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Full Length Article

Mentawai Taro (*Colocasia esculenta* var. Mentawai) Corm Flour Ameliorates Insulin Resistance and Leukocytosis Promoted by High-Fat Diet in Mice

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Abstract

Excessive intake of a high-fat diet (HFD) is profoundly linked with various diseases, including dyslipidemia, inflammation, obesity, type 2 diabetes mellitus (T2DM), and inflammation. Meanwhile, Mentawai taro, a variety of taro in the *Colocasia esculenta* species, has traditionally served as a daily staple food for the local people in the Mentawai Islands (West Sumatra, Indonesia). However, it remains unclear whether Mentawai taro corm can effectively counteract the detrimental effects of an HFD. This study investigated whether Mentawai taro corm flour (MTF) can significantly prevent HFD-induced T2DM and leukocytosis. The experimental study involved adult male mice (n = 27) divided into three groups: normal diet, HFD, and HFD supplemented with 20% MTF. After a 12-week treatment, the levels of blood glucose, plasma insulin, glucose tolerance, insulin tolerance, homeostasis model assessment for insulin resistance (HOMA-IR), malondialdehyde (MDA) levels as well as leukocyte counts were determined. Results showed that supplementation of 20% MTF in the HFD substantially improved blood glucose profiles, reduced blood glucose levels ($P < 0.01$), enhanced glucose and insulin tolerance ($P < 0.01$) and prevented hyperinsulinemia and insulin resistance. Additionally, Mentawai taro flour effectively reduced pancreatic tissue MDA ($P < 0.05$) and regulated leukocyte profiles, including total leukocyte number ($P < 0.01$), and numbers of lymphocytes, monocytes, and granulocytes ($P < 0.01$). Hence, our study suggests that MTF supplementation in the context of an HFD exerts beneficial effects on glucose homeostasis, insulin sensitivity, oxidative stress, and inflammation. It implies potential antidiabetic and anti-inflammatory properties of MTF to manage diet-induced diseases.

Keywords: Diabetes mellitus; Hyperinsulinemia; Mentawai; Oxidative stress; Inflammation

Introduction

Excessive intake of a high-fat diet (HFD) is an increasingly prevalent dietary pattern worldwide in modern society (Machate *et al*. 2020). It is firmly linked to a spectrum of health issues, including dyslipidemia, heart diseases, obesity, type 2 diabetes mellitus (T2DM) and chronic inflammation (Harrison *et al*. 2020). These diseases collectively represent a growing public health concern, necessitating a comprehensive exploration of potential interventions that could alleviate the adverse effects of HFD on metabolic health. Various medications have commonly been used to treat such diseases, particularly chemical or synthetic drugs (Nauck *et al*. 2021; Abdul-Rahman *et al*. 2022). Despite the high efficacy of chemical or synthetic drugs in managing health problems related to metabolic diseases and inflammation, unwanted side effects have been widely observed (Mali *et al*. 2021; Ramu *et al*. 2022; Vell *et al*. 2023). Hence, further efforts to determine safer interventions in managing HFD-induced diseases should consider alternative approaches, including the utilization of functional foods from local plants.

Among potential candidates of plant-based functional foods, taro (*Colocasia esculenta*; Araceae) corm offers a plethora of medicinal benefits in managing various diseases, including diet-induced metabolic diseases and associated health problems (Gupta *et al*. 2019). Traditional practices use taro corm to treat constipation, alopecia, stomatitis, hemorrhoids and fatigue (Simsek and Nehir 2015). Moreover, phytochemical analysis has revealed that the extract of taro corm is rich in flavonoids and triterpenoids, including letolin, vicenin-2, orientin and vitexin (Chandrasekara and Kumar 2016). Taro is also rich in anthocyanin, including cyanidine rhamnoside, cyanidine

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glucoside, and pelargonidin glucoside, with high antioxidant activity (Singh *et al*. 2011). Another study on *C. esculenta* var. antiquorium has reported its hepatoprotective effect against CCl4-induced liver degeneration (Pawar *et al*. 2018). It also found that cyanoglucoside from *C. esculenta* could counteract hyperglycemia (Ferdaus *et al.* 2023). Furthermore, taro has been suggested to exert a hypolipidemic effect due to its arabinogalactan and mono and digalactosyl diglycerol contents (Eleazu *et al*. 2016).

