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Review

Effects of rice on submaximal exercise endurance capacity

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Summary – The effects of rice (compared to bread and aspartame) on submaximal exercise performance were investigated. A first study included ten healthy subjects who performed three sessions in random order. After a 150 minute low intensity cycling session in fasting conditions to slightly reduce blood glucose, they were fed either aspartame (40 mg) given in water, rice (65 g raw rice, ie, 50 g carbohydrate) or bread (100 g, ie, 50 g carbohydrate). Subjects then exercised at 85% of their theoretical maximal heart rate (ie, 75% VO_{2max}) until exhaustion. A second study included six healthy volunteers who performed three sessions in random order with either aspartame, rice or bread under the same protocol without a previous fatiguing exercise session. The chemical composition of bread compared to rice revealed mainly significant ($P < 0.05$) higher protein and amylose contents. In the first study, the subjects performed greater work after rice (91.20 ± 7.2 kJ) than either aspartame (29.86 ± 4.28 kJ, $P < 0.01$) or bread (54.99 ± 5.36 kJ, $P < 0.01$), because the duration of exercise until exhaustion was longer after rice (19.20 ± 1.28 vs 8.4 ± 0.97 or 11 ± 1.03 min respectively, $P < 0.01$). In the second study, subjects performed greater work ($P < 0.01$) after rice (83.77 ± 11.90 kJ) than after either aspartame (49.98 ± 10.62 kJ) or bread (49.98 ± 10.62 kJ). Exercise duration was longer after rice (16 ± 1.52 vs 9.16 ± 1.87 or 11 ± 1.88 min, respectively, $P < 0.01$). In both studies, blood lactate was lower after rice than either aspartame or bread. This study shows that rice is more effective than bread in improving the duration of submaximal exercise until exhaustion.

rice / exercise / work load / blood glucose / blood lactate

Résumé – Effets du riz sur l'endurance à l'exercice submaximal. *Nous avons étudié les effets du riz (comparé au pain et à l'aspartame) sur l'adaptation de l'organisme à un exercice submaximal. Une première étude portait sur dix sujets sains réalisant trois séances de pédalage en ordre randomisé. Après 150 minutes de pédalage à jeun, à faible puissance, pour réduire les réserves disponibles de glucides, les sujets ont reçu de l'aspartame (40 mg) dans un verre d'eau, du riz (poids sec avant cuisson : 65 g soit 50 g de glucides) ou du pain (100 g, soit 50 g de glucides). Les sujets réalisaient ensuite un exercice sur cycle ergomètre à 85 % de leur fréquence cardiaque maximale théorique (équivalent approximativement à 75 % de leur* VO_{2max}*) jusqu'à épuisement.*

Une première étude a porté sur six sujets sains réalisant trois séances de pédalage en ordre randomisé et recevant de l'aspartame, du riz ou du pain selon le même protocole mais sans période préalable de déplétion glycogénique. L'analyse chimique du pain montrait en comparaison avec le riz un contenu supérieur en protéines (P < 0,05). Au cours de la première étude les sujets ont réalisé un travail supérieur après prise de riz (91.20 ± 7,2 kJ) que d'aspartame (29,86 ± 4,28 kJ, P < 0,01) ou de pain (54,99 ± 5,36 kJ, P < 0,01), car la durée d'exercice jusqu'à épuisement était supérieure après prise de riz (19,20 ± 1,28 contre 8,4 ± 0,97 ou 11 ± 1,03 min respectivement, P < 0,01). Au cours de la seconde étude les sujets ont également réalisé un travail plus important (P < 0,01) après riz (83,77 ± 11,90 kJ) qu'après aspartame (49,98 ± 10,62 kJ) ou pain (49,98 ± 10,62 kJ), la durée de l'exercice ayant été plus importante après riz (16 ± 52 contre respectivement 9,16 ± 1,87 ou 11 ± 1,88 min ; P < 0,01). Au cours des deux études la lactatémie à l'exercice était moins élevée après riz qu'après aspartame ou pain. Ces travaux montrent que le riz est plus efficace que le pain pour prolonger la durée d'un exercice submaximal jusqu'à épuisement.

riz / exercice / charge de travail / glycémie / lactate

Impaired glucose availability in muscle cells is an important mechanism of fatigue during prolonged exercise [4, 9, 46]. Blood glucose seems to be a marker of this substrate availability [9, 10]. An oral supplement of carbohydrates maintains blood glucose levels during exercise and delays muscle fatigue [4, 9, 26, 30–32, 35, 46]. On the whole, carbohydrate feeding prior to exercise improves exercise performance [25].

Two aspects of this question remain unclear. First, the effects of a carbohydrate meal ingested less than 60 minutes before exercise are controversial, since some reports show that it may reduce performance [18], while others indicate a beneficial effects [19, 43]. On the other hand, the effects of some complex carbohydrate meals ingested before exercise remain poorly known. Most studies used glucose as a rapidly accessible source of exogenous carbohydrates [4, 9, 10, 30–32, 35] while more complex carbohydrates such as pasta are characterized by a less 'rapid' availability and are thus better used before and after exercise than during [22, 23]. Little is known about rice as a source of glucids for exercise, while this carbohydrate meal is both highly digestible (high glycemic index) and moderately insulinogenic in resting subjects [11, 12, 20, 39, 40]. Rice appears to be an intermediate between glucose (high glycemic index and high insulinogenic index) and complex carbohydrates characterized by a low glycemic and insulinogenic index [39, 40]. It has been shown to maintain a more stable plasma glucose level during a 2 hour cycling exercise at 60% VO_{2max} despite a lower increase in insulin compared to potatoes, bread and pasta [23]. However, we are not aware of studies showing the influence of rice on exercise performance. Since rice has both a high glycemic index and a low insulinogenic index, it could be expected to provide rapidly available carbohydrates without the hypoglycemic risk of hyperinsulinemia, ie, it may have advantages of both glucose and pasta. Therefore, this study was undertaken to determine whether rice, compared to bread and aspartame as a placebo, improves exercise performance and delays fatigue.

