Trop J Nat Prod Res, September 2025; 9(9): 4130 - 4136 ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

Tropical Journal of Natural Product Research

Available online at https://www.tjnpr.org

Original Research Article

Effects of Parboiled Immature Rice Starch (*Oryza sativa* L.) on Glucose and Lipid Metabolisms in High Fat Diet-induced Obese Mice

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ARTICLE INFO

Article history:
Received 04 April 2025
Revised 01 August 2025
Accepted 17 September 2025
Published online 01 October 2025

ABSTRACT

Metabolic disorders, driven by the overconsumption of simple carbohydrates in processed foods, pose significant global health challenges. Immature rice (*Oryza sativa* L.), rich in beneficial phytochemicals, has garnered considerable dietary interest, especially through parboiling. This widely utilized technique transforms the physicochemical properties of simple carbohydrate into resistant starch, which is hypothesized to enhance its health-promoting effects. Therefore, this research examined the effects of parboiled immature rice starch (PIRS) on glucose and lipid metabolisms in high fat (HF) diet-induced obese mice. Male MLAC: ICR mice were randomly divided into 3 groups of 5 animals each. The first group was fed with a basic diet (10% of energy from fat), the second group and the third group were each fed with a high-energy lard-based fat diet (45% of energy from fat) that was supplemented with conventional (rapid-release cornstarch) -HF or PIRS-HF diet for 90 days, respectively. The result revealed that PIRS had a mild effect on weight control and body fat deposit (P>0.05) while significantly elevated HDL-c level (P<0.05). PIRS significantly suppressed blood glucose and insulin levels, which thereby lowered HOMA-IR index as compared to the conventional-HF diet group (P<0.05). PIRS demonstrated a preventive effect against hepatic stenosis, as indicated by GGT levels and histological appearances of hepatocytes that were comparable to those of mice fed a basic diet. The result of this study suggested that PIRS may be a valuable alternative carbohydrate source for those who are attempting to control blood glucose level and reducing insulin resistance.

Keywords: Parboil, Immature Rice, Blood Glucose, Lipid, High Fat

Introduction

Rice (*Oryza sativa* L.) is the one of the staple cereal ingredients in Thai cuisine. It possesses a high volume of beneficial phytochemicals such as γ-oryzanol (OZ)[1], tocopherols, tocotrienols[2] and phenolic compounds[3]. Rice is also a valuable alternative carbohydrate source for people who are allergic to gluten found in other cereal crops, therefore processed rice flour is often substituted for other flour types in many dishes. Current rice consumption in Thailand and throughout Asia has proportionally increased alongside with the exponential increased consumption outside of the continent.[4] People all over the world procure and include rice as their carbohydrate source in their preferred diet plan. Meanwhile, improper consumption of rice could lead to adverse health consequences, such as metabolic diseases (MD). While the underlining mechanism of MD is still unclear, it is often associated with genetic factor, environmental factor, dietary factor, or dietary lifestyle.[5]

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Citation: Oonmetta-Aree J, Phanurak W, Tanamool V, Oonsivilai R, Singthong J, Sukwan C. Effects of parboiled immature rice starch (*Oryza sativa* L.) on glucose and lipid metabolisms in high fat diet-induced obese mice. Trop J Nat Prod Res. 2025; 9(9) 4130 – 4136 https://doi.org/10.26538/tjnpr/v9i9.8

Official Journal of Natural Product Research Group, Faculty of Pharmacy, University of Benin, Benin City, Nigeria

Contemporary Asian lifestyle favors convenient diet that often lacks proper nutrients or provide low quality carbohydrates, most of which has been reported to raise lipid level and become one of the major causes of MD.[6] Han and colleges[7] illuminated the association between habitual consumption of wheat flour or polished white rice with obesity. The glycemic index (GI) of rice is higher than any other starch ingredients,[8] and continuous consumption may predispose an individual to obesity and insulin resistance by interfering with peroxisome proliferator-activated receptor gamma and GLUT4 cascades.[9,10] In contrast, many researchers demonstrated rice extracts' benefit to offer anti-oxidative or anti-inflammatory effects[11] that may inhibit the formation of atherosclerotic plaque[12] and ameliorates the energy expenditure and glucose metabolisms.[13] Ghasemzadeh et al.[14] revealed pharmaceutical components that exhibit significant anti-proliferation effects on MCF-7 and MDA-MB-231 cell lines. Moreover, rice at various maturity levels contains different quality carbohydrates and other useful constituents.[15] Their study demonstrated nutritional differences of Korean immature rice grains that presented high level of vitamin B2, B3, and B6, as well as γ-tocochromanols when compared with matured rice grains. These findings suggested potential health benefits of immature rice.