Mentawai taro (*C. esculenta* var. Mentawai) refers to a variety of taro in the species that is traditionally cultivated and consumed by the Mentawai people, an indigenous group living in the Mentawai islands, located off the west coast of West Sumatra, Indonesia (Syarif *et al*. 2017). Morphologically, Mentawai taro has distinctive characters forming a separated cluster from other varieties of this same species in Sumatra and other islands in Indonesia (Syarif *et al*. 2017). Recently, Mentawai taro has been promoted at the national level as one of Indonesia's alternative foods. However, despite its traditional role and national endorsement, it remains uncertain whether Mentawai taro corm can effectively counteract the detrimental effects induced by the consumption of an HFD. This study, therefore, sets out to fill this critical knowledge gap by investigating the potential benefits of Mentawai taro corm flour (MTF) in the context of HFD-induced health complications. Specifically, the research aimed to determine whether MTF possesses the capability to significantly prevent the onset of T2DM and irregular leukocyte profiles, both of which are recognized as deleterious consequences of HFD consumption.

Materials and Methods

Preparation of Mentawai taro corm flour

The Mentawai taro corms were freshly harvested at 7 months old from a farm in Sipora (Mentawai District, West Sumatra Province). The taxonomical validation of the sample was performed by a botanist at the Herbarium of Andalas University (ANDA). The corm flour was prepared following previously described procedures (Zhang *et al*. 2022). The corms were washed five times using distilled water before being peeled and sliced using an electric slicer then dried in a dehydrator at 45°C for 48 h. Following drying, the samples were crushed using an electric grinder equipped with a mesh (100 sieve size) to produce the flour. The flour (MTF) was then stored in a sterilized plastic bag for later analysis and use.

Proximate analysis of Mentawai taro corm flour

The concentration of protein, fat, carbohydrates, fiber, ash, and moisture in the MTF was analyzed in accordance with established protocols by the AOAC (AOAC 1990). Specifically, the concentration of protein was determined using the Kjeldahl method (AOAC 988.05), the fat content was assessed through the acid hydrolysis method (AOAC 950.54), and carbohydrate level was measured employing an enzymatic method (AOAC 979.10), while fiber concentration was determined utilizing an enzymatic-gravimetric method (AOAC 991.43). Moreover, the moisture content was assessed *via* the vacuum drying method (AOAC 934.01). Ash content was measured by a direct ashing method (AOAC 942.05).

Experimental animals and treatments

Adult male mice (BALB/c strain, aged 2 months, weighing 23–26 g; n = 27) were provided by the Veterinary Center in Baso, West Sumatra. Upon arrival, the animals underwent a one-week acclimatization period in an animal room with controlled temperature, humidity, and lighting conditions (25–26.1°C; 68–69%; 12 h dark and 12 h light phase). During this period, the animals were fed with a standard chow diet (Ratbio; CitraInna-Feed, Jakarta) and tap water ad libitum. Each animal was housed in a separate cage. Following the acclimatization period, the mice were randomly assigned to three groups based on their respective diets namely:
Diet 1: standard chow diet (normal diet; ND)
Diet 2: high-fat diet (HFD)
Diet 3: HFD combined with 20% of Mentawai taro corm flour (HFD MTF; w/w)

The diet composition is depicted in Table 1. The dose of Mentawai taro flour was justified based on the preliminary experiment in adult male mice for 30 days showing that such a dose was effective in preventing blood glucose elevation.

Measurement of blood glucose levels

Random blood glucose values were measured at the beginning (0 week) and the latest day of the experiment (12 weeks). Blood drops were drawn from the vein of the tail in the morning (08:00–09:00 AM), while the levels of blood glucose were detected using a glucometer (AGM-100 Glucometer). Furthermore, the levels of fasting blood glucose were determined after an 18-h fasting period. During the fasting period, food was removed from the cage, but water bottles were provided ad libitum.

Glucose tolerance test (GTT)

The test was performed at the end of the treatments. Mice were subjected to a 6-h fasting period prior to the test. Subsequently, each mouse was injected intraperitoneally with a 20% d-glucose solution (20 g/kg BW; Sigma-Aldrich). Next, blood glucose levels were monitored periodically (0, 15, 30, 60, 90 and 120 min after injection). Eventually, the values of area under the curve (AUC) of the GTT were determined based on blood glucose values during the test.