MATERIALS AND METHODS

Subjects

First study

Ten healthy volunteers (nine males and one female; age: 27.7 ± 1.6 years; weight: 66.7 ± 2.1 kg; height: 1.74 ± 0.02 m; body mass index 22.02 ± 0.71 kg/m^2; VO_{2max} calculated from a previous submaximal test according to Astrand's nomogram 47.4 ± 2.6 mL (min^{-1} ± kg^{-1}) were included in the study after informed consent. All of them participated in a recreational sports activity only. Each subject performed three sessions in random order with either aspartame, rice or bread.

Second study

Another group of six healthy volunteers (four males and two females; age: 25.7 ± 1.4 years; weight: 66.2 ± 3.3 kg; height: 1.74 ± 0.09 m; body mass index 22.01 ± 0.8 kg/m^2; VO_{2max} calculated from a previous submaximal test according to Astrand's nomogram 46.7 ± 4.6 mL (min^{-1} kg^{-1}) was included in the second study after informed consent. None of the subjects were involved in a regular sports activity other than at leisure time. Each subject performed three sessions in random order with either aspartame, rice or bread.

Protocol

The experimental procedures were in accordance with the Helsinki declaration of 1975.

First study

Subjects were asked to remain in a fasting state overnight for > 12 hours until 0900, when they started the exercise protocol. A catheter was placed in an antecubital vein for repeated blood sampling. They performed two exercise sessions, with the first being a long-duration, low-intensity cycling session to slightly reduce muscular glycogen. Subjects exercised for 150 minutes at 65% of the theoretical maximal heart rate (TMHR) predicted for their age [17]. According to the regression equations, between %TMHR and %VO_{2max} during cycling [34] approximates 48% VO_{2max}. At the 150th minute the exercise was stopped, and subjects immediately received the meal: aspartame 40 mg in 200 mL water vs bread 100 g (ie, 50 g carbohydrate) vs rice (weighing 64 g when uncooked, which corresponds to 50 g carbohydrate), in random order. The duration of the meal did not exceed 15 minutes.

The second exercise session started 20 minutes after the end of the first. Subjects were asked to exercise at 85% (ie, 75% VO_{2max}) of their TMHR until exhaustion. Exhaustion was reached when subjects, despite encouragement to continue, could no longer cycle at 85% of their TMHR. Blood samples were drawn at -20, 0, 5, 10, 15 and 20 minutes for plasma glucose, insulin and lactate. The work load (kJ) was calculated from the area under the curve (AUC) of power output plotted against time with 1 J = 1 W x 1 s. The rating of perceived exertion according to Borg [1] was also checked by the subjects on a category-ratio scale. Subjects were not allowed to drink beverages other than the water contained in the experimental meal.

Second study

The exercise protocol was the same as for the first study except that subjects did not perform the previous low-intensity, long-duration cycling session.

Measurements

Chemical analysis of rice and bread

These analyses were performed before the study on samples representative of the meals used for the experiments. Raw rice, lyophilized rice and bread were ground to pass through a 0.5 mm sieve. Ground samples (5 g) were used to determine dry matter (residue weighed after heating at 130 °C for 2 hours), ash content (residue weighed after calcination at 900 °C for 2 hours) and chemical analysis. Cooked samples were used to determine dry matter (residue weighed after heating at 100 °C for 24 hours and ground and heated at 130 °C for 2 hours). The nutrient content of raw and cooked rice, and that of flour and white bread were measured separately. Nitrogen content was determined by a semi-automatic method [15] on 1 g of the ground samples (rice protein = N x 5.95; white bread protein = N x 6.1); the lipid content was determined from hydrolyzed extract (3 hours acid hydrolysis) weighed after extraction in ethyl ether for 3 hours and evaporation of the solvent; the carbohydrate content was deduced from lipid, protein and ash contents; starch content was measured using an enzymatic method with thermostable alpha amylase (thermamyl 60L, NOVO) as adapted by Mestres et al [36]. Amylose content was measured by iodine colorimetry using potato amylose-waxy rice starch standards (ISO 6647). All chemical analyses were performed in duplicate.

Meal characteristics

The rice used in this study came from the Camargue country (variety: Cigalon; location: Arles, France). The test meals consisted of rice and bread portions yielding the same carbohydrate load (50 g), resulting in 65 g of white rice and 100 g of white bread. The weight of rice after cooking was 236.8 g. The rice was cooked in a pressure cooker for 6 minutes and was afterwards puffed with the cooking water for 4 minutes. Water was salted (1.5 g NaCl per portion) and its volume (320 mL) was standardized to avoid any residual liquid after cooking. The rice was not rinsed before consumption. Bread was cooked everyday at the central hospital kitchen and was consumed within the proceeding 4 hours.

Influence of the duration of cooking on the glycemic and insulinogenic index of rice

We performed a study on the effect of cooking time on the glycemic and insulinemic index of this rice, complementing our previous study on rice cooked 6 minutes [39, 40] which was the preparation used in this experiment. Seven subjects (three males and four females; age 26 ± 0.7 years, height 1.69 ± 0.03 m; weight 69.4 ± 5.5 kg; body mass index 22.1 ± 1.6 kg/m^2) underwent blood samplings over 180 minutes after they ate 62 g of rice (plus 1.5 g salt) with a quantity of water which changed according to the duration of cooking (respectively, 320, 410 and 450 mL for 3, 10 and 20 minutes).

Plasma glucose

Plasma glucose was assayed on a Beckman glucose analyzer 2 (Beckman Instruments Inc, Galway, Ireland). This technique uses the measurement of oxygen concentration in media under the influence of the enzyme glucose oxidase, which converts D-glucose + oxygen into gluconic acid + H_2O_2. The precision of this measurement is 2.5 mg/dL (within-run variation) and 3 mg/dL (day-to-day variation).

