was higher in *Canna* and *Pachyrhizus* as compared with *Colocasia* and *Maranta* (Figure 3A). Moreover, the dietary fibers of the tuberous plants were predominantly composed of water-insoluble dietary fiber (Figure 3B) with a lesser content of water-soluble and crude fibers (Figure 3CD).

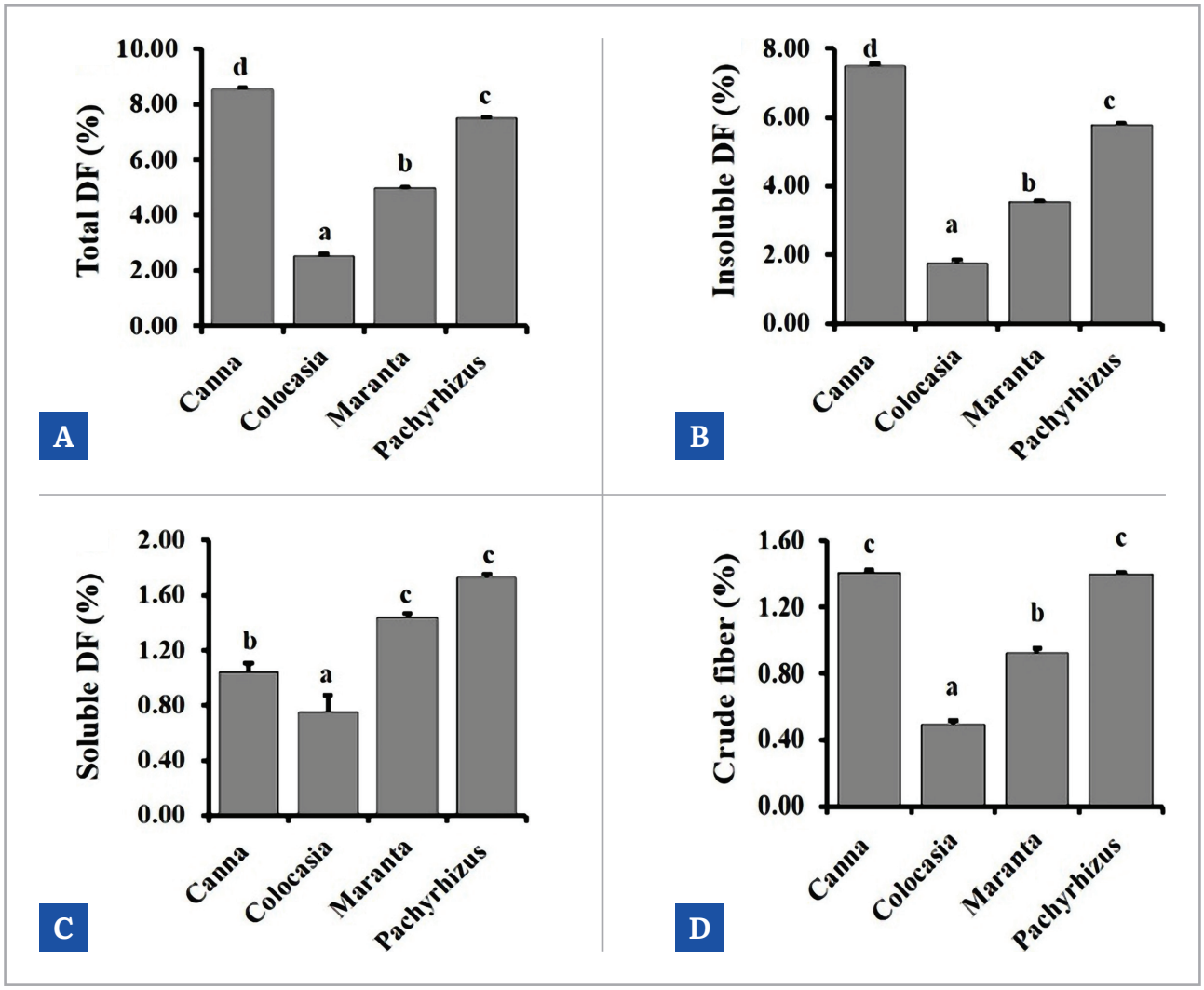

Figure 3: Composition of dietary fibers extracted. A – total dietary fiber; B – insoluble dietary fiber; C – soluble dietary fiber; D – total crude fiber.

