

Role of Glycemic Index for Sports Nutrition

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Introduction

Today's athletes can not rely solely on physical talent and strength in order to achieve optimal performance during long bouts of moderate to high intensity exercise. Athletes either recreational or professional need take a holistic approach to their exercise strategy. What an athlete eats and drinks can affect health, body composition and weight, substrate availability during exercise, recovery from exercise and exercise performance (American College Sports Medicine [ACSM], 2000).

Body fat and carbohydrate (CHO) provide a major source of fuel during exercise. Although fat stores are plentiful there is a limited store of CHO in the body. During prolonged high intensity exercise of more than 60 minutes CHO stores become depleted limiting exercise performance. Sports nutrition guidelines have focused on strategies aimed at enhancing CHO availability during exercise, optimising performance and promoting efficient recovery from exercise. These strategies include ingesting CHO before, during and after exercise (Burke, Kiens and Ivy, 2004). CHO and food containing CHO are digested and absorbed at different rates. The rate at which CHO releases energy, the glycemic index, plays a significant role in the nutritional strategy of any athlete today.

Energy release

During exercise certain demands are placed on the body in order to function efficiently, the muscles of the body need to contract more forcefully, the heart beats stronger and faster and the lungs have to work harder by supplying the body with sufficient oxygen in order to sustain exercise (Bean, 2003). The capacity to produce energy and the rate of transfer of this energy to the working

muscles determines an individual's capacity and performance during exercise (Mc Ardle, Katch and Katch, 2006). Energy is released when a small molecule adenosine triphosphate (ATP) loses one of its phosphate groups to become adenosine diphosphate (ADP). ADP is then converted back into ATP. This cycle of converting ATP into ADP releases energy (Bean, 2003). The body stores only small amounts of ATP, just enough to sustain basic energy requirements or to fuel several seconds of explosive or all out effort. An additional energy source is required for continual re-synthesis of ATP for exercise lasting longer than 10 seconds. Additional ATP is produced in the body from the breakdown of CHO, protein, fat and alcohol with fat and CHO (glycogen) providing the major energy source. These macronutrients are broken down in the digestive system and absorbed into the bloodstream. Although they follow different metabolic paths in the body, they each produce water, carbon dioxide and ATP (Eberle, 2000).

CHO such as sugar or starch is broken down into sugar units called glucose, fructose and galactose and is stored as glycogen in the muscles and liver. Glycogen is the body's principal energy source. There is however a limited storage of glycogen in the body, on average about 500g, with 400g stored in the muscles and 100g in the liver (Bean, 2003), approximately 1,800 to 2,000 calories worth of energy or enough energy for between 90 – 120 minutes of vigorous exercise (Eberle, 2000). CHO is the only nutrient that can generate ATP anaerobically. The anaerobic breakdown of muscle glycogen generates ATP rapidly and for a short amount of time. CHO is the primary fuel for all out exercise lasting 1 to 2 minutes (Eberle, 2000). During exercise muscle glycogen stores are depleted and blood glucose is required to maintain the body's energy requirements. If blood glucose levels fall the body goes into a state of hypoglycaemia or low blood sugar. The amount of available glycogen stored in the muscles and liver and blood glucose directly influences exercise performance and capacity (Bean, 2003).

Fat is the body's other main source of fuel providing more than twice as much energy as CHO or protein (9 calories per gram versus 4 calories per gram). Fat is broken down into fatty acids with approximately 300-400g of fat stored in muscles and as triglycerides in adipose tissue (Bean, 2003). During exercise fat is broken down into fatty acids and transported in the blood to the muscles for fuel. The complete breakdown of fat is also dependent on CHO therefore if CHO levels in the body fall, the breakdown of fat is simultaneously effected (Eberle, 2000).

Protein is broken down into amino acids forming muscle and organ tissue. Protein is not a primary source of energy during exercise but can contribute as an energy source when glycogen stores become depleted particularly in the latter stages of exercise (ACSM, 2000; Burke et al., 2004).

Alcohol is not broken down but is absorbed straight into the blood stream. Alcohol can only be broken down in the liver and the rate at which it is broken down is unaffected by exercise (Bean, 2003).