Insulin tolerance test (ITT)

The ITT was carried out after GTT. Firstly; animals were fasted during 6 h prior to the ITT. Thereafter, exogenous insulin (0.75 IU/kg BW; Actaprid) was intraperitoneally administrated to the mice followed by the measurements of blood glucose values periodically (0, 15, 30, 60, 90 and 120 min after injection). The AUC value was also subsequently calculated.

Plasma insulin measurements and calculation of homeostasis model assessment of insulin resistance (HOMA-IR)

Mice were terminated under fasting conditions, and blood was drawn through a cardiac puncture. Subsequently, the plasma was extracted using a refrigerated centrifuge (M1416R Refrigerated Centrifuge; RWD-Life Science) at 4°C for 10 min with a speed of 3000 RPM. Then, plasma was kept at -80°C prior to insulin measurement. The insulin was detected by using an ELISA kit (mouse insulin kit, Abcam, ab277390) as per the manufacturer's protocols. The absorbances of samples were determined using a microplate ELISA reader (Multiskan™ FC Microplate Photometer 51119100; Thermo Fisher Scientific). Furthermore, the HOMA-IR was calculated as follow:

$$\mathrm{HOMA-IR} = \frac{\text{Fasting insulin level } \left(\frac{\mathrm{IU}}{\mathrm{L}}\right) \text{ x Fasting glucose level } \left(\frac{\mathrm{mg}}{\mathrm{dL}}\right)}{405}$$

Malondialdehyde (MDA) content in pancreas tissue

MDA levels in the pancreas tissue were determined using procedures described elsewhere (Al-Fawaeir *et al*. 2011; Santoso *et al*. 2022). Briefly, the pancreas tissues were collected immediately upon mice scarification. Then, 0.25 g of tissue sample was prepared from each mouse and stored immediately at -80°C. Subsequently, the sample was subjected to homogenization in phosphate-buffered saline (PBS) solution using a tissue homogenizer (Tissueruptor II, Qiagen) and centrifugation at 5000 rpm for 15 min. Next, the levels of MDA in the samples were detected using a lipid peroxidation assay kit (Abcam). The sample absorbances were detected by a UV-Vis Spectrophotometer (Raptor UV1100N).

Measurement of leucocyte counts

The blood was taken by a cardiac puncture and stored in a heparinized microtube. After that, the samples were subjected to haematological analyses using a haematology analyser (BC-20S Mindray) to determine the numbers of total leukocytes, lymphocytes, monocytes, and granulocytes.

Statistical analysis

Statistical analysis was performed by means analysis of variance and subsequent Bonferroni test using SPSS v. 22 (IBM) with a significant value was considered at $P < 0.05$.

Results

Proximate composition of Mentawai taro corm flour

The proximate analysis results for MTF are depicted in Table 2, showing that the flour was predominantly composed of carbohydrates, with substantial protein, fiber and mineral contents. When compared with *C. esculenta* from Tanibar Island (Maluku Province, Indonesia), it was found that MTF contained relatively similar levels of protein (6.39% *vs*. 6.17%) and fiber (3.04% *vs*. 2.94%) (Siletty *et al*. 2022). However, the fat content of the flour was lower (0.50% *vs*. 4.44%), while the ash content was higher (3.54% *vs*. 1.48%) compared to *C. esculenta* from Tanimbar. The total carbohydrate content was also relatively higher (78.03%) than that of *C. esculenta* from Tanibar (76.71%). Another study on *C. esculenta* corm flour from Côte d'Ivoire (Africa) (Amon *et al*. 2014) found a different proximate composition, with lower fiber content (1.7%), lower protein content (2.4%) but higher carbohydrate content (84.4%) than MTF.

Effect of Mentawai taro corm flour on blood glucose profiles and insulin sensitivity

The measurements of blood glucose levels (Fig. 1) revealed that mice fed with HFD exhibited a substantial elevation in random blood glucose values after 12 weeks of diet regime compared to the initial treatment time (Fig. 1A; $P < 0.01$). In contrast, random blood glucose levels remained comparable between the initial time and the end of treatment in mice fed with MTF (HFD + MTF). Importantly, the levels of random blood glucose in the HFD + MTF group were statistically similar to those in the ND group ($P > 0.05$). At the end of treatment, the blood glucose levels in the HFD + MTF group were significantly lower than those in the HFD group ($P < 0.01$). Furthermore, fasting blood glucose levels determined at the end of treatment (Fig. 1B) also exhibited a similar pattern, with mice in the HFD + MTF group having significantly lower fasting blood glucose than those in the HFD group ($P < 0.01$). Conversely, fasting blood glucose levels in the HFD + MTF group were comparable to those in the ND group ($P > 0.05$).

