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Original Article

The consumption of riceberry rice combined with exercise enhances the production of circulating glucagon-like peptide-1 and inhibits creatine kinase compared to that with white rice

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Abstract:
The effects of the consumption of rice-berry rice compared with white rice on circulating total glucagon-like peptide-1 (GLP-1), glucose, and creatine kinase related to appetite perception and muscle pain score are not well understood. *Purpose:* The present study aimed to investigate the effects of pre-exercise consumption of rice-berry rice compared with white rice on postprandial total glucagon-like peptide-1, glucose, creatine kinase, muscle pain scores, and appetite perception. *Material and methods:* Twelve males performed cycling exercise for one hour at 80% maximum heart rate, followed by either consumption of rice-berry rice or white rice, in a randomized crossover design. It took venous blood samples at baseline, 30, 60, 90, 150, and 180 minutes. Total glucagon-like peptide-1, glucose, creatine kinase, appetite perception, and muscle pain scores were measured. We analyzed the data using a two-factor repeated-measures ANOVA and a paired t-test. *Results*: The consumption of white rice and rice-berry rice enhanced the production of total glucagon-like peptide-1 immediately post-exercise. However, a longer production of postprandial total glucagon-like peptide-1 concentration was found in the rice-berry rice condition at 30 minutes following the exercise. We observed a higher postprandial glucose concentration in the white rice condition immediately after exercise. The perception of fullness was elevated during and 30 minutes following exercise in both rice conditions, with fullness perception increasing immediately following exercise in the rice-berry rice condition. The perception of hunger perception was suppressed immediately following exercise in the rice-berry rice condition. Creatine kinase concentration increased significantly immediately following exercise in the white rice condition; it tended to increase in the rice-berry rice condition. Muscle pain scores increased during, immediately following, and 30 minutes following exercise in the two conditions. *Conclusions:* Ingestion of rice-berry rice before exercise enhanced the production of total glucagon-like peptide-1 for longer than in white rice conditions. Hunger scores were suppressed while the perception of fullness was elevated in the rice-berry rice condition. Creatine kinase and muscle pain scores in rice-berry rice condition were lower than in the white rice condition.
Key Words: -GLP-1, Glucose, Cycling exercise, Appetite perception, Muscle pain scores

Introduction

There are many different varieties of rice, such as white rice, brown rice, and rice-berry rice. It is a staple food in numerous countries. It has been demonstrated that circulating postprandial glucose concentration increased following the consumption of white or brown rice (Elliott et al., 1993; Ito et al., 2005; Kameyama et al., 2014). In comparison with brown rice, the consumption of white rice enhanced the production of postprandial glucose concentration (Ito et al., 2005; Sakuma et al., 2009). Consumption of brown rice has been associated with decreased body mass, insulin resistance, and lipid profiles (Shimabukuro et al., 2014). Rice-berry rice, a combination of Hom Nin rice and Thai Hom Mali rice (Kongkachuichai et al., 2013), is a type of purple and black brown rice, respectively. However, less is known about the effect of the pre-exercise ingestion of rice-berry rice compared with white rice on circulating appetite hormones and inflammatory markers related to appetite perception and muscle pain score.

Energy intake is influenced by several appetite hormones. It has been demonstrated that consuming white rice decreases circulating ghrelin concentration (Erdmann, Hebeisen, Lippl, Wagenpfeil, & Schusdziarra, 2007). Circulating glucose-dependent insulinotropic polypeptide (GIP), glucagon-like peptide-1 (GLP-1), and insulin concentrations elevate after consuming brown rice (Elliott et al., 1993). Alternatively, the administration of rice-berry rice supplements has been demonstrated to decrease the amount of food consumption in animals (Prangthip et al., 2013). This is likely due to the greater fiber and protein content in rice-berry rice (Settapramote, Laokuldilok, Boonyawan, & Utama-ang, 2018) influencing the perception of appetite (Schroeder, Gallaher, Arndt, & Marquart, 2009). Consequently, the secretion of appetite hormones in response to ingesting rice-berry rice may be different from consuming white rice.

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It has been demonstrated that circulating glucagon-like peptide-1 and peptide YY (PYY) concentrations were elevated, ghrelin concentration and the perception of hunger were suppressed following exercise (King et al., 2017; Martins, Morgan, Bloom, & Robertson, 2007). Consumption of white rice or brown rice stimulates the production of postprandial glucagon-like peptide-1 concentration (Akilen et al., 2016; Elliott et al., 1993; Kameyama et al., 2014). In comparison to white rice, the consumption of barley and brown rice increases the perception of fullness (Golloso-Gubat et al., 2016; Sakuma et al., 2009). Therefore, consuming rice-berry rice before exercise might have an additive effect on preventing obesity as a consequence of elevating the production of postprandial glucagon-like peptide-1 concentration to further suppress the perception of hunger.