Insulin

To determine plasma insulin, we used the SB-INSI-5 radioimmunosassay kit (CIS Bio International, 91192 Gif-sur-Yvette,

Table I. Chemical composition of rice and bread.

	Rice	*Bread*
Protein	7.97 ± -0.03	14.33 ± -0.03*
Lipid	0.67 ± 0.04	1.71 ± -0.04*
Carbohydrate total	90.93 ± 0.03	83.47 ± -0.03*
Starch	83.24 ± -0.49	82.04 ± -0.03
Amylose	15.80 ± -0.10	25.90 ± -0.20*
Ash	0.43 ± -0.01	0.49 ± -0.01
Water content	11.31 ± -0.13	12.27 ± -0.03

Values are means ± SD. Contents are expressed in g/100 g of dry matter, * $P < 0.05$ vs rice.

France). The principle of the assay is based on the competition between labeled insulin and insulin contained in standards or specimens to be assayed for a fixed and limited number of antibody binding sites. The methodology used for the separation of bound and free fractions is based on the use of an immunoprecipitating reagent in which a second antibody is pre-precipitated and in excess. The coefficient of variation for this method ranges from 5.5 to 10.6% (within-assay) and from 6.2 to 10.8% (between-assay).

Plasma lactate

Lactate concentration was determined with lactate dehydrogenase and NAD [24].

Borg's scale of perceived exertion

Individual's perception of exertion during physical work was assessed by the category-ratio scale of Borg [1] in which exertion is quoted by a number ranging from 0 to 10.

Palatability

Palatability was assessed with an analogic-numeric scale as previously reported [2]. Subjects were asked to quote the pleasure of eating the meal on a 14 cm line which had on one extremity (value -7 arbitrary units) marked "extremely unpleasant" and at the other (value +7 arbitrary units) marked "extremely pleasant." Value zero on the middle of the line indicated neutrality.

Statistics

Glucose, insulin and blood lactate responses exhibited a non-normal distribution and thus were analyzed by non-parametric analysis of variance (Kruskall and Wallis test) and by paired Wilcoxon tests when appropriate. Chemical analysis results were compared by the Newman-Keuls procedure.

RESULTS

Chemical analysis

Results from the chemical analysis for raw and cooked meals are shown in table I. We found higher protein, lipid, total carbohydrate, and amylose contents in bread ($P < 0.05$) compared to rice. Table II shows the composition of each meal, calculated from these in vitro measurements, and taking into consideration the quantity which was given as well as the amount of water it contained.

Table II. Composition (expressed as weight, caloric content, and percentage of total caloric content) of the rice and bread meals used in the study evaluated from the chemical study of table 1.

	65 g rice (and 320 mL water)	*100 g bread*
Protein		
Weight (g)	4.4	8.6
kCal	17.6	34.4
%	8	14.1
Lipid		
Weight (g)	0.4	1
kCal	3.6	9
%	1.5	3.7
Carbohydrate		
Total (g)	50	50
Starch (g)	45.8	49.1
Amylose (g)	8.7	19.5
Glucidic (kCal)	200	200
%	90.5	82.2
Total kCal /meal	221	243.4

Influence of the duration of cooking on the glycemic and insulinogenic index of rice

The AUC values of blood glucose over 180 minutes for rice cooked 3, 10 and 20 minutes were, respectively, 961.1 ± 32 $mmol \cdot L^{-1} \cdot 180$ min; 682.5 ± 21.5 $mmol \cdot L^{-1} \cdot 180$ min; 992.7 ± 35.2 $mmol \cdot L^{-1} \cdot 180$ min. For bread used for comparison it was 1041.2± 66.2 $mmol \cdot L^{-1} \cdot 180$ min. This resulted in a glycemic index at 95 ± 7, 97 ± 6 and 98 ± 8% when bread was used as the reference 100% of the time. The peak of glycemia occurred at 30 minutes for every cooking time, while it occurred at 60 minutes for bread. Peak values were, respectively, 6.5 ± 0.3, 6.6 ± 0.3 and 6.5 ± 0.3, while it was 7 ± 0.6 for bread.

AUC values of insulinemia over 180 minutes for rice cooked 3, 10 and 20 minutes were, respectively, 13481.3 ± 307 $\mu U \cdot L^{-1} \cdot 180$ min; 3556 ± 439.6 $\mu U \cdot L^{-1} \cdot 180$ min; 3406 ± 675.5 $\mu U \cdot L^{-1} \cdot 180$ min. For bread used for comparison it was 7465.3 ± 1101.1 $\mu U \cdot L^{-1} . 180$ min, ie, almost two-fold values for the three times of rice (respectively, $P < 0.05$, $P < 0.02$ and $P < 0.05$). This resulted in an insulinogenic index of 54 ± 9, 56 ± 11, and 50 ± 9% when bread was used as the reference 100% of the time. The peak of insulinemia occurred at 60 minutes for

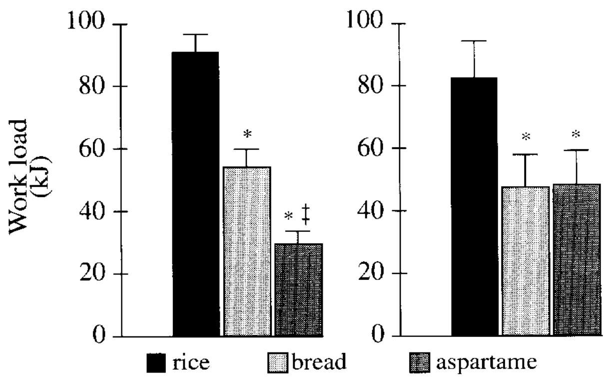

Fig 1. Work load (mean ± SEM) for first (left) and second (right) studies during exercise exercise until exhaustion. Comparisons between meals: $^*P < 0.01$ vs rice; $P < 0.01$ vs bread; E: exhaustion.