Effect of dietary fiber on food and calorie intake of animal model

To determine whether dietary fiber supplementation could affect food intake and calorie intake, we fed mice with 25% of fiber extract from the tuberous plants in the HFD. In the 8th week of treatment, we measured daily food intake and subsequently calculated calorie intake in each group of mice (namely normal diet (ND), HFD, HFD + 25% dietary fiber). Daily food intake data show that dietary fiber supplementation from *Canna*, *Colocasia*, *Maranta*, and *Pachyrhizus* significantly increased food intake ($p<0.05$; Figure 4A) in mice fed with HFD. Likely, daily energy intake was also significantly increased in mice fed with HFD supplemented with dietary fiber ($p<0.05$; Figure 4B). Moreover, particular analysis on calorie intake from fat demonstrated a marked increase in daily fat calorie intake of mice treated with dietary fiber supplementation as compared with groups of HFD alone and ND ($P<0.05$; Figure 4C). Furthermore, based on the fraction of energy source calculation, all dietary fiber-fed groups of mice consumed a comparable amount of calories from carbs and protein but slightly higher in calorie intake from fat in the group fed with *Canna* fiber (Figure 4D). Overall, the amount of energy intake was significantly higher in dietary fiber-supplemented groups than in the HFD group.

Effect of dietary fiber supplementation on body weight of animal model

To examine the anti-obesity effect of dietary fiber supplementation, we measured the body weight of mice every two weeks. As depicted in Figure 5A, HFD induced an apparent increase in body weight starting from the 4th week of treatment ($P<0.05$) as compared with other groups. Moreover, fiber supplementation