Circulating creatine kinase concentration was increased following exercise (Mathes et al., 2017; Silalertdetkul, 2016). It has been revealed that exercise induces muscle soreness (Eddens et al., 2017). Interestingly, rice-berry rice possesses antioxidant properties (Kongkachuichai et al., 2013), and contains vitamin E, beta-carotene, omega-3, and polyphenol, in higher quantities than brown rice (Leardkamolkarn et al., 2011). Indeed, the vitamin E and polyphenol contained in rice-berry rice have been shown to reduce circulating inflammatory markers (Phillips, Childs, Dreon, Phinney, & Leeuwenburgh, 2003; Shukitt-Hale et al., 2008). There is also evidence that consuming carbohydrates during exercise reduces the appearance of inflammatory markers (Mizuno, Kojima, & Goto, 2016). Therefore, rice-berry rice, with its high carbohydrate content and antioxidant properties (Leardkamolkarn et al., 2011; Phillips et al., 2003; Prangthip et al., 2013), may be a suitable food to consume before intense exercise; potentially limiting associated muscle damage.

However, while rice-berry rice contributes to the reduction of inflammatory markers, appetite, and antioxidants in animals, its effects on humans are less well understood and warrant further investigation. Consequently, this study aimed to investigate the effects of pre-exercise consumption of rice-berry rice compared with white rice on circulating total glucagon-like peptide-1, glucose, and creatine kinase concentrations, related to perceived appetite and muscle pain score. We hypothesized that rice-berry rice would stimulate the production of appetite hormones and suppress inflammatory markers compared with white rice.

Material & methods

This research conformed to the Declaration of Helsinki and was approved by the Institutional Ethics Committee. To assess eligibility, participants completed a health history and Physical Activity Readiness Questionnaire (PAR-Q). All participants were non-smokers, not currently taking any prescribed medication, and had a current body mass that had not changed by > 5 kg over the last 3 months. After written informed consent was obtained, all participants were familiarized with the study procedures.

Preliminary tests

Body mass index (BMI), body composition, maximal oxygen consumption, resting heart rate (Omron, Japan), and blood pressure (Omron, Japan) were measured at least seven days before experimental trials. BMI was calculated using the ratio between body mass (Tanita, Japan) and height (Wildcat Mettler Toledo, United States) in square meters. Body composition including total body fat, total fat mass, and fat free-mass, were measured using dual-energy x-ray absorptiometry (Hologic Inc, United States).

Maximal oxygen consumption ($\dot{V}O_{2max}$) was measured using an incremental cycling test (Lode, Netherlands) while simultaneous breath-by-breath measurements were collected (COSMED; Quark PFT Ergo, Italy). The cycling protocol commenced at 50 W and was increased by 25 W every minute (maintaining a cadence of 70 rpm) until volitional fatigue was reached. The participants' $\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) was recorded as the highest 30-s average recorded before volitional exhaustion. Heart rate (Polar, Finland), and ratings of perceived exertion (Borg, 1982) were recorded at the end of each stage.

Research design

After preliminary testing, the participants attended the laboratory on two separate occasions to complete either rice-berry rice or white rice experimental trial. The conditions were conducted in a randomized counterbalanced order, at least one week apart, and at the same time of day after an overnight fast. Upon arrival at the laboratory, the participants were asked to consume 200 grams (Kameyama et al., 2014; Kazemzadeh, Safavi, Nematollahi, & Nourieh, 2014) of either cooked rice-berry rice or white rice (Milled rice) after a baseline venous blood sample. The participants then completed a 60 minutes cycling ergometer protocol, consisting of a 5-minute warm-up (70 W) and 55 minutes of cycling at 80% maximum heart rate. Oxygen consumption and heart rate were continuously measured to estimate energy expenditure during exercise. Participants were asked to complete a visual analog scale (VAS) of their appetite perception (Flint, Raben, Blundell, & Astrup, 2000) pre-, during, and post-exercise at selected time points.

