Square-Stepping HIIT Combined With *Phyllanthus amarus* Supplementation Alleviates Fasting Blood Glucose and Oxidative Stress in Overweight and Obese Individuals

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ABSTRACT

Background: High-intensity interval training (HIIT) exercise and antioxidant supplements are an alternative to lifestyle modification for reducing oxidative stress and preventing cardiovascular risk factors; however, there remains very limited evidence regarding the potential impacts of combination of square stepping HIIT with *Phyllanthus amarus* (PA) on blood biochemical levels in the overweight and obese individuals.

Objectives: This study aimed to investigate the effects of square-stepping HIIT combined with PA supplementation on changes in blood glucose and insulin activity, lipid profile, inflammation, and oxidative stress in overweight and obese individuals.

Methods: The number of 48 overweight and obese individuals was divided into 4 groups (n = 12/group) and total 40 participants were completed the 8-week program: 1) control group (n = 8), 2) PA group (n = 12); received PA at 150 mg/day, 5 days/wk, 3) square-stepping HIIT (n = 9); received square-stepping HIIT training for 15 min/day, 3 days/wk, 8 weeks and 4) HIIT+PA group (n = 11). Venous blood was collected for measurements of the glucose, total cholesterol, triglyceride, low-density lipoprotein, high-density lipoprotein concentrations, the serum proinflammatory cytokines interleukin (IL)–6 and anti-inflammatory cytokine IL-10. Also, plasma malondialdehyde (MDA) was determined by measuring thiobarbituric acid reactive substances.

Results: HIIT+PA has been a significant decrease in fasting blood glucose and oral glucose tolerance test at 120 min compared to baseline ($p = 0.01$). Both HIIT and HIIT+PA reduced oxidative stress by indicating a decrease in plasma MDA compared to baseline in overweight and obese individuals ($p = 0.032$ and $p = 0.009$, respectively); however, there were no significant differences between the four groups. The data on lipid profiles and inflammatory markers did not show any significant differences in all groups.

Conclusion: The square-stepping HIIT combined with PA supplementation improved insulin activity and reduced fasting blood glucose and oxidative stress in overweight and obese individuals.

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INTRODUCTION

Excess body-weight and obesity are recognized as modifiable risk factors of non-communicable diseases including cardiovascular disease (CVD), metabolic syndrome, and type 2 diabetes mellitus (DM). All of which are linked to common pathological factors like insulin resistance, increased oxidative stress, and inflammation (Eeg-Olofsson et al., 2009; Merino, 2021). Overweight and obesity are directly related to the development of type 2 DM due to the causation of insulin resistance – a condition in dampened response to insulin action of target tissues and manifesting as hyperglycemia and compensative hyperinsulinemia (Sasaki et al., 2020). It has been reported that plasma adeponectin, which regulates lipid and glucose metabolism is reduced (Gariballa et al., 2019), and inflammatory cytokines such as C-reactive protein (CRP), interleukin-6 (IL-6), and tumor-necrosis factor-alpha (TNF-α) are increased in overweight and obese individuals (Popko et al., 2010; Selvaraju et al., 2019).

Regular exercise is known as one of the effective approaches to reduce body weight and prevent CVD (Tian & Meng, 2019). High-intensity interval training (HIIT) is a exercise regimen that has been reported to provide health benefits to a similar extent to moderate-intensity continuous training (Dregney et al., 2023; Wewege et al., 2017). HIIT programs were more effective than moderate-intensity continuous training in reducing abdominal/visceral fat mass in overweight/obese postmenopausal women (Dupuit et al., 2020). Several model studies have reported HIIT improved glucose and lipid metabolism and body composition (Nazari et al., 2020; Zheng et al., 2020), cardiovascular and cardiac autonomic nervous system function (Dun et al., 2019), inflammation, and oxidative stress (Zwetsloot et al., 2014). Square-stepping exercise is one among the exercises that is easy to execute and uses a few apparatus. A recent systematic review has recommended square-stepping exercise to improve physical performance and prevent falls and injury related to falls in older adults with impaired balance (Fisseha et al., 2017). Also, the square-stepping exercise program has been reported to increase brain-derived neurotrophic factor levels in older adults (Cha et al., 2022).