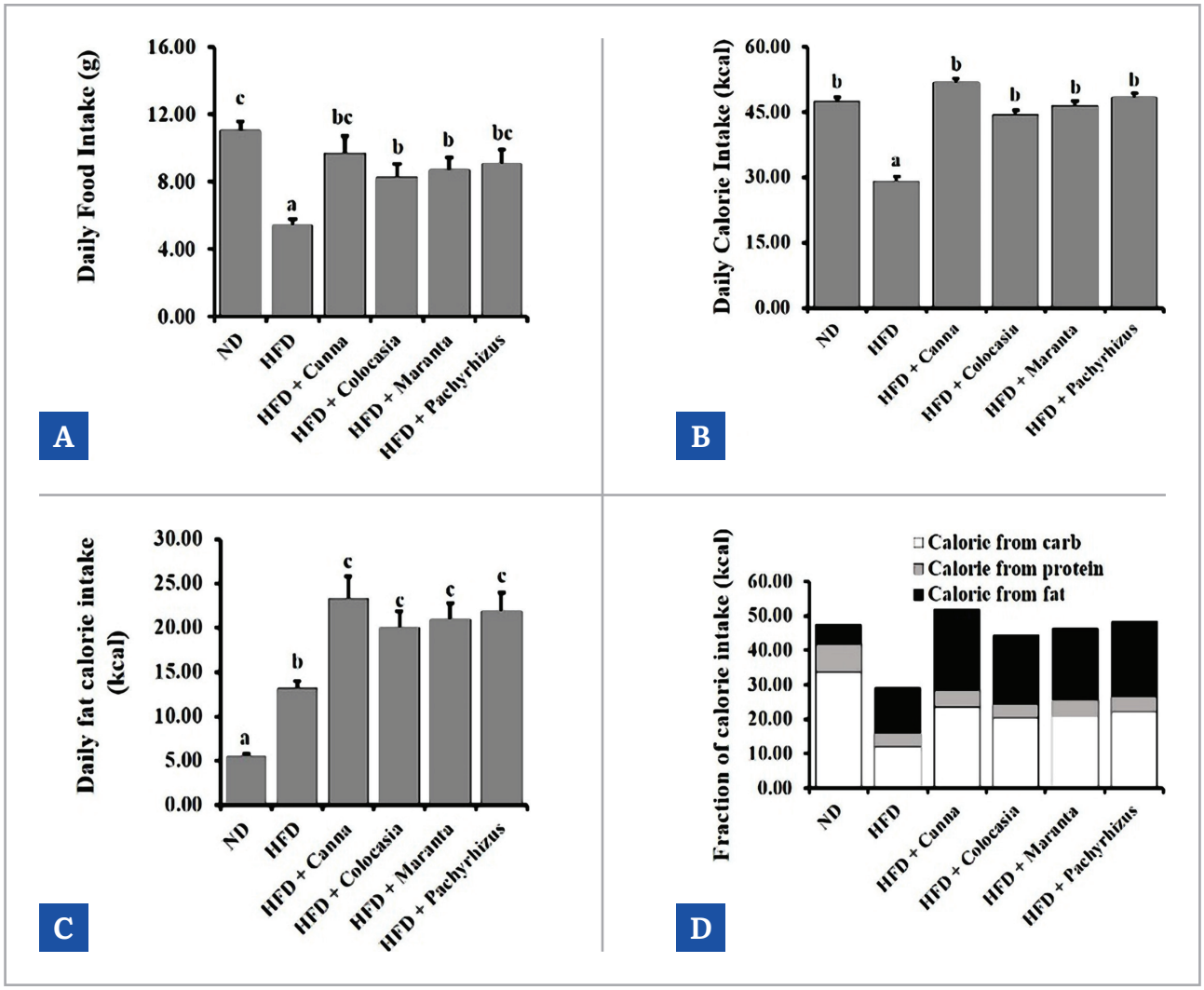

Figure 4: Effect of dietary fibers on food intake and calorie intake of mice. A – daily food intake; B – daily calorie intake; C – daily fat calorie intake; D – fraction of calorie intake from carbs, protein, and fat.

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of *Canna*, *Colocasia*, *Maranta*, and *Pachyrhizus* could effectively hamper the excessive body weight increase promoted by HFD (Figure 5A). Bodyweight gain was highly elevated by HFD and significantly reduced by fiber supplementation ($P<0.05$; Figure 5 B–D). Noticeably, the magnitude of reduction was strongest in mice treated with *Canna* fiber, suggesting the most effective fiber against diet-induced obesity among other tested fibers (*Colocasia*, *Maranta*, and *Pachyrhizus*).

Analysis of the resistance of body weight to calorie intake (Figure 6AB) indicated that dietary fiber supplementation strongly increased the resistance of mice to diet-induced obesity. Accordingly, the risk of being obese in HFD-fed mice was effectively anticipated by the supplementation of dietary fiber extracted from tubers of *Canna*, *Colocasia*, *Maranta*, and *Pachyrhizus*. Moreover, the fiber of *Canna* was the most effective in increasing mice's resistance to HFD-induced obesity.

Discussion

In this current study, we demonstrated that tubers and rhizomes of *Colocasia sp.*, *P. erosus*. *M. arundinaceae*, and *C. edulis* contained dietary fiber with a different composition but predominantly consisted of water-insoluble dietary fiber. The extraction process deployed to obtain the fiber effectively removed unwanted compounds such as fat, protein, and starch from the fiber extract. Moreover, *C. edulis* and *P. erosus* contained higher dietary fiber than *Colocasia sp.*, and *M. arundinaceae*. Hence, the rhizome of *C. edulis* and the tuber of *P. erosus* are preferable as resources of dietary fiber to the rest of the species. Furthermore, we revealed that all of the fiber extracts could effectively prevent HFD-induced obesity in mice and increase the resistance to obesity caused by excessive calorie intake, particularly from fat. However, the fiber of achira