Blood sampling

Venous blood samples were taken from a forearm vein and collected (10 ml) into serum clot activator vacuette tubes (Greiner bio-one, Austria), plasma vacuette tubes (anti-coagulant ethylenediaminetetra acetate, EDTA, Greiner bio-one, Austria), and sodium fluoride vacuette tubes (with EDTA K3, Greiner bio-one, Austria). The vacuette tubes were spun at 5,000 rpm at 5°C for ten minutes (NF400R, Austria). The venous blood plasma samples were stored at -40°C for further analysis. The blood samples were taken at baseline (0 minutes), 30, 90, 150, and 180 minutes, respectively.

Blood biochemistry

Plasma total GLP-1 (Millipore, United States) concentrations were measured using the enzyme-linked immunosorbent assay (ELISA) according to the manufacturer's instructions. The minimum detection was 2.5 pg/mL. Glucose and creatine kinase concentrations were measured using the enzymatic colorimetric method (Cobas 6,000 analyzer series, Switzerland).

Appetite perception

The participant's perception of appetite (Flint et al., 2000) was assessed using a VAS of subjective feelings of hunger (not hungry at all to as hungry as I ever have) and fullness (not full at all to very full). Participants indicated their perception of appetite by marking a vertical line across a 100 mm horizontal line at baseline and every 30 minutes during both trials. We calculated the VAS scores using the distance from the beginning and end of the line and converted them to a percentage value.

Muscle Pain score

The participants were asked to score their perceived muscle pain at baseline and every 30 minutes during both trials. The perceived muscle pain in the legs muscle was measured using a 100 mm VAS, which was labeled 0 (no pain) to 10 at either end (highest pain imaginable) (Nunes et al., 2016).

Statistical analysis

All data were analyzed using statistical software (SPSS Statistics for Windows, Version 22, Armonk, NY: IBM Corp). The number of participants was based on a previous study (Martins et al., 2007). A two-factor [Condition (rice-berry rice and white rice) and Time (baseline, 30, 60, 90, 150, and 180 min)] repeated-measures ANOVA was used to analyze differences between the rice-berry rice and white rice conditions. Where a significant interaction between condition and time was observed, *post hoc* comparisons were performed using a Bonferroni correction. Paired sample *t*-tests were used to compare the differences between the two trials for the areas under the curve. The relationship between parameters was tested using the Pearson product-moment test. The statistical significance was accepted at the 5% level ($P < 0.05$). Data are presented as mean ± SD.

Results

Participants

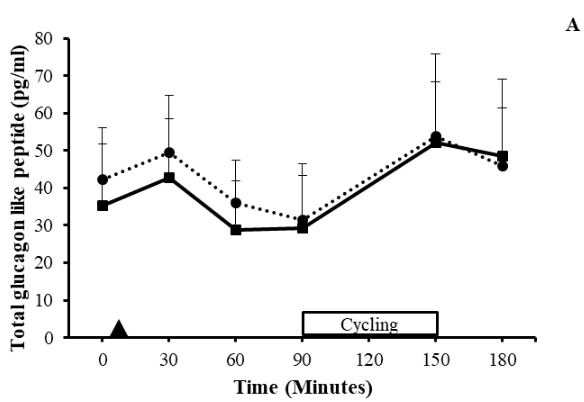
Twelve healthy men participated in this study (Age, 20 ± 1 years; body mass, 68 ± 10 kg; body mass index, 23 ± 3; total percent body fat, 18 ± 8 %; total fat-free mass, 54 ± 6 kg; systolic blood pressure, 115 ± 12 mmHg; maximum oxygen consumption, 49 ± 5 $mL \cdot kg^{-1} \cdot min^{-1}$)

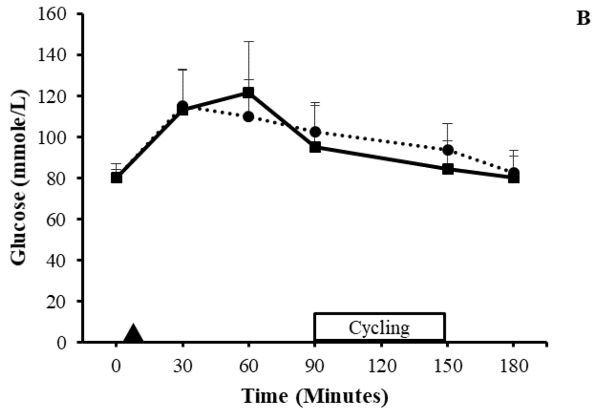
Total glucagon-like peptide-1 (GLP-1)

In comparison with the baseline, total GLP-1 concentrations were significantly increased immediately (rice-berry rice, $P = 0.002$; white rice, $P = 0.001$) and 30 minutes (rice-berry rice, $P = 0.001$) following exercise (Figure 1). Total GLP-1 concentrations were higher after rice-berry rice consumption compared with white rice at 30 minutes (P = 0.016) and 60 minutes ($P = 0.008$). Postprandial total GLP-1 concentrations increased at 30 minutes ($P < 0.011$), and subsequently decreased at 60 minutes ($P < 0.02$) and 90 minutes ($P < 0.01$) following the consumption of both types of rice, respectively (time effect, $P < 0.001$).