Phyllanthus amarus (PA) is a herbal plant widely spread all over tropical and subtropical areas, including in Thailand. Its extract has been reported to comprise alkaloids, lignins, flavonoids, and polyphenol compounds (Roengrit et al., 2015) that exhibit several pharmacological effects including anti-diabetic (Al-Ishaq et al., 2019), antihyperlipidemic and antioxidant (Bencheikh et al., 2021), anti-inflammatory (Obidike et al., 2010), and anti-carcinogenic activities (Kiemer et al., 2003), and enhanced immune system function (Kalaiselvi et al., 2018). Acute supplementation with PA 200 mg before and after a moderate- or high-intensity exercise significantly reduced oxidative stress and muscle soreness in sedentary men (Roengrit et al., 2015).

High-intensity interval training (HIIT) exercise and antioxidant supplements are an alternative to lifestyle modification for reducing oxidative stress and preventing cardiovascular risk factors; however, there remains very limited evidence regarding the potential impacts of the combination of square stepping HIIT and PA on blood glucose and insulin activity, lipid profiles, inflammation, and oxidative stress in the overweight and obese individuals. Additionally, there was no established minimum effective dose for PA. Accordingly, this study aimed to examine the effects of square-stepping HIIT combined with PA supplementation on changes in blood glucose and insulin activity, lipid profile, inflammation, and oxidative stress in overweight and obese individuals. We hypothesized that these outcomes could be improved following square-stepping HIIT combined with PA supplementation. Findings from this study may be applied to health management programs and modified risk factors such as insulin resistance, inflammation, oxidative stress, and dyslipidemia in overweight and obese individuals.

METHODS

STUDY POPULATION

The number of participants was calculated according to a previous study by Bocalini and coworkers (Bocalini et al., 2017). They performed HIIT in hypertensive patients to evaluate changes in blood pressure. The sample size was calculated using a statistical formula by Bonferroni t test for means comparison. When setting alpha error at 0.05, beta error at 1.645, standard deviation at 3, and effect size at 3, the number of participants was 48 (8 participants × 4 groups: plus 4 in each group for in case of drop-out).

Forty-eighth participants were included after criteria selection. Study participants were either overweight or obese, with 7 being overweight and 41 being obese. All participants were recruited from Burapha University, the Bangsaen campus. A poster that explains the study was posted by the researcher at faculty buildings in Burapha University and shared via Line application. Participants who were interested in participating in the study contacted staff or a research assistant via telephone or Line application. Inclusion criteria consist of male or female ages 20 years, and body mass index (BMI) ≥ 23 kg/m^2 (BMI 23–24. kg/m^2 define as overweight, and ≥ 25 kg/m^2 define as obese) based on WHO Asian-BMI classification (Consultation, 2004; Jitnarin et al., 2011). Exclusion criteria consist of participants who have recently been hospitalized, have symptomatic cardiovascular diseases, respiratory infections, neuromuscular diseases, renal or hepatic disease, and have a medical history of food and drug allergies. In addition, people who had an inability to exercise and any medical contraindications were not included.

The study was conducted after approval by the Burapha University Human Ethics Committee (the approval number is HS 006/2564) and after completion of written informed consent from each participant.

INTERVENTION

The experiment was carried out between the years 2021–2022. The country is being locked down and physically distanced due to the COVID-19 pandemic, which has caused some participants to be unable to continue their training and lose follow-up, as shown in the CONSORT diagram in Figure 1.