In addition, GTT results (Fig. 2A) indicated that mice in the HFD group exhibited glucose intolerance, with excessive increases of blood glucose upon intraperitoneal administration of glucose solution. Conversely, mice in the HFD + MTF and ND groups showed sustained lower blood glucose levels at many time points (15, 30, 60 and 90 min post glucose injection), which were significantly different from the HFD group ($P < 0.05$ and $P < 0.01$). The area under the curve (AUC) derived from the GTT results (Fig. 2B) showed that the HFD + MTF group had a substantially lower AUC value

Table 1: Diet compositions used in the experiment

Materials	Composition (%/100 g diet)		
	ND	HFD	HFD + MTF
Carbohydrate (refined corn starch)	59.3	42.3	22.3
Protein (isolated soy protein)	20	20	20
Fat (milk fat)	8	25	25
Mentawai taro corm flour	0	0	20
Fiber (physillum)	3	3	3
Mineral and vitamin mix	9.7	9.7	9.7

ND (normal diet), HFD (high-fat diet), MTF (Mentawai taro corm flour)

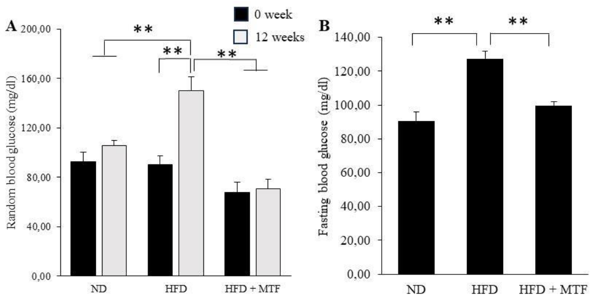

Fig. 1: Effect of Mentawai taro corm flour on random blood glucose and fasting blood glucose levels in mice fed with HFD. (**A**) Random blood glucose measured at the beginning and the end of diet treatments, (**B**) Fasting blood glucose levels determined at the end of treatments. ND (normal diet), HFD (high-fat diet), MTF (Mentawai Taro Flour), **) indicates significant difference based on Bonferroni Post Hoc Test (*P < 0.01*)

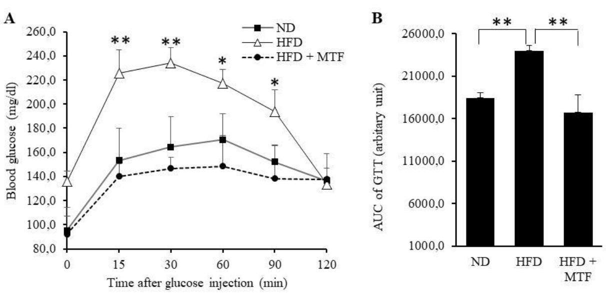

Fig. 2: Effect of Mentawai taro corm flour on glucose tolerance in mice. (**A**) Blood glucose levels in GTT, (**B**) Area under curve derived from blood glucose levels in GTT. *) and **) indicate significant difference as compared with other groups (*P < 0.05* and *P < 0.01*, respectively)

compared to the HFD group (*P < 0.01*). Furthermore, the AUC value of the GTT in the HFD + MTF group was statistically similar to that in the ND group (*P > 0.05*).

Furthermore, the ITT results (Fig. 3A) revealed that, upon insulin administration, blood glucose levels in mice fed with HFD + MTF significantly decreased at 15 and 30 min after injection. There was a slight increase at 60, 90 and 120 min after insulin administration. In contrast, the blood glucose levels of the HFD group exhibited slow responses to insulin injection, remaining significantly higher compared to the HFD + MTF group at all-time points (*P < 0.01*). Mice fed with an ND diet showed relatively similar response, with blood glucose levels decreasing significantly upon insulin injection. However, at 120 min after insulin injection, the blood glucose levels of mice in the ND group were almost completely recovered to the initial values (before injection), while in the HFD + MTF group, the blood glucose levels remained markedly lower compared to the ND and HFD groups (*P < 0.01*). This finding might indicate that insulin efficacy was even higher in the HFD + MTF group than in the ND group. Consequently, administrated insulin remained capable of exerting its effect in reducing blood glucose levels after 120 min post-administration. Furthermore, the AUC of ITT (Fig. 3B) also