In addition to the traditional benefits of the mentioned active ingredients, scientists working with food and nutrition technology are attempting to modify the physical property of rice grain or rice starch to explore the possibility of weight control or the risk-reduction of type 2 diabetes (type 2 DM). Parboiling is a pre-processing by hydrothermal process (steeping, heating, and drying) of rice grain by altering the physicochemical properties such as polymorphic form of starch while improving nutritional values. Starch is gelatinized by thermal treatment and retrograded by drying, which creates microstructure of the biopolymer modification and making digestion difficult.[16,17] Larsen et al.[18] demonstrated that traditional parboiled rice contains low GI value, and the consumption of parboiled rice significantly reduces blood sugar profile in type 2 DM over non-parboiled rice. Hamad et al.[19] suggested the process of parboiling rice starch could produce a resistance to help diabetic subjects lower their hyperglycemia levels in the late phase of glucose disposal.

Immature rice has recently gained popularity in Thai diets and has been tailored for several consumption methods. The increasing demand for immature rice suggests the ingenuity of Thai farmers to elevate the value of cultivating naturally developed immature grains into a valuable product. While the grain development process varied according to traditional methods or local practices of different regions throughout the country, the grains are commonly made from glutinous rice that contains high carbohydrate ratio, which is locally presumed to have no effect on the general health of the consumer. This research studies non-glutinous rice due to its lower fat and carbohydrate ratio, with higher protein than glutinous rice, therefore it is more suitable to be developed for consumers that are monitoring their health and diet.[20] The objective of this research is to investigate the effect of parboiled immature rice starch (PIRS) on lipid profile, glucose metabolism, and liver health in high fat (HF) diet-induced obesity mice. The result shall determine the nutritional benefit of the grain and offer an alternative natural source of carbohydrates made available for consumers.

Materials and Methods

Animals and experimental design

Chronic HF diet-induced obesity is recognized as an onset of metabolic disorders that include type 2 DM, cardiovascular diseases, and some forms of cancer,[21] and therefore, this is the model used in this research. Fifteen matured male mice (MLAC:ICR) from the National Laboratory Animal Center, Mahidol University, Thailand were enrolled. The mice were individually housed in polycarbonate cages maintained at 24±1 °C with a 12:12 h light: dark cycle and free access to food and water. All mice were acclimatized for 7 days and randomly designated into 3 groups of 5 mice each. These groups were basic diet, conventional-high fat (HF) diet, and modified-HF diet. The amount of fat in each diet was designed as described by Kalupahana et al.[22] with slight modification. The diet plans were meticulously customized according to the recommendation of the National Research Council.[23] Caloric intake within the diets was determined based on 4.50 kcal/g for basic diet and 6.25 kcal/g for HF diets. Throughout the 90-day experimental period, the mice of the first group were fed with a basic diet (10% of energy from fat), the second and third groups were each fed with a high-energy lard-based fat diet (45% of energy from fat) that was supplemented with rapid-release cornstarch (conventional-HF diet) or PIRS-HF diet, respectively. All experimental procedures were approved by the Experimental Animal Care and Use Committee of Suranaree University of Technology, Nakhon Ratchasima, Thailand (U1-02503-2559). All care and consideration involving animals were performed to standard to minimize pain and discomfort.

Plant materials and diets preparation

Parboiled immature rice starch (PIRS) was prepared from whole grain immature non-glutinous rice (Khao Hom Mali Thoungsamrit rice; GI 61100118), which is one of most popular rice in Thailand.[24] Rice samples were harvested at 80% of mature rice from Thoungsamrit, Pimai District, Nakhon Ratchasima, Thailand. The rice samples originated from the same batch and processed into pregelatinized starch (partially resistant starch) with slight modification suggested by Larsen et al.[18] Rice samples were gently soaked in hot water (70-75°C) for approximately 10 ± 5 min and dried in an oven until moisture content dropped below 13%. The dried soaked rice was then steamed with an atmospheric pressure for 25 ± 5 min and further dried at an ambient temperature. Rice samples were milled and supplemented as carbohydrate source in the modified-HF diets.