Glucose

Glucose concentrations were lower after rice-berry rice consumption at 60 minutes ($P = 0.07$) and 150 minutes ($P = 0.07$) compared with white rice (Figure 1). Postprandial glucose concentrations were elevated at 30 minutes ($P < 0.001$), 60 minutes ($P < 0.002$), and 90 minutes ($P < 0.006$) following consumption of both types of rice (time effect, $P < 0.001$). Postprandial glucose concentration was increased immediately following exercise in the white rice trial ($P = 0.004$).





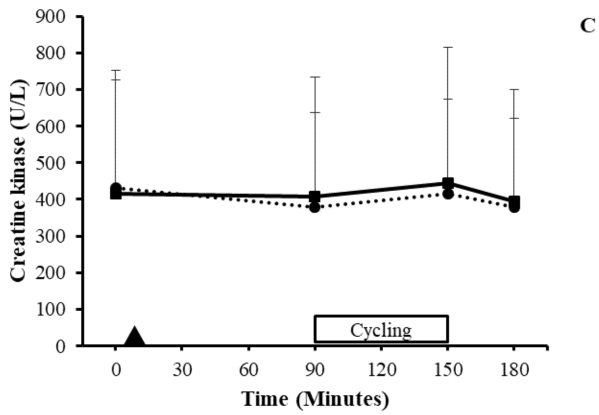
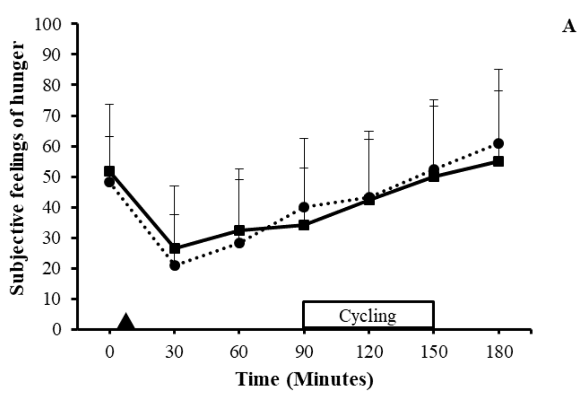
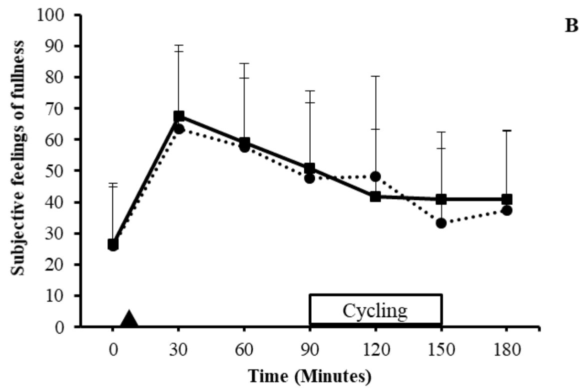


Figure 1. Total glucagon-like peptide-1 (A), glucose (B), and creatine kinase concentrations (C) for white rice (●) and rice-berry rice (■) consumption at baseline (0), 30, 60, 90, 120, 150, and 180 minutes. Values are mean ± SD (n = 12).

Creatine kinase

Creatine kinase concentrations were similar between conditions at baseline and before exercise (Figure 1). Post hoc analysis indicated that circulating creatine kinase concentration was increased immediately after exercise (time effect, P = 0.026) in the white rice trial (P = 0.001), while it tended to increase in the rice-berry rice trial (P = 0.06).