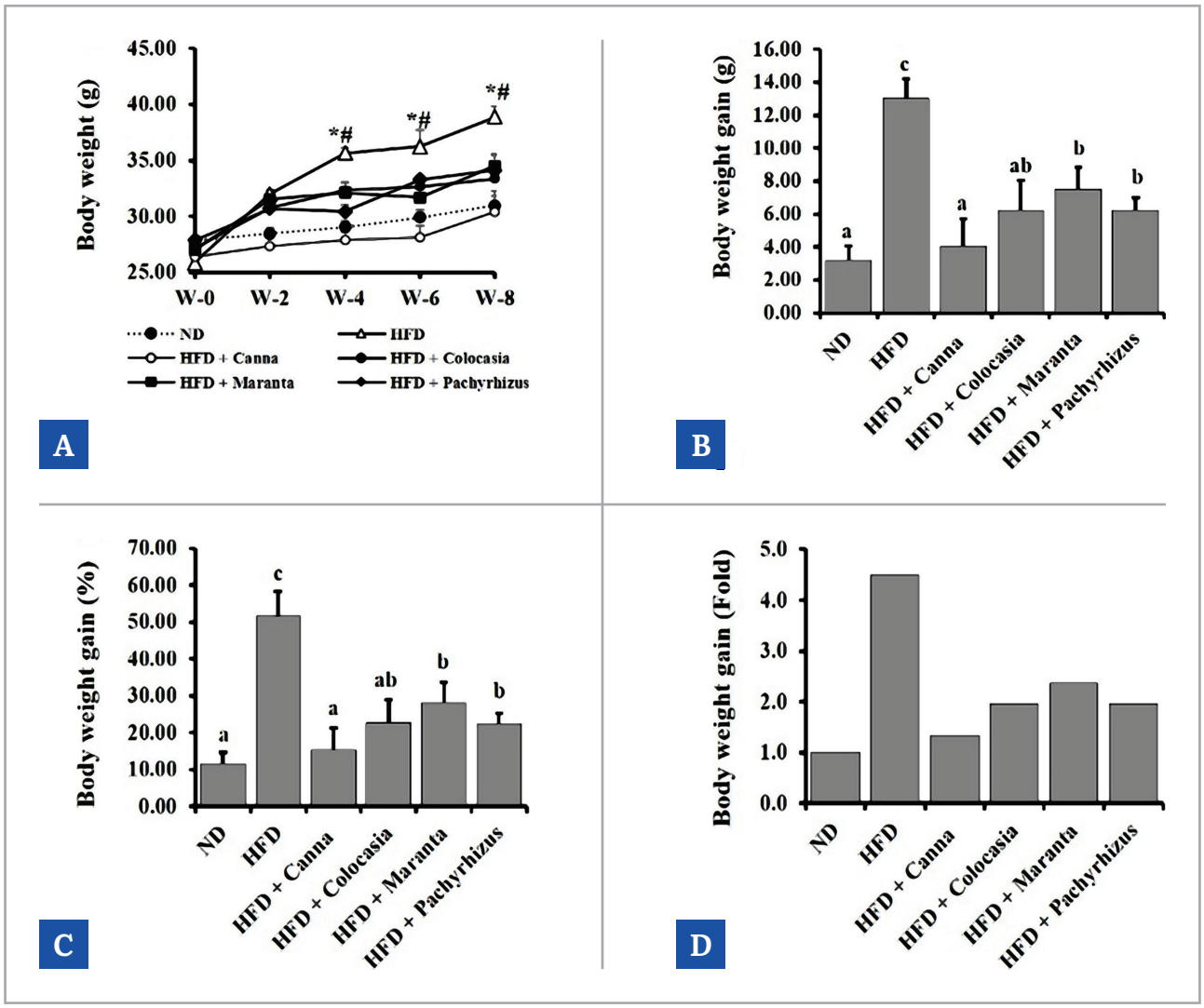

Figure 5: Effectivity of dietary fibers in counteracting body weight increase in mice. A – Body weight as measured every two weeks; B – Body weight gain; C – Percentage of body weight gain; D – Fold increase of body weight.