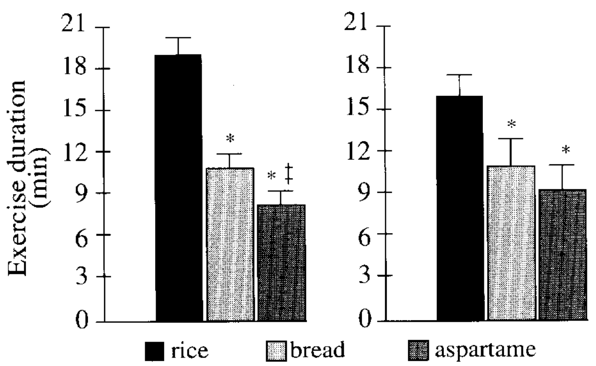

Fig 2. Exercise duration (mean ± SEM) for first (left) and second (right) studies during exercise exercise until exhaustion. Comparisons between meals: $^*P < 0.01$ vs rice; $P < 0.01$ vs bread; E: exhaustion.

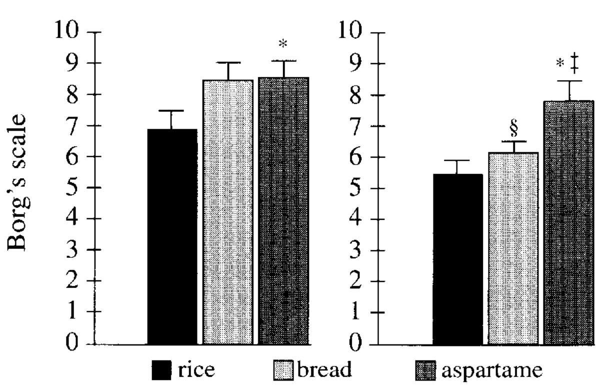

Fig 3. Rating of perceived exertion (Borg's scale, mean ± SEM) for first (left) and second (right) studies during exercise exercise until exhaustion. Comparisons between meals: $^*P < 0.01$ vs rice; $P < 0.01$ vs bread; E: exhaustion.

bread and rice cooked for 3 minutes, and at 30 minutes for rice cooked ten and 20 minutes. Peak values were, respectively, 27.7 ± 4.4, 36.7 ± 6.3 and 24.5 ± 4.3 for rice with the three cooking times, while it was 64.57 ± 9.4 for bread.

First study

Work load

During the first exercise session (before meal), which aimed at reducing muscular glycogen content, the power output varied between 25 and 80 W (mean: 46.8 ± 4.4 W). Total work outputs (area of power output during cycling) were similar (before aspartame 387.56 ± 46.14 kJ; before bread 374.73 ± 39.94 kJ; before rice 386.43 ± 43.64 kJ). By contrast, after the meal (fig 1), subjects performed different work according to the previous meal. This is not evident when viewing power values (varying from 40 to 160, ie, after rice 92.9 ± 5.3; after bread 100 ± 6; after aspartame 85.9 ± 6 W). However, when AUC of power plotted vs time are measured, a difference could be found (aspartame 29.86 ± 4.28 kJ; bread 54.99 ± 5.36 kJ; rice 91.20 ± 7.20 kJ). Greater work was performed after rice than after either aspartame ($P < 0.01$) or bread ($P < 0.01$). Work after bread was greater than after aspartame ($P < 0.01$). Heart rate was 122 ± 1 and 160 ± 1 beats/min for the first and second sessions, respectively.

Exercise duration

Before the meal the fatiguing session always had the same duration (150 minutes). After the meal subjects were able to exercise 8.40 ± 0.97 min with aspartame, 11.00 ± 1.03 min with bread and 19.20 ± 1.28 min with rice (fig 2). The duration of exercise until exhaustion was higher with rice than bread ($P < 0.01$) and placebo ($P < 0.01$). After bread the subjects were able to exercise longer than after aspartame ($P < 0.01$).

Perceived exertion

During the first exercise session (fatiguing session) the rating of perceived exertion was the same in the three conditions (ie, before aspartame 4.7 ± 0.5; before bread 4.5 ± 0.2; before rice 4.5 ± 0.6). During the after meal session the rating of perceived exertion was higher ($P < 0.01$) after both bread (8.5 ± 0.6) and aspartame (8.6 ± 0.6) than after rice (7 ± 0.6) (fig 3).

Palatability

Palatability scores on the analogic-numeric scale were as follows: 1.6 ± 0.9 for rice; 0.9 ± 0.9 for bread; -1.4 ± 0.54 for aspartame. Values for rice were higher than values for aspartame ($P < 0.05$) but there was no

Table III. Characteristics of plasma glucose and insulin responses during the low-intensity long-duration cycling session.

	Before rice	*Before bread*	*Before aspartame*
Glycemia			
Concentration			
Baseline (mmol/L)	4.8 ± -1	4.8 ± -0.1	4.8 ± 0.2
Post exercise (mmol/L)	4.1 ± -0.1*	4.2 ± -0.1*	4.4 ± -1*
AUC above baseline 0-150 min (mmol/L x 150 min)	-70.2 ± -19.0	-42.9 ± -9.2	-33.3 ± -7.3
Insulinemia			
Concentration			
Baseline (mmol/L)	7.6 ± -0.4	8.2 ± -0.2	7.7 ± -0.7
Post exercise (µU/mL)	5.8 ± -1.7*	6.3 ± -0.5*	5.7 ± -0.7*
AUC above baseline 0-150 min (mmol/mL x 150 min)	-108 ± -63.8	-153.5 ± -71.1	-99 ± 103.3
Lactacidemia			
Concentration			
Baseline (mmol/L)	0.8 ± -0.4	0.8 ± -0.1	0.8 ± -0.1*
At the 30th min (mmol/L)	2.4 ± -0.2*	2.2 ± -0.1*	2.4 ± 0.1*
Post exercise (mmol/L)	0.9 ± -0.8*	1 ± 0.6*	1 ± -0.1*
AUC above baseline (mmol/L x 150 min)	124.7 ± -9.6	106.3 ± -14.6	134.7 ± -17.2

Concentrations and AUC are means ± SEM; *$P < 0.05$ vs the preceding value in the same column; AUC: area under the curve.

significant difference between rice and bread, nor between aspartame and bread.