Energy sources during exercise

CHO, fat and protein are all capable of providing energy during exercise with fat and CHO contributing the main source of fuel (ACSM, 2000; Bean, 2003; Burke et al., 2004). The proportion of fuel utilised during exercise is dependent on a number of different factors: duration and intensity of exercise, gender, nutritional status, the amount of stored glycogen and fitness level of the individual (Burke et al., 2004). The body uses a mixture of fat and CHO during every activity. As exercise intensity increases there is a greater utilisation of CHO (muscle glycogen

and plasma glucose derived from liver or dietary CHO intake) as the main energy source. As exercise duration increases the source of CHO may change from muscle glycogen to blood glucose provided levels of blood glucose remain high. If blood glucose diminishes the intensity of exercise is likely to reduce (ACSM, 2000; Burke et al., 2004). Fat (plasma free fatty acids (FFA) derived from adipose tissue and intramuscular triglycerides) contributes to the energy source during low to moderate intensity exercise up to 65% maximal aerobic capacity. The contribution of fat as an energy source decreases as the intensity of exercise increases. Fat oxidation requires CHO, therefore performance and capacity during exercise is affected if the body's CHO stores become depleted even during low to moderate intensity exercise (Eberle, 2000; Bean, 2003).

Careful consideration needs to be given by individuals participating in any type of physical activity. CHO, protein and fat need to be consumed as part of a daily diet in order to replenish glycogen stores, maintain body weight, assist in repair and building of muscle tissue. As the body has an essential requirement for CHO and because there is limited supply of glycogen, individuals particularly athletes need to maintain a diet that contains sufficient amounts of CHO in order to promote glycogen synthesis, storage and to maintain blood glucose levels during exercise (ACSM, 2000). As a result individuals need to incorporate CHO as part of their before, during and after exercise strategy. The recommended daily allowance (RDA) for CHO intake is 55 – 60% of calories or 6 – 10g/kg body mass depending on an individuals daily energy expenditure (ACSM, 2000; Mc Ardle et al., 2006). But what type of CHO is best consumed before, during and after exercise?

The Glycemic Index

CHO and food containing CHO are digested and absorbed at different rates. The rates at which CHO is absorbed is dependent on a number of factors: digestion and absorption, the type of starch, method of cooking, size, amount of fiber, fat and protein (Jenkins et al., 2002; McArdle et al., 2006). The glycemic index (GI) was developed to provide a numeric classification of CHO rating from 0 - 100. The GI is a measure of increase in blood glucose concentration in the 2 hours after ingestion of food containing 50g of CHO. This figure is then compared to the standard food generally white bread or glucose whose value is 100. The GI is then calculated by dividing the area under the curve of the test food by the area under the curve of the standard food. The GI is given as a percentage of test food against the standard food. For example the GI of porridge is 42 therefore porridge produces a rise in blood glucose which is 42% as great as ingesting glucose. These foods are then classified as high GI (60-100), medium GI (40-59) and low GI (<40). The higher the GI the higher the blood sugar levels after ingesting that food (Eberle, 2000; Bean, 2003; McArdle et al., 2006). Consuming a meal that is high GI will result in: a faster rate of glucose absorption, increased rise in gut hormones and insulin, followed by a dramatic reduction in blood glucose and fatty acid concentrations, increase in CHO oxidation and a reduction in fat oxidation (Jenkins et al., 2002). Conversely, consuming a meal that is low GI will result in: a reduced rate of glucose absorption, reduced rise in gut hormones and insulin, increase fat oxidation, reduced CHO oxidation and promotes satiety (Brand-Miller, Holt, Pawlak and McMillan, 2002; Jenkins et al., 2002).

The GI was originally developed to assist diabetics in promoting healthy blood sugar levels. However GI is widely used amongst the general population for

weight control as well as in athletic and sporting circles to promote optimum nutrition and promote optimum recovery from exercise (Brand-Miller et al., 2002; Jenkins et al., 2002; Bean, 2003).

Much debate exists over which type of meal should be consumed before, during and after exercise, should the meals be of low GI (LGI) or high GI (HGI) in value? The answer in reality is not a straight forward one. It is dependent on a number of factors: the intensity, duration and type of exercise, time of day, the length of time prior to exercise, temperature and the rest period between bouts of exercise.

Pre-exercise nutrition

The pre-exercise meal or snack forms an essential part of any recreational or professional athletes training schedule, its main role is to prepare the individual for the upcoming exercise bout, leaving the individual feeling satisfied and not hungry and having little or no undigested food in the stomach, as this may lead to gastrointestinal distress. Each snack or meal should be composed of enough fluid to maintain levels of hydration, low in fat and fibre to optimise gastric emptying, high in CHO and moderate in protein (ACSM, 2000).

Ingestion of CHO has been shown to improve performance compared to exercising in a fasted state (Kirwan, O’Gorman and Evans, 1998; DeMarco, Sucher, Cisar and Butterfield, 1999; Febbraio, Chiu, Angus, Arkinstall and Hawley, 2000). Consumption of a high CHO meal is recommended in the hours before exercise in order to: provide a sustained source of CHO during exercise, increase both muscle and liver glycogen stores, maintain levels of blood glucose and minimise insulin release prior to exercise (Wu, Nicholas, Williams, Took and Hardy, 2003).