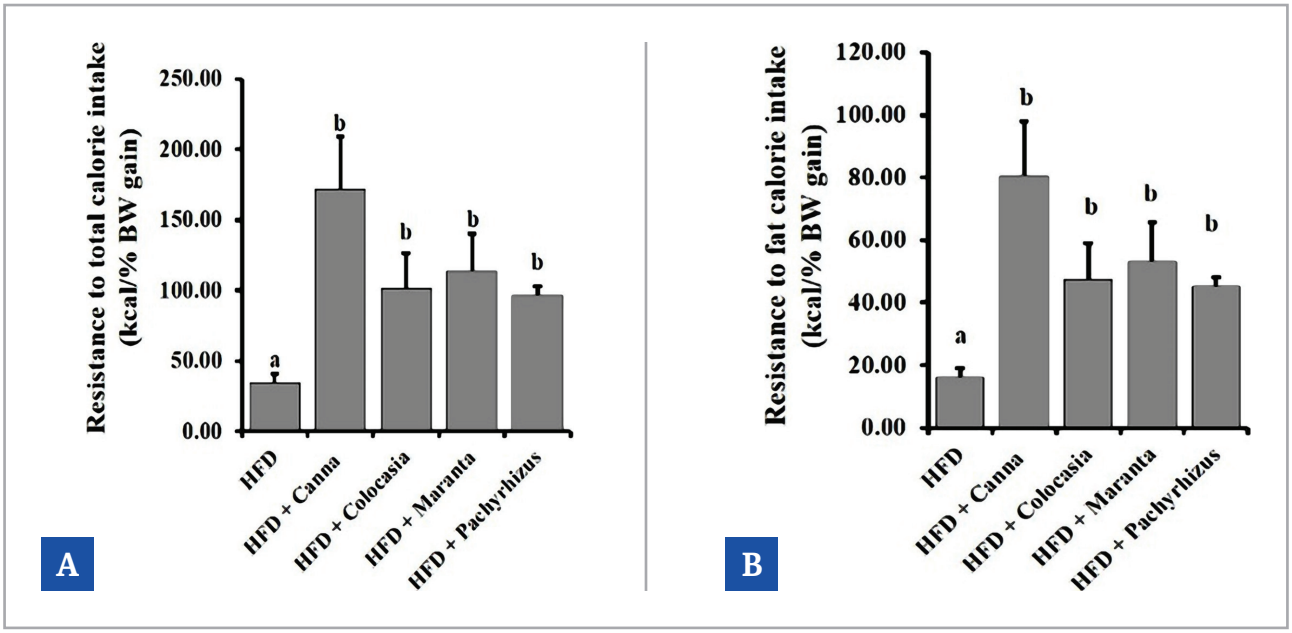

Figure 6: The resistance of body weight gain to calorie intake. A – Resistance to total calorie intake; B – resistance to fat calorie intake.

(*C. edulis*) was the most pronounced one to exert an anti-obesity effect against HFD.

The majority of dietary fibers extracted from tubers and rhizomes in our study were predominantly composed of water-insoluble fiber. Such fiber could not be fermented by the microbes in the intestine to produce short-chain fatty acids (SCFAs), including butyrate, propionate, and acetate [16]. As a result, it could not directly elevate SCFA levels and their subsequent physiological outcomes in the body. Otherwise, water-soluble dietary fiber is profoundly involved in the increase of SCFAs due to its fermentability in the intestinal tract [17]. Thus, the anti-obesity effect exerted by the fiber extract in this study might be commonly attributed to the water-insoluble dietary fiber component.

Our data showed that dietary fiber supplementation markedly increased the daily food intake and calorie intake in mice fed with HFD. Higher food and calorie intake could reflect the appetite state promoted by the orexigenic hormones, including ghrelin secreted by gastric cells and neuropeptide Y produced by the arcuate nucleus in the hypothalamus [18]. Moreover, it might result from the activity of neuronal circuits controlling feeding behavior and energy balance in the central nervous system, particularly in the hypothalamus and brain stem [19]. However, the secretion of orexigenic hormones and the activity of orexigenic neurons promoting feeding are unlikely directly induced by the high-fat content in the diet [20] as used in our study. Alternatively, the increment of food intake and calorie intake could be closely associated with the lower energy density of the diet. It has been reported that dietary fiber decreases the energy density of the diet [21]. Thus, to reach an adequate amount of energy for the body, mice fed with HFD supplemented with dietary fiber consumed more food than those fed with HFD alone.

Excessive food intake without any proper energy expenditure will result in obesity [22]. In our study, mice treated with dietary fiber extracted from tuberous plants consumed a high amount of food. Nevertheless, their body weight was sustained at the normal range, indicating resistance to diet-induced obesity. This phenomenon might indicate that mice fed with HFD supplemented with dietary fiber had a higher energy expenditure than those in HFD alone. Consumption of dietary fiber leads to an increment of energy expenditure [23]. However, in our present study, we could not provide the data to support our speculation. Thus, further study is required to confirm it.