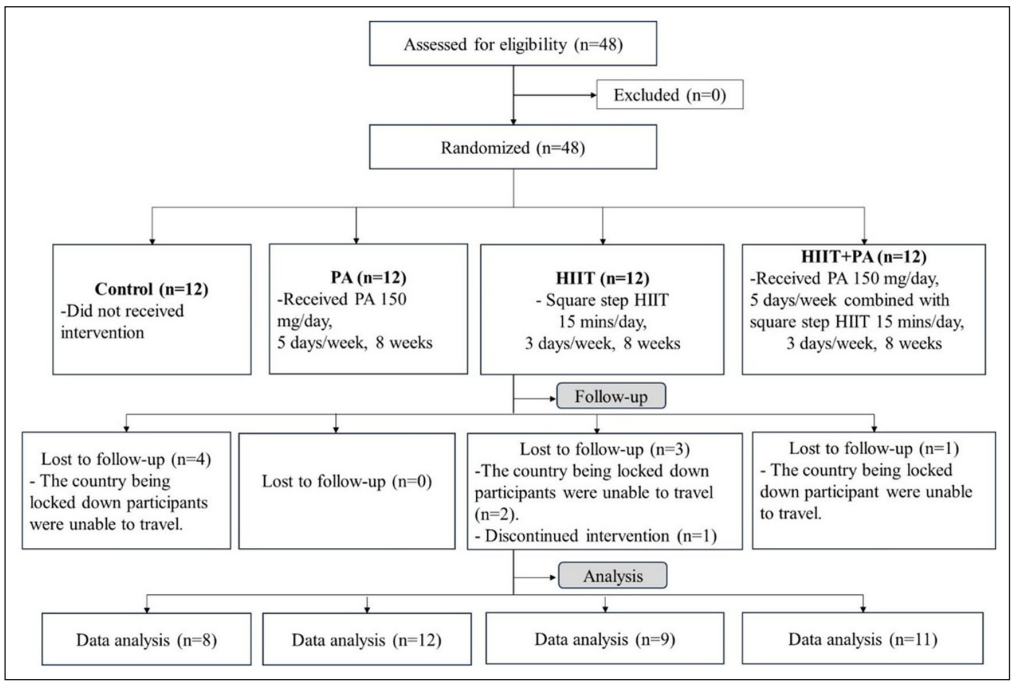


Figure 1 CONSORT Diagram.

This study was a randomized controlled trial. The participants were simply randomly assigned into 4 groups. Participant numbers were subsequently assigned, with the sample selected randomly. In this study, age and sex matching was not carried out. There was a control group, and the participants did not receive any intervention. In the PA group, participants received a PA capsule of 150 mg/day, 5 days/week, for 8 weeks. In a HIIT group, participants performed 10-cycle square stepping exercise sessions at high intensity (target heart rate 70% of age-predicted maximum heart rate) for 30 seconds, followed by square stepping exercise at low intensity (target heart rate 50% of age-predicted maximum heart rate) for 60 seconds, 15 minutes/day, 3 days/week, for 8 weeks. Square-stepping HIIT was performed in a 9-square box (150 × 150 cm) towards the anticlockwise (Figure 2A) alternating with clockwise direction (Figure 2B). The target heart rate was monitored during exercise using Polar (Figure 2C). In a HIIT and PA group (HIIT+PA group), participants performed 10-cycle square stepping exercise sessions at high intensity (target heart rate 70% of age-predicted maximum heart rate) for 30 seconds, followed by square stepping exercise at low intensity (target heart rate 50% of age-

predicted maximum heart rate) for 60 seconds, 15 minutes/day, 3 days/week, combined with supplement of PA capsule of 150 mg/day, 5 days/week, for 8 weeks. During the 8 weeks of the experiment, all participants maintained their usual habits and were not required to change their diet or routine activity.