In vitro digestibility of animal diets

The aim of this part of the research was to analyze the digestibility of corn starch (basic diet and conventional-HF diet) and PIRS (modified-HF diet). Starch digestibility was analyzed according to the method of Serrano, Goni, and Saura-Calixto[25] with modifications. Grounded sample (50 mg) was mixed with 1 ml of pepsin, pH 1.5 (0.2 ml in 0.2 M HCl-KCl 300 mg/ml), incubated at 37ºC for 1 h, then centrifuged for 15 min at 3000 g. Residue was incubated at 37ºC for 6 h with 2 ml of porcine bile extract (in 17.5 mg/ml 0.1 M phosphate buffer), incubated with 1 ml of α-amylase (in 120 mg/ml Tris-maleate buffer, pH 6.9) at 37ºC for 16 h, centrifuged for 15 min at 3000g. Supernatant was analyzed for total and reducing sugar content and percent hydrolysis was calculated with the following formula:

$$\text{Hydrolysis (\%)} = [\frac{Total\ sugar\ (before\ digestion) - Reducing\ sugar\ (before\ digestion)}{Reducing\ sugar\ (After\ digestion) - Reducing\ sugar\ (before\ digestion)}]x100$$

Animal weight gain, liver, and white adipose tissue (WAT) determination

Mice were weighed weekly using an electronic balance, and their body weights were recorded. The percentage of average weight gain each week was calculated with the following formula:

$$\text{Average gain weight (\%)} = \left[\frac{\text{(body weight on a certain day (g)} - \text{body weight on initial day (g))}}{\text{body weight on initial day (g)}}\right]x100$$

At the end of the experiment, the mice were fasted overnight and euthanized by CO_2 asphyxia. Blood samples were drawn by cardiac puncture to obtain serum samples and kept at -80ºC for biochemistry analysis. Livers and white adipose tissue (WAT) fat pads that include peritoneal, mesenteric, inguinal, and epididymal adipose tissues were dissected, collected, and weighed.[26] Relative weight of the liver or WAT were calculated with the following formula:

$$\text{Relative liver or WAT weight (\%)} = \left[\frac{\text{liver weight or WAT (g)}}{\text{body weight (g)}}\right]x100$$

Blood biochemical analysis

After the mice was euthanized by CO_2 asphyxia, fasting blood glucose levels were immediately measured using glucose monitor (ACCU-CHECK Active Roche Basel, Switzerland). Serum insulin, total cholesterol (TC), triglyceride (TG), low-density lipoprotein cholesterol (LDL-c), very low-density lipoprotein cholesterol (VLDL-c), and high-density lipoprotein cholesterol (HDL-c) levels were determined by the colorimetric method as described previously.[27] The homeostasis model assessment for insulin resistance (HOMA-IR) index[32] was calculated using the following formula:

$$\text{HOMA} - \text{IR index} = \frac{\text{[fasting blood glucose (mmol/l) x fasting serum insulin (mU/ml)]}}{22.5}$$

Serum aspartate aminotransferase (AST), alkaline phosphatase (ALP) and gamma-glutamyl transferase (GGT) were performed to evaluate the hepatic damage induced by chronic HF diet consumed.

Liver histology analysis

Liver samples collected from the mice were rinsed with normal saline and immediately fixed in 10% buffered neutral formalin for 48 hours. Following fixation, the samples were sectioned into small pieces and processed using the paraffin embedding technique. 5μm thickness tissue sections were prepared and stained using standard hematoxylin and eosin (H&E) methods. Images of the stained sections were captured with a Leica Upright Microscope and imaging software (Leica Microsystems, Germany), and histopathological examinations were carried out.

Statistical analysis

All data are expressed as mean ± se. Statistical analyses were performed with SPSS version 26 (SPSS Institute, Chicago, IL, USA). Multiple comparisons between the diet groups were conducted by ANOVA and Turkey post hoc tests. The level of statistical significance was set at $P<0.05$.

 ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

Results and Discussion

In vitro digestibility of diets

One of the nutritional interventions proposed to counteract MD is dietary supplementation with resistant starches (RS). RS offers practical advantages to manage obesity-associated pathologies when compared to other fibers.[28] RS is unable to be digested and absorbed in the small intestines. The residue from this inability to digest is the remaining enzymes in the stomach and intestines, which will eventually become fiber moving to the colon.[29] The basic diet and conventional-HF diet group showed a significantly higher percentage of digestion than the PIRS-HF diet (Figure 1).

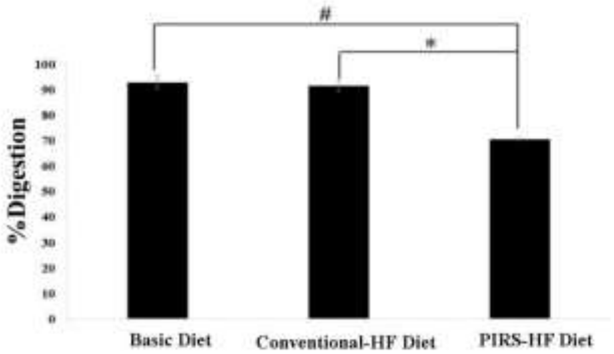


Figure 1: Percentage of digestion (% hydrolysis) of basic diet, conventional-HF diet, and PIRS-HF diet. Data expressed as mean ± sd. **and # means the statistical significance as compared to basic diet and conventional-HF diet group, respectively (P<0.05).*

This evidence implies that enzymes in the stomach and intestines were able to digest more cornstarch in both the basic diet group and the conventional-HF diet group than PIRS-HF diet group. The implication is parboiled process used to prepare the PIRS-HF diet enhanced the resistance of immature rice starch to digestion more than corn starch in either the basic diet or the conventional-HF diet group. This evidence suggested that the parboiling process could enhance the ability of immature rice starch's resistance, as indicated from the lowest percentage of hydrolysis in the PIRS-HF diet group. This might occur due to the pre-processing of immature rice, when rice granules were heated to the excess amount of water, starch in granules absorbed the water, resulting in expansion and gelatinization before drying for dehydration. This condition causes starch retrogradation and irreversibly modify the microstructure of the rice[30] and formed amylose crystallization.[31] The structure of the starch was rearranged, with several physiochemical changes because of annealing, such as increase gel strength. Further, unpolished rice maintains the membrane on the outside of the grain such as aleurone layer, pericarp, making digestive enzymes more difficult to penetrate the gel and starch granules. Immature rice holds a high protein content that can bind the granules and interfered the digestion of the starches.[32] When comparing the impact of the parboiling process on starch digestibility of cooked immature rice to polished rice and brown rice, the process of parboiling changed the crystallinity of starch granule, the thin surface of parboiled rice formed compact layers that act as physical barrier and reduce starch digestibility.[17]

Feed intake, weight gain, final body weight, WAT, and liver weight

Based on PIRS' digestibility and essential phytochemical compounds in rice, especially to OZ that have been well documented to ameliorate liver function,[33] improve lipid metabolism[34] and regulated glucose homeostasis,[35] we hypothesized that PIRS in modified-HF diet could prevent the complication of HF-induced pathologic related conditions. Therefore, we further investigated the effects of a HF diet supplemented with PIRS on various metabolic parameters in mice. The results demonstrated key differences between mice fed with conventional HF diet, a PIRS-supplemented HF diet, and a control (basic) diet. Long term consumption of HF diet can lead to obesity and the development of MD.[36] This study exhibited that both HF diet groups had an average daily feed intake that was slightly higher than that of the basic diet group, there was no significant difference in behavior between the groups. While there was no significant difference of feed intake between the groups, the maximum feed intake rate was observed in mice fed with basic diet, PIRS-HF diet, and conventional-HF diet, respectively (Table 1). The body weight gained gradually over the course of the experiment in all diet groups (Figure 2). Compared to those fed with conventional-HF diet, the mice fed with PIRS-HF diet had a significantly lower rate of weight gain but still maintained a higher rate than the basic diet group. The result of this study found that mice fed with conventional-HF diet has the highest weight gain rate, which they gained weight correlates with the rate of fat stored as %WAT, while the mice fed with PIRS-HF diet tends to gain weight and still maintain lesser fat than the conventional-HF diet group (P>0.05, Table 1). These results coincides with another researches that studied patients with type 2-DM and metabolic diseases consuming RS-enriched flour diet, indicating that RS has no significant effects on body weight, fat mass, or body fat depots.[37,38] The evidence obtained in this study suggests PIRS hold a slight protective effect on fat accumulation instigated from the amount of fat in the diet, by increasing energy expenditure or inhibiting the absorption of excess fat in the diet.[39] Previous studies supported that HF diets reduce the formation of butyrate and increase succinate, inflammation, liver fat, and cholesterol. This may be due to HF diets negatively altering the intestinal flora and impair gut health when compared with low-fat diet.[40] While this study found that RS does not impact body fat deposit, it revealed that RS has a significant impact on blood cholesterol profiles in metabolic disease individuals or in ob/ob-mice model.[41]