Dietary fiber can also reduce nutrient absorption in the intestine such as sugar and fatty acids [24]. Fiber supplementation in the diet could increase the intraluminal viscosity [25]. As a result, lipase activity will be markedly lower under the viscous substrate condition. Another study also demonstrated that fiber has a direct inhibitory effect on lipase [26]. Moreover, fiber is reported to hamper the activity of bile acids that essentially function in emulsifying fat in the intestine [27]. Under the supplementation of resistant starch, the level of bile salt excreted in the feces was significantly

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elevated in HFD-fed mice, suggesting a reduction of its use for the fat digestion process in the intestine. Collectively, those mechanisms profoundly contribute to the decrement of lipid absorption in the intestinal wall thereby minimalizing the lipid load into the circulatory systems and the subsequent outcomes including obesity and dyslipidemia.

Among all species of plants used in this study, the fiber of achira (*C. edulis*) exhibited the most pronounced effect against HFD-induced obesity. The composition analysis revealed that the fiber of *C. edulis* was the highest one in terms of concentration of dietary fiber particularly water-insoluble dietary fiber. Thus, this high concentration of a particular fiber type might contribute to its stronger anti-obesity effect against HFD among other species. A previous study on *C. edulis* collected in the Himalayan region found that the extract of *C. edulis* rhizome contained a high level of phenolic compound and exhibited high antioxidant activity [28]. It may also be plausible that some bioactive substances in the fiber extract of *C. edulis* used in our study act as an anti-obesity agent. Further investigation is needed to clarify it.

In our current study, we did not determine the adiposity profiles, including mass and microscopic features of white adipose tissue. Moreover, we also did not measure the plasma lipid concentration. Furthermore, the digestibility and fermentability of dietary fiber used in this study also still need to be validated. These aspects are important to be addressed in future studies.

Conclusion

In conclusion, our research revealed that dietary fiber extracted from tubers and rhizomes of plants, including *C. edulis*, *Colocasia sp.*, *M. arundinacea*, and *P. erosus*, commonly consisted of water-insoluble dietary fiber. Supplementation of the fibers could prevent obesity development in mice fed with HFD. Moreover, *C. edulis* fiber exhibited the most salient anti-obesity effect among others. Therefore, this dietary fiber is recommended to be used as a supplement to diminish the detrimental effect of a fatty diet.

Acknowledgments

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Conflict of interest

The authors declare no conflict of interest.