Table 2: Proximate Composition of Mentawai taro corm flour (MTF)

Parameter	Content (% per 100 g of flour)
Moisture	9.59
Ash	3.54
Protein	6.39
Fat	0.50
Carbohydrates	78.03
Crude fiber	3.04

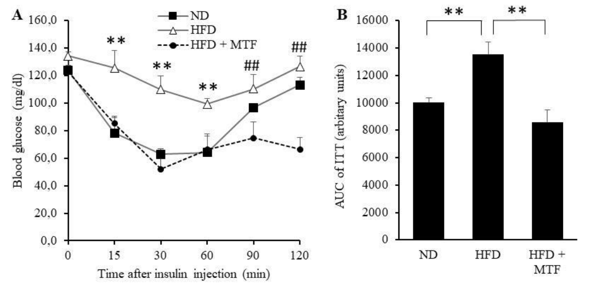

Fig. 3: Effect of Mentawai taro corm flour on insulin tolerance in mice. (**A**) Blood glucose levels after insulin intraperitoneal injection in ITT, (**B**) AUC values derived from blood glucose levels in ITT. **) in A and B indicates significant difference between HFD and other groups (*P < 0.01*); ##) indicates significant different between HFD and HFD + MTF group (*P < 0.01*)

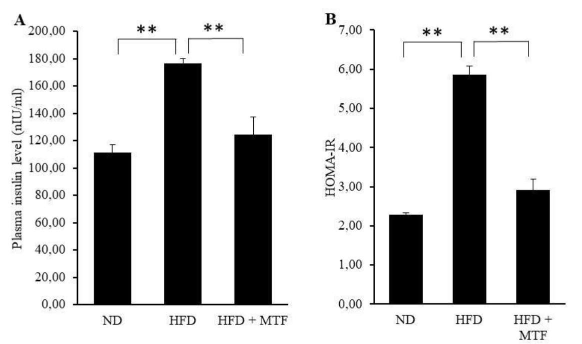

Fig. 4: Effect of Mentawai taro corm flour on plasma insulin and HOMA-IR of mice. (**A**) Plasma insulin concentration measured at the end of diet treatments, (**B**) homeostasis model assessment of insulin resistance (HOMA-IR) calculated based on plasma insulin and fasting blood glucose levels. **) indicates significant difference statistically based on Bonferroni post hoc test (*P < 0.01*)

showed that the HFD group had substantially higher AUC values compared to the other groups (ND and HFD + MTF groups; $P < 0.01$).

To assess the effect of MTF on insulin production, the levels of insulin in the blood were measured. As shown in Fig. 4A, mice fed with HFD alone had significantly higher plasma insulin concentrations compared to the other groups ($P < 0.01$), indicating hyperinsulinemia. In contrast, mice fed with HFD + MTF exhibited lower insulin levels compared to the HFD group ($P < 0.01$) but comparable to the ND group ($P > 0.05$). Furthermore, to predict insulin resistance, the HOMA-IR was determined. The data showed that mice fed with HFD had the highest HOMA-IR values, while those fed with HFD + MTF had significantly ($P < 0.01$) lower HOMA-IR than the HFD group (Fig. 4B). Importantly, the HOMA-IR in the HFD + MTF group was comparable to that in the ND group ($P > 0.05$).

Effect of Mentawai taro corm flour on tissue oxidative stress in pancreas

As depicted in Fig. 5, the HFD-fed group experienced elevated MDA levels in pancreatic tissue that were significantly higher compared to the control (ND) group ($P < 0.01$). In contrast, mice fed with HFD + MTF exhibited a lower MDA level in pancreatic tissue that was substantially less than the HFD group ($P < 0.05$). However, the magnitude of MDA reduction in the MTF-treated group was not as great as in the ND group.