Table 1: Effect of PIRS-containing diet on average daily intake, final body weight, WAT, and liver weight.

Parameter	Basic Diet	Conventional-HF Diet	PIRS-HF Diet
Average daily intake (g/day)	4.78 ± 0.12^a	3.95 ± 0.14^a	4.12 ± 0.16^a
Final body weight (g)	43.02 ± 0.84^a	53.12 ± 3.32^b	47.97 ± 2.26^{ab}
WAT weight (%)	1.39 ± 0.32^a	1.66 ± 0.28^b	1.57 ± 0.03^b
Liver weight (%)	2.67 ± 0.24^a	3.63 ± 0.24^b	3.49 ± 0.07^b

All values present as mean ± se. Means with different superscripted letters in the same row indicate statistical significance (P<0.05).

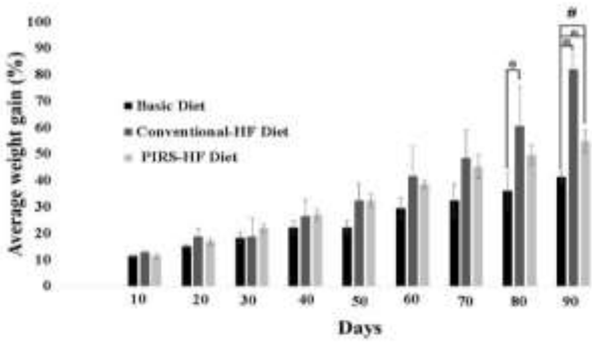


Figure 2: Effect of PIRS-containing diet on the percentage of average weight gain in mice. Data expressed as mean ± se. * or # means the statistical significance as compared to basic diet and conventional-HF group, respectively (P<0.05).

Blood biochemical parameters

Lipid indices

The serum lipid parameters obtained from the PIRS-HF group were less desirable than those from the basic diet group. Compared to the basic diet group, both HF diet groups had a significant rise in TC and TG levels. The LDL-c and VLDL-c levels were not affected in both HF groups compared to the basic diet group. Although, the highest level of HDL-c was observed in the basic diet group, the HDL-c level was also significantly higher in mice fed with PIRS-HF diet when compared to the conventional-HF diet fed mice (Table 2). However, the PIRS-HF diet demonstrated significant positive effects on the lipid indices, resulting in lower TC and TG levels. Additionally, the PIRS-HF group showed significantly higher HDL-c levels compared to the conventional-HF diet group. This finding agrees with a recent report by Choi et al.[42] in C57BL/6 mice that illustrated the consumption of HF diet supplemented with cooked rice for 12 weeks significantly lowered body weight gains and abdominal fat mass, lower serum TC, LDL-c, hepatic lipid content, and lipid droplet number and size. Their study suggested cooked rice may prevent fat accumulation instigated by high amount of fat in diet by regulating lipid metabolism-related gene expression through down-regulating the acyl-CoA:cholesterol acyltransferase 1 expression, and it also correlates with another research that studied patients with MD, which suggested RS consumption significantly improve the patients' blood cholesterol profiles.[38] Similarly, Dodevska et al.[43] showed that increasing RS intake in a diet of prediabetic overweight and obese adults significantly decreased their total serum cholesterol levels. Hence, these findings suggest the preparation of rice through various heating methods, whether it is parboiled, cooked, or processed into RS will yield comparatively positive effect on fat metabolism in animals consuming HF diet or patients with MD**.**