References

1. Suwardi AB, Indriaty, Navia ZI. Nutritional evaluation of some wilde edible tuberous plants as an alternative foods. Innovare J of Food Sciences 6(2): 9-12, 2018.
2. Purnamaningsih R, Sianipar NF. Analysis of bioactive compounds and morphological traits in indonesian rodent tuber mutant clones of pekalongan accession using GC-MS. J Teknologi 80(2), 2018.
3. Dufie WMF, Oduro I, Ellis WO, Asiedu R, Maziya-Dixon B. Potential health benefits of water yam (Dioscorea alata). Food Function 4(10):1496-501, 2013.
4. Ramadan MF, Oraby HF. Fatty Acids and Bioactive Lipids of Potato Cultivars: An Overview. J Oleo Sci. 65(6): 459-70, 2016.
5. Ng M, Fleming T, Robinson M, Thomson B. 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. Lancet 384(9945); 766-781, 2014.
6. Purnamasari D. The Emergence of Non-communicable Disease in Indonesia. Acta Med Indonesia 50(4):273-274, 2018.
7. Santoso P, Amelia A, Rahayu R. Jicama (Pachyrhizus erosus) fiber prevents excessive blood glucose and body weight increase without affecting food intake in mice fed with high-sugar diet. J Adv Vet Anim Res 6(2): 222-230, 2019.
8. Santoso P, Maliza R, Insani SJ, Fadhilah Q, Rahayu R. Preventive effect of jicama (Pachyrhizus erosus) fiber against diabetes development in mice fed with high-fat diet. J Appl Pharm Sci 11(01):137–143, 2021.
9. Santoso P, Maliza R, Fadhilah Q, Insani SJ. Beneficial effect of pachyrhizus erosus fiber as a supplemental diet to counteract high sugar-induced fatty liver disease in mice. Rom J Diabetes Nutrition and Metabolic Diseases 26(4): 353-360, 2020.
10. Kumalasari ID, Nishi K, Harmayani E, Raharjo S, Sugahara T. Immunomodulatory activity of Bengkoang (Pachyrhizus erosus) fiber extract in vitro and in vivo. Cytotechnology 66: 75–85, 2014.
11. Arisqueta L, Navarro-Imaz H, Labiano I, Rueda Y, Fresnedo O. High-fat diet overfeeding promotes nondetrimental liver steatosis in female mice. Am J Physiol Gastrointest Liver Physiol 315(5):772-780, 2018.
12. Li Q *et al*. Retarding effect of dietary fibers from bamboo shoot (Phyllostachys edulis) in hyperlipidemic rats induced by a high-fat diet. Food Funct 12(10): 4696-4706, 2021.
13. Chen *et al*. Soluble Fiber and Insoluble Fiber Regulate Colonic Microbiota and Barrier Function in a Piglet Model. Biomed Res Int. 7809171, 2019.
14. Phillips KM, McGinty RC, Couture G, Pehrsson PR, McKillop K, Fukagawa NK. Dietary fiber, starch, and sugars in bananas at different stages of ripeness in the retail market. PLoS One 16(7):e0253366, 2021.
15. Gong *et al*. The effects of energy intake of four different feeding patterns in rats. Exp Biol Med (Maywood)241(1):52-59, 2016.
16. Gill SK, Rossi M, Bajka B, Whelan K. Dietary fibre in gastrointestinal health and disease. Nat Rev Gastroenterol Hepatol 18(2): 101-116, 2021.

17. Wang G *et al*. Water soluble dietary fiber from walnut meal as a prebiotic in preventing metabolic syndrome. J Functional Foods 78:04358, 2021.
18. Kageyama H, Takenoya F, Shiba K, Shioda S. Neuronal circuits involving ghrelin in the hypothalamus-mediated regulation of feeding. Neuropeptides44(2):133-138, 2010.
19. Suyama S, Takano E, Iwasaki Y, Nakata M, Yada T. Roles and functional interplay of the gut, brain stem, hypothalamus and limbic system in regulation of feeding. Nihon Rinsho 67(2):277-286, 2009.
20. Nunez-Salces M, Li H, Christie S, Page AJ. The Effect of High-Fat Diet-Induced Obesity on the Expression of Nutrient Chemosensors in the Mouse Stomach and the Gastric Ghrelin Cell. Nutrients 12(9):2493, 2020.
21. Raynor HA, van Walleghen EL, Bachman JL, Looney SM, Phelan P, Wing RR. Dietary energy density and successful weight loss maintenance. Eat Behav12(2):119-125, 2011.
22. Hill JO, Wyatt HR, Peters JC. Energy balance and obesity. Circulation 126(1):126-132, 2012.
23. Hervik AK, Svihus B. The Role of Fiber in Energy Balance. J Nutr Metab 4983657, 2019.
24. Clark MJ, Slavin JL. The effect of fiber on satiety and food intake: a systematic review. J Am Coll Nutr 32(3):200-211, 2013.
25. Tamargo A, Cueva C, Alvarez MD, Herranz B, Moreno-Arribas MV, Laguna L. Physical effects of dietary fibre on simulated luminal flow, studied by in vitro dynamic gastrointestinal digestion and fermentation. Food Funct 10(6):3452-3465, 2019.
26. Ribichini *et al*. Role of Fibre in Nutritional Management of Pancreatic Diseases. Nutrients 11(9):2219, 2019.
27. Naumann S, Schweiggert-Weisz U, Haller D, Eisner P. Retention of Primary Bile Acids by Lupin Cell Wall Polysaccharides Under In Vitro Digestion Conditions. Nutrients 11(9), 2117, 2019.
28. Mishra T, Goyal AK, Middha SK, Sen A. Antioxidative properties of Canna edulis Ker-Gawl. Indian J natural product 2(3): 315-321, 2011.

https://doi.org/10.46389/rjd-2024-1194