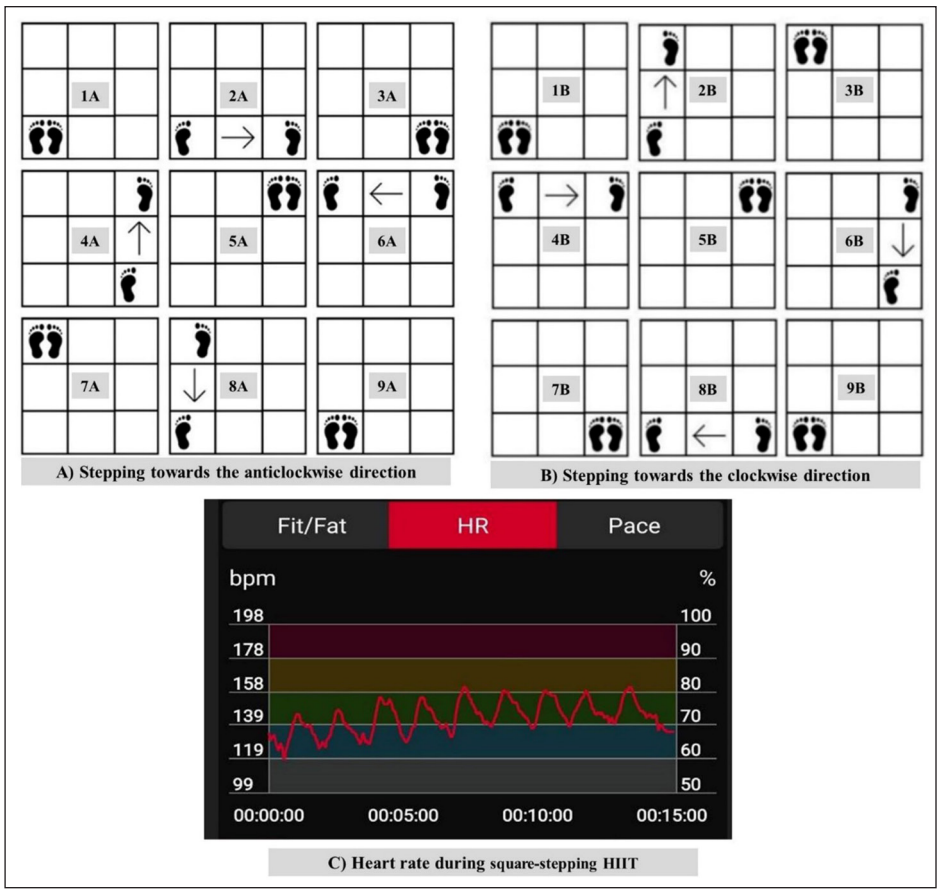


Figure 2 Square-stepping HIIT protocol. **A)** Stepping towards the anticlockwise direction, **B)** Stepping towards the clockwise direction **C)** Heart rate during square-stepping HIIT.

PHYLLANTHUS AMARUS CAPSULE

This study used PA capsules which were purchased from Khaolaor Laboratories CO. LTD., Thailand. Each capsule content of 150 mg dry weight is composed of stem, leaves, flowers, and fruit of the PA (Schumach & Thonn).

BLOOD PRESSURE AND HEART RATE MEASUREMENTS

The measurements of systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) were performed in a sitting position. Three consecutive measurements were averaged.

BODY COMPOSITION MEASUREMENT

The body composition including muscle mass, fat mass, percentage of body fat (% BF), and abdominal fat level was measured using a body composition analyzer based on the principle of bioelectrical impedance analysis (InBody 270, Oramed Co., Ltd, Seoul, Republic of Korea).

BLOOD BIOCHEMISTRY

Venous blood was collected for measurements of the glucose, total cholesterol, triglyceride, low-density lipoprotein (LDL), and high-density lipoprotein (HDL) concentrations. In addition, the kidney and liver function tests were assessed in both pre- and post-tests in all experiment groups. Liver inflammation biomarkers were evaluated by AST and ALT. The AST and ALT levels. OGTT was applied to observe insulin activity.

ORAL GLUCOSE TOLERANCE TEST

The day before the experiment, each participant was asked to starve for eight hours. Fasting blood glucose was measured on the measurement day (T0) followed by an oral glucose load of

75 g. Further blood samples were then taken at 90 min (T90) and 120 min (T120) to evaluate blood glucose levels, which indicated insulin resistance.

CYTOKINE MEASUREMENT

The serum proinflammatory cytokines interleukin (IL)–6 and anti-inflammatory cytokine IL-10 were measured by ELISA using a human cytokine IL-6 and IL-10 ELISA set (BD Biosciences, USA) as per the manufacturer's instructions. The absorbance was measured using a microtiter plate reader (Molecular devices, USA) at a wavelength of 450 nm.

MALONDIALDEHYDE MEASUREMENT

Plasma malondialdehyde (MDA) was determined by measuring thiobarbituric acid reactive substances, as previously mentioned (Nakmareong et al., 2012). To summarize, blood was collected in an EDTA tube and centrifuged at 3,500 rpm for 10 minutes at 4°C. The mixture of 150 µL plasma samples was made up of 10% TCA, 5 mM EDTA, 8% SDS, and 0.5 g/ml of BHT. The mixture was incubated for 10 minutes at room temperature with 500 µL of 0.6% TBA added. The mixture was then boiled for 30 minutes. After the mixture cooled to room temperature, it was centrifuged at 10,000 rpm for 5 minutes. A spectrophotometer was used to measure the absorbance of the supernatant at 532 nm. A standard curve was generated with appropriate concentrations of 1,1,3,3-Tetraethoxypropane (0.310 µM).

STATISTICAL ANALYSIS

All data are presented as means ± standard deviation. Normal distribution of data was applied according to the Shapiro-Wilk test. One-way analysis of variance (ANOVA) was used to compare differences among various groups and Bonferroni's post-hoc test was used to determine the variances between groups. The differences before and after among groups were determined using a paired *t*-test. The statistical significance of a p value < 0.05 was considered.

RESULTS

The demographic data of all subjects was shown in Table 1. The number of obese subjects and baseline exercise duration and body composition did not differ between groups. SBP, DBP, and HR fell within normal ranges in all groups (Table 1).