Glucose

During the previous fatiguing session, plasma glucose slightly decreased ($P < 0.05$), as shown in table III. Before either rice, bread or aspartame, the glucose area for this session was the same. At the onset of the after meal exercise session, plasma glucose was lower after aspartame than after rice ($P < 0.01$) and bread ($P < 0.01$), while plasma glucose after rice and after bread did not significantly differ (fig 4). At 5 minutes of exercise plasma glucose was lower with aspartame than with rice, ($P < 0.001$) or bread ($P < 0.01$). At 15 and 20 minutes plasma glucose remained stable at 4.5 mmol/L after rice while subjects fed aspartame or bread had already stopped cycling. Exhaustion after bread or aspartame always occurred with a lower plasma glucose level ($P < 0.05$) than the initial pre-exercise value, although this is not clearly evident in figure 4, which presents the mean values.

Insulin

During the previous fatiguing session insulin decreased significantly ($P < 0.05$) and the AUC of insulinemia was the same before either rice, bread or aspartame (table III). At the onset of the after meal exercise session insulin was higher after rice than after either aspartame ($P < 0.01$) or bread ($P < 0.01$) (fig 5). Insulinemia after bread was higher than insulinemia after aspartame ($P < 0.01$). Differences between aspartame and bread and between bread and rice disappeared at 5 minutes. At 5 minutes insulinemia after rice remained significantly higher than insulinemia after aspartame. At 10 minutes there was no significant difference among insulin values after either aspartame, rice or bread. The evolution of insulinemia was characterized by a progressive decline after rice ($P < 0.01$ between 0 and 10 minutes) while it remained statistically unchanged after bread or aspartame.

Blood Lactate

At 30 minutes of the previous fatiguing session, plasma lactate rised slightly ($P < 0.05$) then decreased slightly ($P < 0.05$), as shown in table III. At 5 minutes of the after meal exercise session, blood lactate was lower after rice ($P < 0.01$). Blood lactate remained constant until exhaustion.

Second study

Work load

The power output during this session varied between 45 and 160 W. Mean values were: after rice 82.5 ± 6.7 W; after bread 86.3 ± 7.4 W; after aspartame 86.7 ± 6.6 W). After the meal, subjects performed a different work according to the previous meal (aspartame 49.98 ± 10.62 kJ; bread 49.12 ± 10.68 kJ; rice 83.77 ± 11.90 kJ) (fig 1). A greater work was performed after rice than after either aspartame ($P < 0.01$) or bread ($P < 0.01$). The work after bread was not significantly

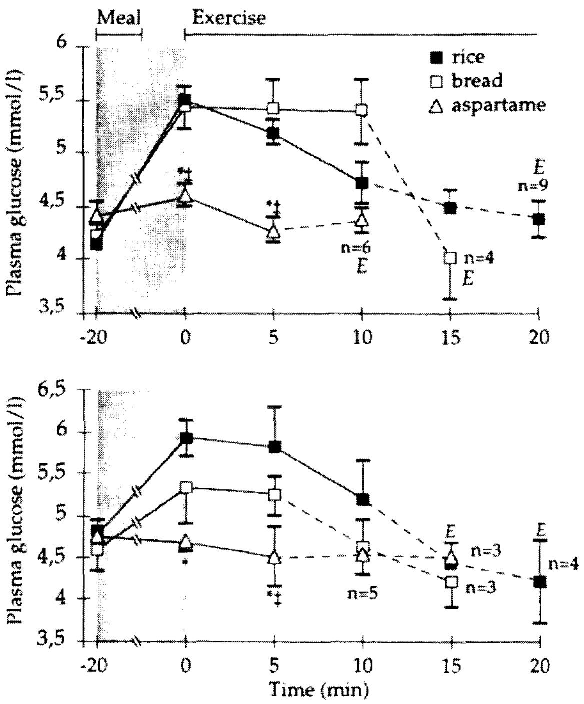

Fig 4. Plasma glucose (mean ± SEM) for first (top) and second (bottom) studies during exercise exercise until exhaustion. Comparisons between meals: $*P < 0.01$ vs rice; $P < 0.01$ vs bread; E: exhaustion.

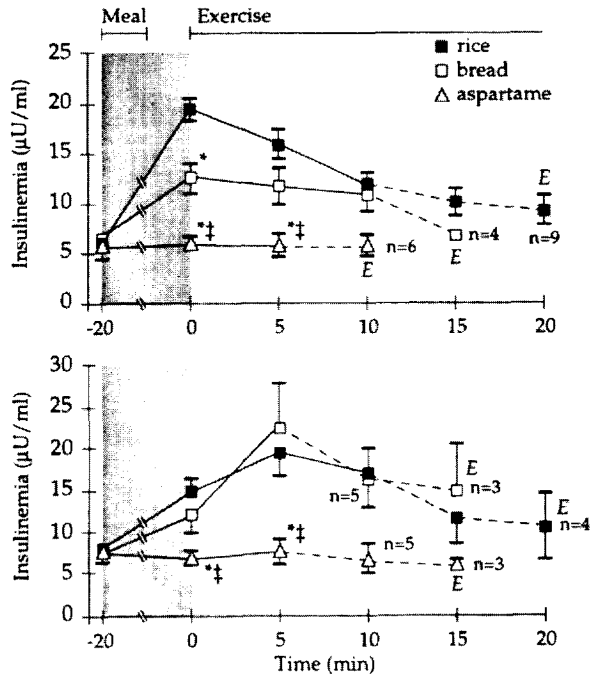

Fig 5. Plasma insulin (mean ± SEM) for first (top) and second (bottom) studies during exercise until exhaustion. Comparisons between meals: $*P < 0.01$ vs rice; $P < 0.01$ vs bread; E: exhaustion.

greater than after aspartame. The heart rate was 161 ± 1 beats/min^{-1}.