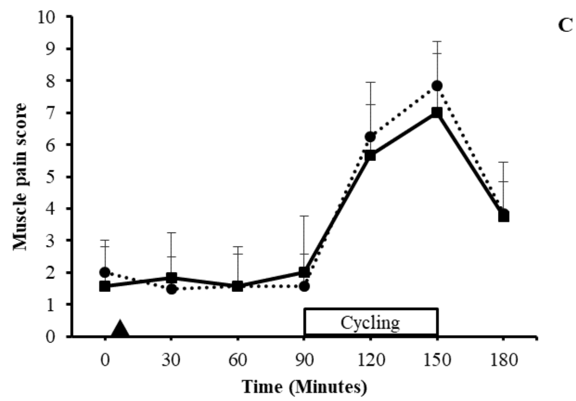


Figure 2. Subjective feelings of hunger (A), subjective feelings of fullness (B), and muscle pain scores (C) for white rice (●) and rice-berry rice (■) consumption at baseline (0), 30, 60, 90, 120, 150, and 180 minutes. Values are mean ± SD (n = 12).

Appetite perception

Perception of hunger was lower at 30 minutes ($P < 0.001$) and 60 minutes ($P < 0.01$) compared with the baseline in both conditions, respectively (time effect, $P < 0.007$). In the rice-berry rice condition, perception of appetite decreased at 90 minutes ($P = 0.01$) and suppressed at 120 minutes ($P = 0.06$) compared with the baseline (Figure 2).

Before exercise, the perception of fullness increased at 30, 60, and 90 minutes in both conditions ($P < 0.008$). In the rice-berry rice trial, an increased sensation of fullness was perceived during ($P = 0.002$), immediately ($P = 0.04$), and 30 minutes ($P = 0.04$) after exercise. Similarly, fullness was perceived to be greater during exercise ($P = 0.001$) and 30 minutes ($P = 0.008$) post-exercise in the white rice trial.

Muscle pain score

While muscle pain scores were similar between conditions at baseline and before exercise ($P > 0.05$), scores generally increased during, immediately post, and 30 minutes following exercise ($P < 0.01$) after rice consumption (time effect, $P < 0.01$). The muscle pain score is presented in Figure 2.

Ratings of perceived exertion

A significant increase in ratings of perceived exertion was observed during exercise, immediately after exercise (time effect, $P < 0.01$), and 30 minutes after exercise in the white rice condition ($P < 0.05$). The consumption of rice-berry rice induced a significant increase in ratings of perceived exertion during and immediately after exercise ($P < 0.05$).

Discussion

The main findings of this study indicated that the consumption of rice-berry rice before exercise enhanced the production of total glucagon-like peptide-1 concentrations longer than white rice. Postprandial total glucagon-like peptide-1 concentration was observed to increase within 30 minutes after consuming both types of rice, before subsequently decreasing after 60 minutes. These results are consistent with the previous finding that postprandial glucagon-like peptide-1 levels elevated after eating white rice or brown rice (Akilen et al., 2016; Elliott et al., 1993; Kameyama et al., 2014). Glucagon-like peptide-1 is secreted by the K and L cells in the intestinal wall (Kieffer & Habener, 1999) and is stimulated by the rice protein hydrolysates (Ishikawa et al., 2015). Previously, exercise *per se* induces an elevation in fasting total glucagon-like peptide-1 and postprandial glucagon-like peptide-1 concentrations (Hallworth, Copeland, Doan, & Hazell, 2017; Martins et al., 2007;

McIver, Mattin, Evans, & Yau, 2019). High-intensity cycling exercise (Martins et al., 2007) resulted in greater production of circulating total glucagon-like peptide-1 concentration compared with low-intensity exercise like walking (McIver et al., 2019). The secretion of glucagon-like peptide-1 is associated with the composition of food intake (Shah et al., 2017). A high protein-carbohydrate diet (Martins et al., 2007) consumed before exercise encourages a higher production of postprandial glucagon-like peptide-1 concentration compared with a low protein-carbohydrate diet (McIver et al., 2019). Therefore, the higher carbohydrate and fiber content in rice-berry rice might lead to the prolonged production of total glucagon-like peptide-1 levels and higher post-exercise levels compared to white rice. The independent effects of the exercise protocol on total glucagon-like peptide-1 concentration could not be assessed due to the absence of a controlled trial. This represents a study limitation, which should be addressed in future research.