Table 2 shows biochemical data between the pre-test and post-experiment. Participants in the HIIT+PA group had significantly decreased FBG compared to the pre-test. Notably, posttest FBG

PARAMETERS	CONTROL (n = 8)	PA (n = 12)	HIIT (n = 9)	HIIT+PA (n = 11)
FEMALE (%)	87.50	66.67	77.78	63.64
Age (years)	25.50 ± 5.40	22.80 ± 2.99	21.20 ± 0.67*	21.00 ± 0.77*
BMI (kg/m^2)	31.20 ± 4.63	33.00 ± 7.06	29 ± 5.26	27.80 ± 3.52
Body composition				
Muscle mass (kg)	23.38 ± 3.83	30.77 ± 9.98	23.51 ± 4.27	26.66 ± 5.05
Fat mass (kg)	35.0 ± 7.05	35.08 ± 14.17	33.28 ± 11.55	27.54 ± 6.22
%PBF	44.71 ± 4.89	39.55 ± 9.48	42.88 ± 6.18	36.38 ± 7.23
Abdominal fat (kg)	19.75 ± 2.71	23.58 ± 3.56	19.87 ± 3.17	21.9 ± 3.37
Obese subject (%)	87.50	100.00	77.80	72.70
Blood pressure				
SP (mmHg)	114.0 ± 16.20	125.25 ± 14.65	112.70 ± 9.78	117.94 ± 9.00
DP (mmHg)	89.38 ± 39.57	76.75 ± 10.69	80.56 ± 8.10	72.39 ± 6.66
HR (beats/min)	89.50 ± 12.53	76.83 ± 12.48	86.15 ± 8.67	77.24 ± 9.99
Exercise times (mins/week)	33.33 ± 46.10	70.71 ± 101.00	54.00 ± 92.52	76.82 ± 67.24
Exercise subject (N)	4	6	5	5

Table 1 Baseline demographic data of all participants.

Data were expressed as mean ± SD, Control group (n = 8), PA; Phyllanthus amarus group (n = 12), HIIT; High intensity interval training group (n = 9), HIIT+PA; High intensity interval training + Phyllanthus amarus group (n = 11), BMI; Body mass index, %PBF; Percentage of body fat, SP; Systolic blood pressure, DP; Diastolic blood pressure, and HR; Heart rate, *P < 0.05 pre versus control group.

in the PA group was significantly higher than in the pre-test. No changes were observed in both control and HIIT groups.

Total cholesterol, triglycerides, LDL, and HDL showed no changes in pre- and posttest in all experiment groups.

SERUM BIOCHEMISTRY LEVELS	CONTROL (n = 8)		PA (n = 12)		HIIT (n = 9)		HIIT+PA (n = 11)	
	PRE-TEST	POST TEST	PRE-TEST	POST TEST	PRE-TEST	POST TEST	PRE-TEST	POST TEST
FBG (mg/dL)	94.6 ± 10.3	98.1 ± 10.1	99 ± 7.5	103 ± 8.4*	96.9 ± 8.1	93.2 ± 7.3	100.5 ± 11.9	90.9 ± 5.5*
Cholesterol (mg/dL)	197.1 ± 3.6	194.4 ± 40.1	205 ± 56.9	214.4 ± 67.0	187.3 ± 27.1	182.3 ± 2 8.3	191.6 ± 29.2	182.2 ± 28.1
Triglyceride (mg/dL)	84.5 ± 34.4	101.1 ± 27.1	118.7 ± 3.9	143.7 ± 66.1	100.8 ± 45.9	107.8 ± 40.1	118.5 ± 107.9	95.4 ± 72.9
HDL (mg/dL)	50.6 ± 7.3	48.8 ± 6.8	50.2 ± 7.4	49.3 ± 5.7	47.7 ± 11.2	50 ± 9.5	54.6 ± 9.6	52.6 ± 7.8
LDL (mg/dL)	119.3 ± 13.2	116.1 ± 13.4	117.9 ± 16.9	117 ± 12.6	117 ± 13.5	115.1 ± 12.7	118.5 ± 10.9	113.6 ± 13.8
Creatinine (mg/dL)	0.8 ± 0.1	0.7 ± 0.1*	0.9 ± 0.2	0.8 ± 0.1*	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.2	0.7 ± 0.2
AST (U/L)	24.3 ± 11.8	17.3 ± 8.9	27 ± 15.1	21.5 ± 8.6	19.9 ± 10.5	19.2 ± 5.1	18.4 ± 6.2	17.8 ± 8.9
ALT (U/L)	16.8 ± 11.4	15 ± 7.8	31.6 ± 25.7	35.5 ± 23.4	11.8 ± 4.3	17.8 ± .2	14 ± 10.3	19.8 ± 17.3

Table 2 The effect of square stepping HIIT combines with Phyllanthus amarus capsule supplement on biochemistry level.