Exercise duration

After the meal subjects exercised 9.16 ± 1.87 min with aspartame, 11 ± 1.88 min with bread and 16 ± 1.52 min with rice. The duration of exercise until exhaustion was higher with rice than bread ($P < 0.01$) and aspartame ($P < 0.01$) (fig 2). Work duration after bread was not statistically longer than after aspartame. Whatever the previous feeding, all subjects performed exercise until 5 minutes. All subjects fed with rice were still cycling at 10 minutes while one fed with bread and one with aspartame stopped exercise. After 10 minutes two subjects fed with rice stopped cycling and the four others were able to cycle until 20 minutes. At 20 minutes all subjects fed with bread or aspartame had stopped cycling because they were exhausted.

Perceived exertion

The rate of perceived exertion was higher ($P < 0.01$) after aspartame (7.8 ± 0.7) than either rice (5.5 ± 0.4) or bread (6.2 ± 0.1). It was also significantly higher ($P < 0.05$) after bread than rice (fig 3).

Glucose

At the beginning of the exercise session, ie, at 20 minutes after meal, plasma glucose was lower after aspartame than rice ($P < 0.01$) but there was no difference in glucose levels after bread compared to rice (fig 4). A tendency to increase plasma glucose between 20 minutes and to was observed but it was non-significant after rice. After 5 minutes of cycling exercise there was a decrease in plasma glucose ($P < 0.05$ between 5 and 10 minutes) after rice. At 5 minutes, plasma glucose was higher when subjects were fed with either rice or bread than with aspartame ($P < 0.01$). This difference is no longer found at 10 minutes. There was a decline in plasma glucose at the time of exhaustion (when compared to the values measured at the beginning of the exercise session), which was significant for rice ($P < 0.05$), but not for bread. Mean plasma glucose after aspartame remained at 4.5 mmol/L and did not significantly decrease. Actually, all subjects whose plasma glucose was not lowered at the time of exhaustion performed a very short exercise time, which did not allow blood glucose to significantly decrease.

Insulin

Insulin levels were the same at 20 minutes (fasting) and were higher at time 0 (ie, 20 minutes after feeding) in subjects fed rice ($P < 0.01$) or bread ($P < 0.01$) than subjects fed with aspartame (fig 5). This difference is also found at 5 minutes. After this time, some subjects stopped cycling. The increase in insulinemia was significant after bread ($P < 0.01$) and rice ($P < 0.01$) while insulin did not change after aspartame.

Blood lactate

At ten and 15 minutes blood lactate was lower after rice ($P < 0.05$) than after bread and aspartame. There was no difference between bread and aspartame.

DISCUSSION

The goal of this study was to investigate a possible interest of rice in sports nutrition. Compared to aspartame, and also to bread – which has a high glycemic and insulinogenic index [12, 29] – rice appears, in this study, to be more efficient for delaying exhaustion. Subjects fed with rice before exercise were shown to perform a greater amount of work. These results are found when subjects have been previously submitted to a low-intensity, long-duration exercise (protocol one), but also without any previous period of fatiguing exercise (protocol 2).

The previous 150 minutes cycling session was used in our first protocol to induce a certain degree of fatigue resulting from reduced muscle glycogen content. We assumed that such a fatiguing session would place the subjects in a situation where their endurance performance would be more dependent on exogenous sugars, so that the difference among varied sources of carbohydrates would become more apparent. In literature [3, 21, 45] various protocols for such fatiguing exercises associated with a reduction in muscle glycogen content have been described. Since fatigue might be the result of a lactate-induced acidosis instead of a lack of glucose in muscle cells, we chose a low-intensity exercise, considered to be far below the lactate threshold according to various authors [4, 8]. In a study made by Coggan and Coyle [4], a cycling session at 65-73% of VO_{2max} for 170 minutes resulted in hypoglycemia and fatigue. In such a protocol, blood lactate at the time of fatigue returned to normal baseline values after a slight initial rise, and fatigue was explained by an inadequate supply of carbohydrate to the working muscles [9]. Our protocol (150 minutes at 65% of maximal heart rate) did not include a verification of muscular glycogen content by biopsy control, but the similarity with reported protocols in which this was done suggests that a relative reduction of muscle glycogen was obtained. After such a 'sensitizing' (glycogen reducing) session, study 1 showed that previously fatigued volunteers were able to perform significantly more work after rice than either placebo (aspartame) or bread. However, an additional series of experiments (study 2) without such a previous sensitizing session was also performed in order to determine to what extent the effects of rice were dependent on this 'glycogen reduction' protocol. Results are very similar, suggesting that the effects of rice on performance are very easy to observe, even if the subjects had not been previously fatigued. Moreover, there was no significant difference between the performances obtained in protocol 1 and protocol 2. This fact suggests that previous fatigue is not a critical factor for the acute effects of rice on exercise performance. However, the design of the two studies, which include different subjects, implies that their comparison should be interpreted with caution.

There is a general agreement in sports medicine that sportsmen should increase their intake of complex carbohydrates, both in everyday nourishment and before competitions [22, 23, 46]. Concerning the source of carbohydrates that can provide an immediately available fuel during exercise, however, literature [4, 6, 30-32, 41, 42] has mostly emphasized the interest of high glycemic index sugars, such as glucose, in postponing fatigue and exertion during endurance sessions. By contrast, few studies have been devoted to the acute effect of complex sugars (eg, rice) on exercise performance. Our results suggest that rice may have some interest for this purpose.