Blood glucose level and HOMA-IR index

Rodents that received chronic HF diet exhibited obesity, hyperglycemia and hyperinsulinemia,[44] which is a prominent model to study the mechanisms or treatment of impaired glucose tolerance and type 2 DM.[45] We expected the feeding of HF diet for 90 days could interrupt glucose metabolism and induce obesity. Therefore, we evaluated blood glucose, serum insulin levels, and the HOMA-IR index in all mice. The highest significant increase in blood glucose and insulin levels was observed in mice fed the conventional-HF diet compared to those fed the PIRS-HF diet and the basic diet group after 90 days (P < 0.05). Mice fed the basic diet had significantly lower HOMA-IR values than both HF diet groups. Similarly, the PIRS-HF diet exhibited a significantly reduced HOMA-IR value, approximately three times lower than that of the conventional-HF diet. This effect was observed in a comparative manner to the reductions in blood glucose and insulin levels (P < 0.05; Table 2).

Table 2: Effects of PIRS-containing diet on blood biochemical parameters.

Parameter	**Basic Diet**	**Conventional-HF Diet**	**PIRS-HF Diet**
Fasting blood glucose (mmol/L)	11.02 ± 0.81^{a}	24.93 ± 0.33^{c}	16.34±0.33^{b}
Insulin (µU/mL)	3.36 ±0.37^{a}	6.77 ±0.22^{c}	4.01 ± 0.39^{b}
HOMA-IR index	1.65 ± 0.23^{a}	7.51 ± 0.29^{c}	2.65 ± 0.67^{b}
Cholesterol (mg/dL)	150.00±3.29^{a}	194.20±2.80^{c}	173.40±6.11^{b}
Triglyceride (mg/dL)	111.60± 8.08^{a}	142.00±12.71^{b}	138.00±13.58^{b}
LDL-c (mg/dL)	33.44±1.02^{a}	36.63 ± 3.54^{a}	34.86 ± 4.19^{a}
VLDL-c (mg/dL)	22.32± 0.77^{a}	26.64± 2.64^{a}	27.60±1.21^{a}
HDL-c (mg/dL)	79.58±6.91^{a}	64.60±5.40^{b}	75.85±6.99^{a}
AST (mg/dL)	53.80 ± 1.96^{a}	66.60 ± 2.01^{b}	60.40 ± 1.79^{b}
ALP (mg/dL)	69.20 + 2.50^{a}	86.60 + 1.22^{b}	72.40 + 2.21^{b}
GGT (mg/dL)	35.50 + 2.40^{a}	77.75 + 1.55^{a}	48.00 ± 1.96^{a}

All values present as mean ± se. Means with different superscripted letters in the same row indicate statistical significance (P<0.05). AST= aspartate aminotransferase, ALP= Alkaline phosphatase, GGT= Gamma-glutamyl transferase

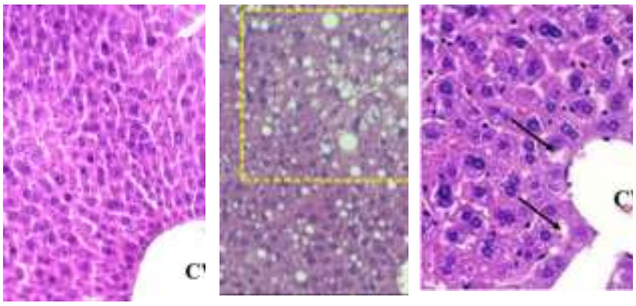
Our result corresponds to a previous study of HF-induced obesity, which improved glucose metabolism by a variety of rice as illustrated by Yoshizaki et al.[46], which demonstrated that 4 weeks of feeding steamed rice Kogi resulted in anti-obesity and anti-diabetes effect in HF-induced obese mice by a different mechanism depending on the type of rice consumed. They clarified that these rice products could reduce blood glucose and HOMA-IR value by increasing glucose uptake and GLUT4 protein expression in L6 myotube cells. Additionally, Yulianto et al.[47] advocated not only the parboiling process or the ability of RS to influence GI value, but also some bioactive or phytochemical compounds contained in rice products can as well. In this study, PIRS is considered to have more proteins and valuable micronutrients as compared to mature rice, while containing less carbohydrate content compared to raw rice,[48] and the parboiling process enhanced nutrients such as Fe and vitamins to transfer from the hull into the grain, increasing benefit by ameliorating glucose metabolism found in this study.[49]