Data were expressed as mean ± SD, Control group (n = 8), PA; Phyllanthus amarus group (n = 12), HIIT; High intensity interval training group (n = 9), HIIT+PA; High intensity interval training + Phyllanthus amarus group (n = 11), FBG; Fasting blood glucose, HDL; High density lipoprotein, LDL; Low density lipoprotein, AST; aspartate transferase, and ALT; alanine aminotransferase, *P < 0.05 pre versus control group.

The control and PA groups had a decrease in creatinine levels in posttest compared to the pre-test.

Liver inflammation biomarkers did not change from pre-test to post-test in all groups, suggested that supplements with PA did not cause liver damage in overweight and obese individuals.

Results showed that at 90 min (T90) after glucose intake, blood glucose increased significantly. At 120 min (T120), blood glucose was lower than T90. Moreover, the percent changes of blood glucose were significantly lower in HIIT+PA group compared to PA group (p = 0.01, 0.008, and 0.024 for T0, T90, and T120, respectively) as shown in Figure 3.

There were no changes in plasma concentrations of IL-6 and IL-10 during the posttest in all groups (Figure 4). In addition, the post-test plasma MDA was significantly reduced compared to the pre-test in the HIIT (p = 0.032) and HIIT+PA groups (p = 0.009). This suggests that HIIT and the combination of HIIT with PA may reduce oxidation in participants with overweight and obesity.

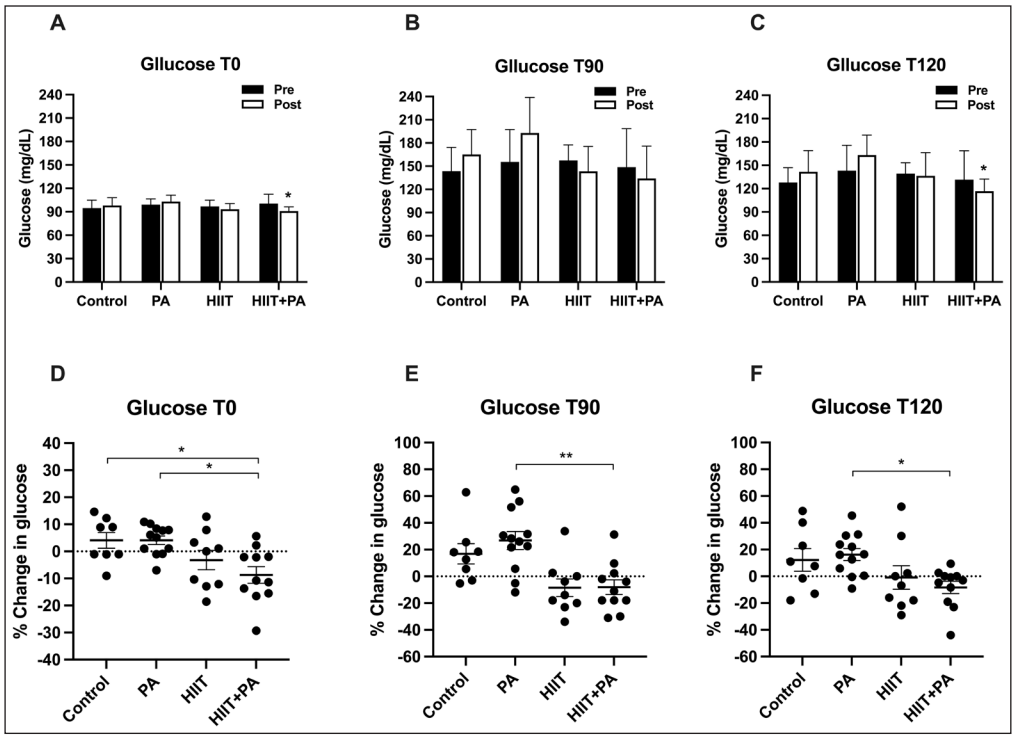


Figure 3 Effect of square stepping HIIT combines with Phyllanthus amarus capsule supplement on blood glucose and %changes in glucose after oral glucose tolerance test (OGTT) at **(A, D)** T0 min, **(B, E)** T90 mins, and **(C, F)** T120 mins in overweight and obese subjects. Data were expressed as mean ± SD, Control group (n = 8), PA; Phyllanthus amarus group (n = 12), HIIT; High intensity interval training group (n = 9), and HIIT+PA; High intensity interval training + Phyllanthus amarus group (n = 11).