The kind of rice used here is characterized by both a high glycemic index, suggesting that its carbohydrates are rapidly available, and a low insulinogenic index, suggesting that insulin would exhibit a lower tendency to increase, which may prevent the occurrence of hypoglycemia [39, 40]. In fact, these properties may differ from other varieties of rice if we make comparisons with results reported by others investigators [12, 29]. When looking at the body's adaptation during exercise after this quality of rice has been eaten, there are two biological particularities which could explain the superiority of rice over bread. First, there is a better stability of plasma glucose (fig 4), and second, subjects fed with rice exhibit a lower increase of blood lactate (fig 6).

Consistent with previous experiments of Guézennec [23], rice appears in both protocols to be more efficient for avoiding a decrease in glycemia during this kind of exercise. However, in our study, exertion is not associated with very low values of blood glucose. Actually, it is now clear that fatigue can be experienced at blood glucose values around 3.5 mmol/L [33, 37, 49]. In addition, the duration of this exercise at 85% of the maximal heart rate was not long enough to allow glycemia

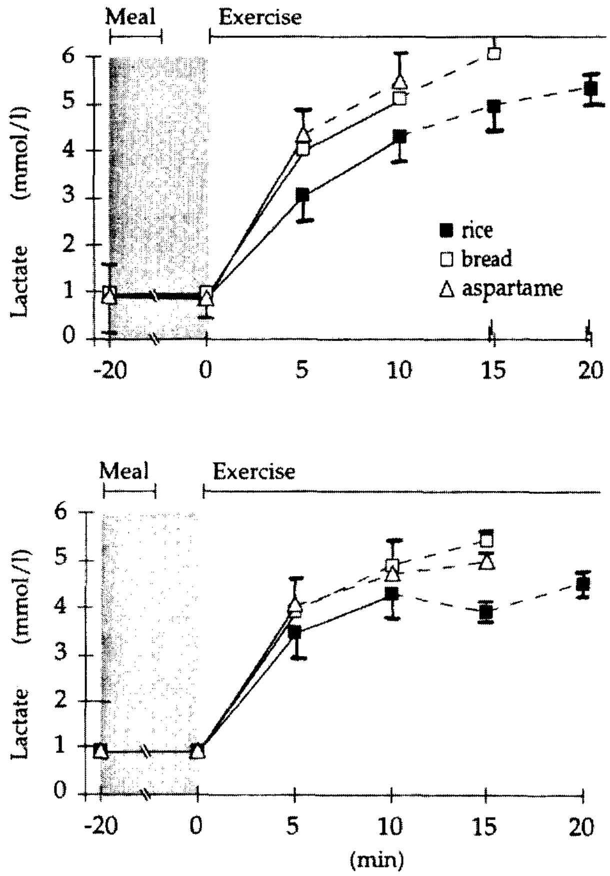

Fig 6. Blood lactate (mean ± SEM) for first (top) and second (bottom) studies during exercise until exhaustion. Comparisons between meals: *$P < 0.01$ vs rice; $P < 0.05$ vs bread; E: exhaustion.

to reach very low values. Physiological mechanisms for glucose production probably remain efficient during this period, avoiding a marked decrease in glycemia. Nevertheless, a relative defect in glucose availability at the muscular level may be involved in the fatigue mechanism, as suggested by the effect of rice intake. Although fatigue is not associated with hypoglycemia, the better stability of blood glucose after rice (evidenced in both this study and the study of Guézennec [23]) suggests that the effect of this meal on performance is related to a better disponibility of carbohydrates for exercising muscles.

Another interesting finding is that the longer cycling performance and the improved stability of blood glucose after rice intake are associated with slightly lower values of exercise-induced blood lactate in our two experiments. In fact, peak lactate values are quite low and the differences we observe are rather moderate, suggesting that blood lactate is not likely to explain most of the fatigue mechanism in this protocol.

Insulin responses after rice, bread or aspartame during exercise sessions do not provide additional information for understanding this effect of rice on exercise performance. However, insulin curves deserve some comments. Interestingly, insulinemia did not increase after aspartame, while it significantly increased after bread and rice, with a peak value at 5 minutes after starting cycling in protocol 2 and at t0 in protocol 1. An insulin peak during exercise can be theoretically expected to favor the occurrence of hypoglycemia, which could reduce exercise performance. Moreover, given the low insulinogenic effect of rice at rest (insulin response 50% less after rice than bread) it would be expected that insulin increases less after rice than after bread during exercise. Yet, we observed either no difference in insulin responses between rice and bread (protocol 2) or a higher insulin peak after rice compared to bread (protocol 1). Actually the difference in magnitude of insulin responses is low (12.33 vs 19.22 μU/mL), although it is significant ($P < 0.01$). Later in the exercise period, this difference disappears, suggesting a correct adaptation of insulin to exercise after either source of carbohydrates. Therefore, differences in insulin response are not likely to explain the difference among rice and bread sessions.

However, this small difference found at the beginning of exercise between insulin responses to rice and bread in protocol 1 is surprising. It might be a spurious finding, but it also may be explained by modifications of carbohydrate absorption in subjects already submitted to an exercise session. Our study of the biochemical composition of these meals offers a possible basis for interpreting such a difference. A rice meal a) is a more hydrated source of carbohydrate for digestion processing, and b) includes a small but significant quantity of soluble starch (2.19 g per 100 g of starch). These two properties suggest that rice behaves as a more rapid stimulus for insulin release. This is not in contradiction with a lower insulinogenic effect during a 2 hours period, which has been observed at rest [39, 40], and would have surely been observed in these subjects if they had not exercised.

Thus, the effect of rice on exercise performance seems to be explained rather by its ability to provide rapidly available carbohydrates than by its insulinogenic effect. However, the mechanism of this effect remains unclear.