The administration of glucagon-like peptide-1 has been shown to increase the perception of fullness (Flint, Raben, Astrup, & Holst, 1998) and suppress hunger (Naslund et al., 1999). Increasing glucagon-like peptide-1 levels after exercise may lead to an increased feeling of satiety and thus have a potential impact on post-exercise energy intake. In the present study, consumption of both types of rice increased satiety during and after cycling, although it was increased immediately after exercise only in the rice-berry rice condition. The perception of fullness is higher after consuming barley and brown rice compared with white rice (Golloso-Gubat et al., 2016; Sakuma et al., 2009). This is likely explained by the greater fiber content contained in brown rice (Ito et al., 2005), with a high-fiber diet observed to conserve an individual's perception of fullness (Holt, Delargy, Lawton, & Blundell, 1999). The perception of hunger was decreased following the ingestion of both types of rice. Increased hunger sensations have been demonstrated after the consumption of white rice compared with brown rice (Golloso-Gubat et al., 2016) or barley (Sakuma et al., 2009). However, it is unclear whether suppressed the perception of hunger during exercise was related to the rice-berry rice *per se* or the exercise since hunger scores can be suppressed by aerobic exercise (Broom et al., 2017; King et al., 2017; Martins et al., 2007). Exercise in a fasted (Broom et al., 2017; King et al., 2017) or fed state (Martins et al., 2007) has been shown to inhibit the perception of hunger. This suppression in hunger is likely associated with a decrease in circulating ghrelin (Akilen et al., 2016; Sakuma et al., 2009), the hunger hormone (Blom et al., 2005). However, this is difficult to ascertain with any certainty since ghrelin was not measured in the present study. Thus, it is recommended that changes in ghrelin be evaluated in future research.

The level of glucose concentration was observed to increase following the consumption of either rice-berry rice or white rice. These data are consistent with previous findings that consuming white rice or brown rice results in increased circulating postprandial glucose concentrations within 30 minutes of ingestion (Elliott et al., 1993; Ito et al., 2005; Kameyama et al., 2014). In comparison to white rice, the consumption of rice-berry rice before exercise inhibited the production of glucose. It has been shown that the consumption of white rice induces a higher postprandial glucose concentration compared with brown rice (Ito et al., 2005; Sakuma et al., 2009). Postprandial glucose concentrations decreased 30 minutes after the completion of the cycling protocol in both rice conditions. Previously, white rice consumed before exercise leads to the suppression of postprandial glucose concentration (Kasuya et al., 2015). Ingestion of chocolate drinks does not appear to lead to marked differences in glucose concentration between rest and exercise (Martins et al., 2007).

Creatine kinase concentration and muscle pain scores tended to be inhibited by the consumption of rice-berry rice before exercise. Creatine kinase is stimulated by cycling exercise (Mathes et al., 2017) and concurrent exercise (Eddens et al., 2017). In comparison with before exercise, a higher creatine kinase level was found after white rice consumption compared with rice-berry rice immediately after exercise. The post-exercise reduction in creatine kinase may be related to the vitamin E and beta-carotene antioxidant properties contained in the rice-berry rice. Carbohydrate ingestion has little effect on creatine kinase concentration (Mizuno et al., 2016). However, creatine kinase concentration may be reduced to a greater extent after consuming protein and carbohydrates compared with carbohydrates alone (Gentle, Love, Howe, & Black, 2014). Therefore, future research may investigate the influence of combining rice-berry rice with protein to reduce the production of creatine kinase after high-intensity exercise. Muscle pain scores were assessed in an attempt to provide a link between muscle damage and exercise. Muscle pain scores increased following exercise, however, there was no difference between the two conditions. Our data are consistent with previous observations that have shown muscle soreness to be elevated following concurrent exercise (Eddens et al., 2017). Previous studies suggest that there is no difference in muscle pain scores between the consumption of carbohydrates and carbohydrates combined with protein (Naclerio, Larumbe-Zabala, Cooper, Jimenez, & Goss-Sampson, 2014).

Conclusions

Our findings showed that consumption of rice-berry rice or white rice before exercise stimulated the production of postprandial total glucagon-like peptide-1 concentration, and postprandial total glucagon-like peptide-1 concentration was elevated longer in the rice-berry rice condition. Circulating glucose concentrations and hunger scores were suppressed immediately following exercise in the rice-berry rice condition. Moreover, ensuing exercise, creatine kinase concentration and muscle pain scores tended to be lower immediately after exercise in rice-berry rice condition. To prevent obesity, rice-berry rice may be a suitable food to consume before exercise to enhance the production of appetite hormones as total glucagon-like peptide-1 concentration and increase the perception of fullness while suppressing the production of glucose concentration and the perception of hunger. Additionally, the consumption of rice-berry rice before exercise potentially limits muscle damage by decreasing the circulating creatine kinase concentration and muscle pain scores.

Conflict of interest The author declares that there is no conflict of interest.

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