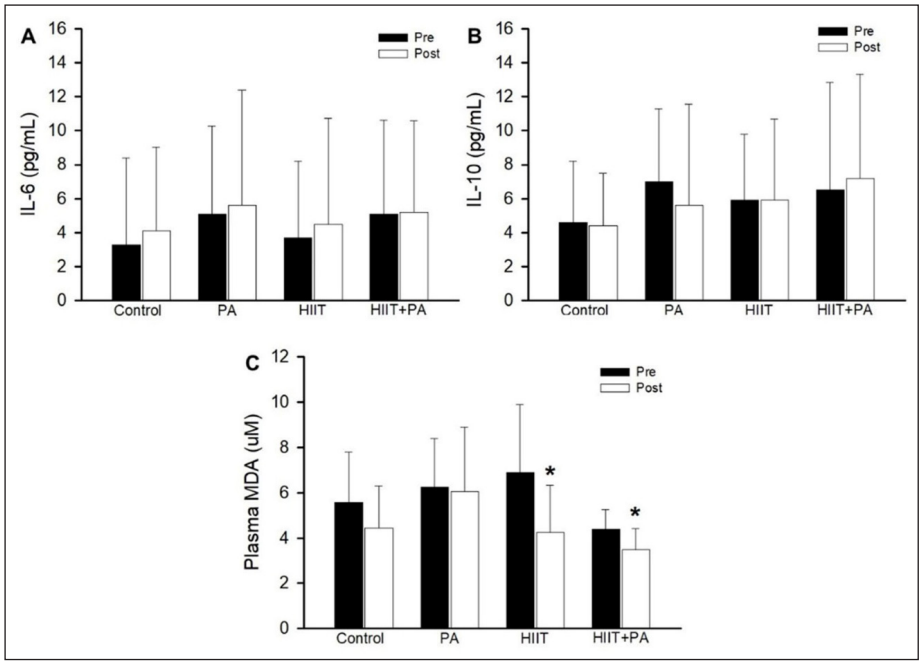


Figure 4 Effect of square stepping HIIT combines with Phyllanthus amarus capsule supplement on **A)** plasma interleukin-6 (IL-6), **B)** interleukin-10 (IL-10), and **C)** malondialdehyde (MDA) in overweight and obese subjects. Data were expressed as mean ± SD, Control group (n = 8), PA; Phyllanthus amarus group (n = 12), HIIT; High intensity interval training group (n = 9), HIIT+PA; High intensity interval training + Phyllanthus amarus group (n = 11), *P < 0.05 pre versus posttest.

DISCUSSION

The present study evaluated the effect of square-stepping HIIT combined with PA supplementation on changes in blood glucose and insulin activity, lipid profiles, inflammation, and oxidative stress in overweight and obese individuals. This study found that square-stepping HIIT combined with PA supplementation decreased fasting blood glucose and improved insulin activity, and decreased plasma MDA. Also, PA supplement alone increased creatinine clearance.

Our data revealed that square-stepping HIIT combined with PA supplementation resulted in a significant decrease in fasting blood glucose and blood glucose after oral glucose administration in overweight and obese individuals. These suggest square-stepping HIIT combined with PA supplementation improved insulin activity in overweight and obese participant may enhance insulin-stimulated glucose disposal and affect changes in glycogen stores and glycogen synthase activity (Keshel & Coker, 2015; Samjoo et al., 2013). PA supplement has the potential to enhance insulin sensitivity due to an antidiabetic effect (Patel et al., 2011).

Our findings revealed that plasma MDA decreased significantly after supplementation with PA and square-stepping HIIT in overweight and obese individuals. In consistency with previous studies, there has been reported potential of aerobic exercise in reducing levels of oxidative stress and inflammation cytokine biomarkers in obesity-related liver diseases (Oh et al., 2013). In contrast, HIIT did not alter IL-6, IL-10, or oxidative stress in type 1 diabetes patients (Farinha et al., 2018). Although the amount of PA supplement is very low, its potential to reduce oxidative stress may be due to the antioxidant effect of PA (Bose Mazumdar Ghosh et al., 2022; Patel et al., 2011).