Effect of Mentawai taro corm flour on leucocyte profiles

As depicted in Fig. 6, mice in the HFD group had substantially elevated total leucocyte counts compared to the ND group ($P < 0.01$). Conversely, mice fed with HFD + MTF had a lower total leucocyte count than the HFD group ($P < 0.01$). Importantly, the total leucocyte count was comparable between the HFD + MTF and ND groups ($P > 0.05$). Furthermore, differential leucocyte counts were also determined. The HFD group had a significantly elevated lymphocyte number as compared with ND group ($P < 0.01$). In contrast, the HFD + MTF group exhibited a lower lymphocyte count compared to the HFD group ($P < 0.05$). Although the lymphocyte counts were statistically similar between the ND and HFD + MTF groups, the magnitude of reduction was larger in the ND group compared to the HFD + MTF group. Next, the monocyte counts were not significantly different between the HFD and ND groups ($P > 0.05$). However, the HFD + MTF group exhibited substantially lower monocyte counts than the ND and HFD groups ($P < 0.05$). The granulocyte counts showed an apparent elevation in the HFD group compared to the ND group ($P < 0.05$). However, the counts were significantly lower in the HFD + MTF group compared to the HFD group ($P < 0.01$) and the ND group ($P < 0.05$).

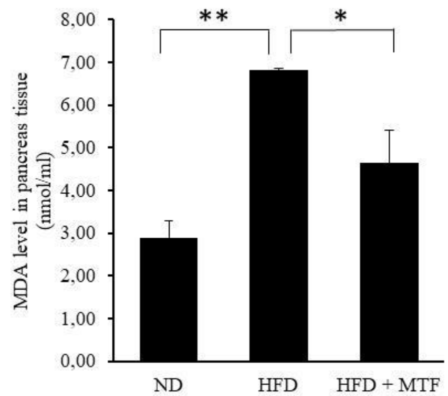

Fig. 5: Effect of Mentawai taro corm flour on MDA levels in pancreatic tissue of mice. **) and *) indicate significant difference statistically based on Bonferroni post hoc test ($P < 0.01$ and $P < 0.05$, respectively)

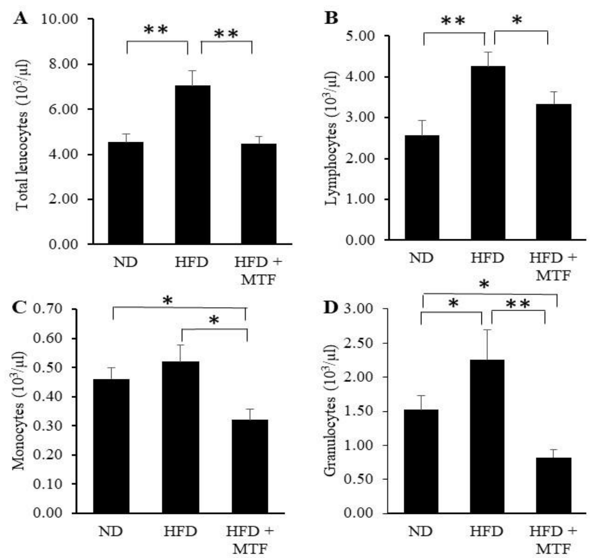

Fig. 6: Effect of Mentawai Taro corm flour on leucocyte profiles. (**A**) Total leucocyte number, (**B**) lymphocyte number, (**C**) monocytes number and (**D**) granulocyte number of mice. **) and *) indicate significant difference statistically based on Bonferroni post hoc test ($P < 0.01$ and $P < 0.05$, respectively)

Discussion

This study, examining the beneficial effect of MTF supplementation on the regulation of blood involving insulin in mice subjected to a HFD, has yielded noteworthy findings with potential implications for metabolic health in the context of unhealthy diets. The random blood glucose levels in mice on the HFD exhibited a significant elevation after 12 weeks, indicating impaired glucose regulation. In contrast, supplementation of MTF in the HFD prevented this increase, maintaining levels comparable to those fed with a standard diet. Moreover, the levels of fasting blood glucose in mice group fed with MTF were significantly lower than those in the HFD group, indicating a positive effect of MTF in managing hyperglycemia.