It should be emphasized that there was a rather short time (20 minutes) between rice intake and the onset of exercise. The choice of this short time was based upon previous experiments. In a preceding study on this variety of rice [39, 40] we observed that blood glucose already increased 15 minutes after rice intake, while in the case of bread there was no significant increase in blood glucose until 30 minutes. Although there seems to be a lack of information on the role of gastric emptying and intestinal digestion in this rapid increase in glycemia after rice intake, these observations are highly suggestive for a very rapid availability of rice carbohydrates, which is probably involved in the effect of this meal on exercise performance.

Previous literature suggests that the duration of time between meal intake and exercise has a major influence on the effects of this meal on performance [6, 27]. Carbohydrate ingestion 30–60 minutes prior to the onset of exercise has been used in some studies with varying results. When glucose is given 30–45 minutes before exercise there is a rapid fall in blood glucose [6, 27] and a higher glycogen utilization [6, 27] with a reduction in exercise time to exhaustion [18]. These effects are believed to result at least in part from the high insulin levels found at that time [30–32]. Presumably, the synergistic effect of insulin on the exercise-induced muscle glucose uptake results in a lowering of blood glucose and greater reliance on muscle glycogen. It should be pointed out that the carbohydrate used in our study is less insulinogenic than the glucose solution of Foster's study [18]. As can be observed in figure 5, mean insulin peak value averages only 20 μU/mL. Thus, the lower insulinogenic effect of rice compared to glucose may explain in part the discrepancy between our results and Foster's.

Some reports in the literature are consistent with our findings on rice. An improvement in endurance exercise performance has been demonstrated when carbohydrate is ingested 45–60 minutes prior to exercise [19, 43]. Probably, in this case, carbohydrate availability is increased and carbohydrate oxidation is maintained [25]. Blood glucose levels during exercise following a carbohydrate meal result from the balance between the stimulatory effects of hyperinsulinemia and contractile activity on muscle glucose uptake, hepatic glucose output and increased glucose availability as a consequence of ongoing absorption of ingested carbohydrate. The complexity of this balance largely explains the discrepancies among studies using various meals and exercise protocols [25]. According to these conceptions, it can be reasonably assumed that a rice ingestion, according to the schedule presented in our study, results in an increased availability of glucose for exercising muscles.

Two characteristics of the rice meal may play a role in this rapid glucose availability. Water content of the preparation probably influences the kinetics of gastric emptying. In this respect, rice was a more hydrated source of carbohydrates than bread, and this fact perhaps explains a part of the differences pointed out in our experiments. Other studies with bread, whether or not with water, could clarify this question. In this study, no additional water was provided. One could also suggest that the conditions of rice cooking influence rice digestion and the following kinetics of blood glucose. Classically, the duration of cooking increases the glycemic index of rice, as it does for pasta [29]. However, we investigated the influence of duration of cooking on the glycemic index of the variety of rice used in this study, and we found no measurable influence of this duration on the glycemic index between rice cooked 3, 10 and 20 minutes. For the variety of rice studied here, duration of cooking does not markedly influence availability of rice carbohydrates at rest. Whether there is an influence of this cooking time on blood glucose kinetics during exercise remains unknown, since modifications of digestive function are likely to occur during cycling. In addition, there appears to be large nutritional differences among varieties of rice [14] and there are probably varieties of rice more sensitive to the cooking duration, as those described in the literature [29].

It should be emphasized that in our protocol there is a rather short time between the meal and the onset of exercise, so that gastric emptying is not complete. Some contradictions exist among the data obtained when studying the gastric emptying during exercise. This literature has been reviewed by Costill [5] and further discussed by Jandrain et al [28]. Available data suggests that there is almost no reduction of gastric emptying when such a carbohydrate meal is taken before exercise. There is some literature on gastric emptying for a rice meal [38], but the effect of exercise on this process in largely unknown. However, the biphasic pattern of gastric emptying, with a rapid first phase [16] which is even faster for carbohydrate-rich meals, suggests that at 20 minutes after meal onset more than 60% of the rice has been cleared from the stomach and is available for absorption in lower parts of the GI-tract. Our experimental data, indicating a good availability of these carbohydrates (as previously discussed), are also consistent with this assumption.

On the whole, the mechanism for this effect of rice (eaten 20 minutes before exercise) on performance remains to be elucidated. As a working hypothesis we suggest that this meal provides carbohydrates rapidly available for muscles, without the high insulinogenic effect observed with other sugars (eg, glucose) which has been supposed to induce a waste in muscular glycogen, thus impairing performance.

Although additional studies are clearly needed, we think that our two experiments on rice and exercise endurance capacity suggest that rice (at least the variety investigated here) might be an interesting meal for sportsmen. It should be further evaluated as a rapidly available source of carbohydrates which can be administered a short time before exercise (20 minutes in this study). We hypothesize that it could have intermediate properties between high glycemic index sugars (interesting during exercise) and other complex carbohydrates with a lower glycemic index, which may be more efficient if given a longer time before exercise (eg, pasta). However, our study investigated rice alone, which may be considered by sportsmen as an unattractive food. Complex meals associating rice and other nutriments could be a more interesting solution, but these meals will have to be tested. In fact, our evaluation of palatability suggests a not so bad acceptability of rice alone in these conditions. We can compare the scores of palatability obtained here with the mean score of a complex hyperglucidic breakfast given just after exercise (score: 2), which averages three arbitrary units. That score was influenced by previous exercise and appeared to be positively correlated to β-endorphin release. Thus, palatability should be considered not only at rest, but also in exercise conditions. In such a context, the score of rice alone, which is significantly higher than that of aspartame, is in an acceptable range (close from +2 units). After this study was completed, we routinely encouraged sportsmen to eat rice before exercise. Although a controlled study will be needed, acceptability appeared to be satisfactory.

In conclusion, we show that rice, when ingested 20 minutes before an endurance exercise session, is a more efficient source of carbohydrates than bread, and increases both the duration and the psychological tolerance of submaximal muscular activity. Studies on other types of exercise, in trained sportsmen, and with different meals associating rice with other nutriments, will be necessary to better assess the potential applications of rice in sports nutrition.

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