Obesity increases inflammation response which in turn generates oxidative stress (Popko et al., 2010; Selvaraju et al., 2019). IL-6, an inflammatory cytokine, is produced by white adipose tissue known as adipokines. IL-10 is an anti-inflammatory. Decreasing IL-10 is associated with insulin resistance (Acosta et al., 2019). A previous study reported that increased IL-10 in patients with lymphoproliferative disorder caused elevated triglycerides, low LDL-C and HDL-C deficiency, thus IL-10 is a potent modulator of lipoprotein levels (Moraitis et al., 2015). Another previous study observed that HIIT programs were effective in reducing abdominal/visceral fat mass in overweight and obese postmenopausal women (Dupuit et al., 2020). Moreover, several model studies have reported that HIIT improved glucose and lipid metabolism, body composition (Nazari et al., 2020; Zheng et al., 2020), and inflammation and oxidative stress (Zwetsloot et al., 2014). Accordingly, an appropriate program design incorporating frequency, volume, and intensity, may produce different effects on lipid profile and inflammatory makers in overweight and obese individuals. This study incorporated square-stepping HIIT for just 15 minutes/day, 3 times a week. Therefore, this program may not produce the optimum amount of frequency and

volume necessary to obtain positive data in accordance with body weight, waist circumference, visceral adipose tissue area, lipid profile, and inflammatory markers (Al-Sharif et al., 2020).

Supplement with PA reduced serum creatinine in overweight and obese individuals. This suggests that PA might improve kidney filtration. In rats fed a high-salt diet, PA has been reported to decrease serum uric acid and creatinine levels (Olorunnisola et al., 2021). Although PA has been found to have several pharmacological effects, including a nephroprotective effect (Obianime & Uche, 2008; Patel et al., 2011), the major active compound to improve kidney function is unclear. Exercise has the potential to raise creatinine levels since creatinine is a waste product from creatine breakdown produced during exercise. However, we found no difference in creatinine levels within the group of square-stepping HIIT combined with PA supplementation.

Drugs are typically administered using one of the following three methods: fixed dosing, weight-based dosing, or body surface area-based dosing. Dosage based on body weight or body-surface area leads to an increase in drug pharmacokinetic parameters in proportion to body size. In contrast, dosing drugs on a fixed basis assumes that drug pharmacokinetic parameters do not increase with body-size (Morrish et al., 2011). A previous study reported that a fixed dose of administered without adjustment for participants' weight, could have contributed to blood drug concentration, drug distribution, elimination, and effectiveness of the intervention (Pai, 2012). Oral bioavailability seems generally unaffected in obesity, or may only increase in morbid obesity (BMI > 40 kg/m^2), however the ultimate impact of pharmacokinetic changes on how to adapt the dose may not always be known (Smit et al., 2018).

Although the dose of PA was set at 150 mg per day and was not adjusted for participants' weight, this dosage renders minimal effectiveness as indicated by decreasing FBG in PA+HIIT groups. In addition, the PA dosage was based on recommendations for the product in Thailand (Khaolaor Laboratories Co. Ltd) to prevent potential adverse effects from longer duration of PA supplementation or a higher dose of PA on the participants. The administration with a fixed dose of PA 200 mg significantly increased creatinine clearance (Roengrit et al., 2015). Some studies have shown that fixed doses of herbal supplements significantly decreased body weight, waist-to-hip ratio, and insulin resistance index in overweight and obese subjects (Maharlouei et al., 2019). Furthermore, a fixed dose of cinnamon, nigella, basil, and turmeric significantly decreased body weight and BMI (Deekshith et al., 2021).

The main finding of this study suggests that combined PA supplementation and square-stepping HIIT may offer multiple benefits including reduced fasting blood glucose levels, enhanced insulin function, and lower plasma MDA levels. These effects could be particularly beneficial for individuals with conditions such as chronic conditions, including metabolic syndrome, type 2 diabetes, and cardiovascular diseases, which are characterized by insulin resistance, elevated blood glucose and oxidative stress.

There are some limitations in this study. There was a small number of subjects and their unequal distribution in each group. Despite the random assignment of all participants, the control group had a higher age range than the other groups. Although this study did not investigate the composition of PA powder, the manufacturer has provided an initial composition report. Further experiments are necessary to identify the chemical constituents and their mechanisms of action. The PA supplement capsule was administered daily at 150 mg to each participant. The dose received by each participant is different due to their body weight. Therefore, it is necessary to conduct further studies by calculating the dose of PA to be identical for all participants.

CONCLUSION

The eight weeks of square-stepping HIIT combined with PA supplementation improved insulin activity and reduced fasting blood glucose and oxidative stress in overweight and obese individuals.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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