A HFD is capable of impairing insulin receptors in various metabolic tissues such as muscle, liver, and adipose tissue thereby promoting insulin resistance (Zhang *et al*. 2020). Previous reports also suggest that an HFD could cause disruption in glucose metabolism and insulin sensitivity (Emerald *et al*. 2022). The GTT and ITT are necessary to examine glucose metabolism and insulin sensitivity (Nagy and Einwallner 2018). In terms of glucose tolerance, our current study found that HFD-fed mice exhibited glucose intolerance, while mice in the HFD + MTF group exhibited enhanced glucose tolerance. In the context of insulin tolerance, mice on the HFD + MTF exhibited improved insulin sensitivity. Plasma insulin levels suggested hyperinsulinemia in HFD mice, while HFD + MTF group had decreased insulin levels, comparable to the ND group, indicating improved insulin regulation. In addition to insulin levels, HOMA-IR is a representative indicator for insulin sensitivity (Tahapary *et al*. 2022). The HOMA-IR values also indicated that chronic HFD intake (12 weeks) promoted the resistance of insulin, while the incorporation of MTF in the diet successfully counteracted insulin resistance. Taken together, our data consistently suggest that MTF has the capability to support blood glucose regulation against HFD by enhancing glucose metabolism and insulin sensitivity.

There are several possible mechanisms by which MTF enhances glucose metabolism and insulin sensitivity against the challenge of HFD. Firstly, MTF, as a combination of resistant starch and dietary fiber, may intervene in enzymatic lipid digestion in the gastrointestinal tract by inhibiting lipase activity and bile acid secretion, in line with a previous study (Wang *et al*. 2023). Another study also suggests that dietary fiber supplementation in the diet can substantially manage lipid absorption, counteracting its further impact on metabolism (Ghavami *et al*. 2023). In another way, MTF could also manage lipid and glucose metabolism in the body against HFD by modulating the short-chain fatty acids (SCFAs) production. SCFAs have been suggested to improve glucose and lipid metabolism, thereby preventing the development of metabolic diseases (He *et al*. 2020). Studies in rats revealed that whole flour and extracted starch from taro corm in the species of *Xanthosoma sagittifolium* exerted modulatory effects on gut microbial diversity and SCFAs production (Surono and Venema 2020; Surono *et al*. 2021).

A study in rats has demonstrated that excessive HFD intake could enhance oxidative stress in muscle tissue (Bielawiec *et al*. 2021), aligning with our present finding in pancreatic tissue of mice. The increase in oxidative stress in tissues due to HFD intake could result from excessive lipid oxidation and mitochondrial dysfunction (Tan and Norhaizan 2019). Therefore, the inhibition of oxidative stress in pancreatic tissue by MTF could be linked to the capability of MTF in regulating lipid metabolism, thereby diminishing lipid oxidation and mitochondrial dysfunction. A study by Lu *et al*. (2021) indicated the association between resistant starch (which might also be contained in MTF) and the reduction of oxidative stress.

The assessment of leucocyte profiles revealed that HFD mice exhibited leucocytosis, indicative of systemic inflammation. A study by Mayasami *et al*. (2015) also found that HFD intake significantly elevated total leucocyte counts, lymphocytes, and neutrophils (granulocytes) in mice. In contrast, HFD + MTF resulted in lower total leucocyte counts, comparable to those fed a normal diet. Furthermore, differential leucocyte counts showed that MTF incorporation in the diet led to lower lymphocyte and monocyte counts compared to HFD alone, indicating a potential anti-inflammatory effect. In line with this finding, a previous study showed that non-starch polysaccharides from taro corm could manage inflammatory response by suppressing the proinflammatory cytokine interleukin-8 (Anwar *et al*. 2022).

Conclusion

Supplementing the flour from Mentawai taro corm (MTF) in a HFD substantially improved blood glucose profiles in adult male mice characterized by lower blood glucose values, higher glucose and insulin tolerances, prevented hyperinsulinemia, and a decrease in the HOMA-IR value. Additionally, MTF effectively reduced the oxidative stress biomarker (MDA) in pancreatic tissue while regulating leucocyte profiles by significantly preventing an increase in total leucocyte count, lymphocyte, monocyte, and granulocyte counts caused by HFD. Hence, MTF supplementation substantially exerts beneficial effects on glucose homeostasis, insulin sensitivity, oxidative stress, and inflammation. These findings imply potential antidiabetic and anti-inflammatory properties of MTF, warranting further investigation, including human studies, to validate the results and elucidate the underlying mechanisms.

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Author Contributions

PS, SI and RR prepared the experimental design, PS, WA and SDH carried out the experiments, PS and RR conducted statistical analysis of data; PS and SY wrote the article.

Conflicts of Interest

No conflict of interest.

Data Availability

Data could be requested with a reasonable scientific purpose to corresponding author.

Ethics Approval

Committee of Research Ethics of Andalas University has approved the protocols of this research (432/unand-rec/2023).

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