Liver enzymes and histological characteristics

Diet containing adequate energy (10-30% originating from fat) is sufficient to promote normal physiology such as facilitating absorption of fat-soluble vitamins or carotenoids to promote normal growth and sexual maturation. Alternatively, diet exceeding this threshold may lead to excessive weight gain and development of MD such as atherosclerosis, insulin resistance, or type 2 DM. The liver is a crucial organ for the modulation of lipid and glucose metabolism, as well as in the maintenance of energy homeostasis. Excessive consumption of fat or caloric intake has been proposed as a causative factor in developing numerous hepatic damages such as modulated fat accumulation, induction of oxidative stress and mitochondrial damage.[50] These conditions may lead to the development of cirrhosis, stenosis, or cholestasis in both human[51] and animals.[52]

This study investigated certain hepatic enzymes that might reflect the pathological effects on hepatocytes by long term consumption of HF diet. The increased enzymes indicate the inflammatory process in the liver. Our study exhibited that both HF groups slightly increased ALP

and AST levels as compared to the basic diet group. Interestingly, the PIRS-HF diet group showed mild liver protection compared to the conventional-HF diet group, as indicated by a trend toward reduced enzyme levels. Additionally, mice fed with PIRS-HF diet had lower GGT levels compared to those on the conventional-HF diet, with comparative levels to those in the basic diet group (Table 2). Our result agrees with the hepatic enzyme patterns shown in previous studies in both healthy and metabolic altered animals. Panchal et al.[53] reported increased liver weight, fat deposition, inflammation, and fibrosis with increased plasma activity of liver enzymes in rats induced by HF or high cholesterol diets. Welch-White et al.[54] reported euthyroid and thyroid altered rats had increased ALP and AST values after fed with HF diet for 8 weeks. GGT, a hepatic enzyme, is strongly associated with liver and bile duct injuries when its levels exceed the normal range.[55] Misslbeck et al.[56] demonstrated that rats fed a diet with ethanol (35% of total calories) and high fat (35% of total calories) experienced a significant increase in GGT levels, along with enhanced lipid accumulation and depletion of hepatic glutathione. More recently, Echeverría et al.[57] reported that hepatic oxidative stress and stenosis can elevate various hepatic enzymes, including GGT.
In addition, the increase in liver weight, fat deposition, and inflammation can be induced by HF or high cholesterol diets.[54] Our study confirmed that consuming a high-fat (HF) diet led to the development of fatty liver, as evidenced by hepatocyte vacuolation, indicating fatty liver changes or steatosis (Fig. 3B; severe hydropic hepatopathy and lipid droplets within hepatocytes). Interestingly, a lower level of hepatic damage or fat deposition was observed in liver sections from the group fed with PIRS-HF diet (Fig. 3C; mild centrilobular hydropic hepatopathy). This finding suggests that the PIRS diet may help mitigate fatty liver development induced by HF consumption.



(A) Basic diet **(B) Conventional-HF Diet** **(C) PIRS-HF Diet**

Figure 3: Representative photomicrographs of liver histological characteristics in mice fed a basic diet (A), which shows normal architecture; a Conventional-HF diet (B), which displays severe hydropic hepatopathy with lipid droplets (yellow dashed rectangle area); and a PIRS-HF diet (C), which exhibits mild centrilobular hydropic hepatopathy (arrows). CV: central vein.

Conclusion

This study demonstrates that incorporating parboiled immature rice starch (PIRS) into a high-fat diet offers several metabolic benefits. While PIRS showed only mild effects on weight management and body fat reduction, it significantly improved glucose metabolism by lowering fasting blood glucose and insulin levels, thus reducing insulin resistance. Furthermore, PIRS enhanced HDL cholesterol levels and offered protection against aspects of high-fat diet-induced liver damage. These findings suggest that PIRS could be a valuable carbohydrate alternative for individuals at risk of metabolic disorders, offering potential benefits for blood glucose control, insulin resistance management, and liver health. Further research, particularly larger human trials, is needed to confirm these findings and elucidate the underlying mechanisms.

Conflict of Interest

The author`s declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

Acknowledgements

The authors appreciate Mr. I.I. Ogunlowo for his assistance during plant collection.

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