It is thought that increased CHO oxidation during exercise will result in a reduction in body's limited CHO stores. Ingestion of HGI meal can result in: a dramatic reduction in blood glucose at the onset of exercise, higher utilisation of CHO during the exercise bout (Febbraio et al., 2000a; Wu et al., 2003; Wee et al., 2005; Wu and Williams, 2006), greater muscle glycogen utilisation (Wee et al., 2005) and reduced plasma glucose during the latter stages of exercise (DeMarco et al., 1999; Febbraio et al., 2000; Stannard et al., 2000; Stevenson et al., 2005b).

Ingestion of LGI meal: may provide a more sustained form of energy, increased fat oxidation (Wee, et al., 1999; Wee, et al. 2005; Wu and Williams, 2006), increased levels of plasma glucose during the latter stages of exercise (DeMarco et al., 1999; Stannard et al., 2000; Stevenson et al., 2005b), increased levels of satiety (Stevenson et al., 2005b; Stevenson et al., 2005c) and reduced level of blood lactate (Stannard et al., 2000). The greater rate of fat oxidation and as a consequence lower rate to CHO oxidation as a result of consuming LGI meal prior to exercise is beneficial during endurance exercise and may delay reduction in CHO stores (Wu and Williams, 2006). However as the intensity of exercise is increased, > 65% maximum aerobic capacity, there is a shift in ratio of fat and CHO utilisation during exercise (Eberle, 2000).

CHO takes 3 to 4 hours to digest, absorb and get stored as muscle and liver glycogen (McArdle et al., 2006). Current pre-exercise CHO recommendations in order to maximise muscle and liver glycogen storage and provide readily available glucose for absorption during exercise is 3 to 5g/kg of body mass where sufficient time, 3 to 4 hours, exists prior to exercise bout (McArdle, et al. 2006) or 1g/kg of body mass for pre-exercise meal 1 hour prior to exercise (Bean, 2003).

In several studies carried out the pre exercise LGI meal consisted of larger amounts of fructose resulting in significantly elevated postprandial blood lactate concentrations (Wu et al., 2003; Stevenson et al., 2005b; Wu and Williams, 2006). Approximately two thirds of fructose is converted to glucose in the liver with the remainder released as the by product lactate. Fructose is therefore not a readily available energy source and may lead to gastrointestinal distress (Stevenson et al., 2005b; McArdle, et al., 2006) and may not be an ideal component of the pre exercise meal.

It is generally recommended that the pre-exercise meal be of LGI, particularly if additional CHO is not taken on during the exercise bout, resulting in slower rate of glucose absorption and reduced rebound glycemic response by reducing insulin surge and providing a slow release of glucose during exercise. Some individuals may also be more sensitive to the variations in blood sugar levels as a result of ingesting a HGI meal. If exercise duration is likely to exceed 60 minutes at moderate to high intensity, greater than 65% aerobic capacity, taking on additional CHO during exercise may form an essential part of an athlete's nutritional strategy (Eberle, 2000; Febbraio et al., 2000; Bean, 2003).

Nutrition during exercise

Ingestion of CHO during exercise has been shown to: improve performance (Febbraio et al., 2000; Earnest et al., 2004), spare muscle glycogen (McArdle et al. 2006), maintain blood glucose levels (Horowitz, Mora-Rodriguez, Byerley and Coyle, 1999; Febbraio et al., 2000) and supply the muscles with glucose when glycogen stores are run down during the latter stages of exercise (McArdle et al., 2006). During exercise ingested CHO and blood glucose is oxidised at a rate of approximately 1g per min. During the latter stages of prolonged exercise this exogenous CHO becomes the primary fuel, potentially delaying fatigue (Coyle, 2004).

The type (HGI or LGI) and form (solid or liquid) of CHO ingested during exercise does not play as significant a role on hormonal response, exercise metabolism or endurance performance. Insulin release during exercise is blunted due to increased levels of hormones (catecholamines). Exercise increases glucose absorption enabling glucose to be absorbed by the muscles with a lower insulin requirement (McArdle et al., 2006). In a study by Earnest et al. (2004) they looked at LGI versus HGI carbohydrate gel ingestion during a simulated 64-km cycling time trial. The study consisted of three different studies ingestion of LGI meal, HGI meal and a placebo containing no CHO. The study found that performance time between groups was not significant upon completion however when CHO intake as a whole was compared with the no CHO placebo results, there was a significant performance advantage in CHO study versus no CHO placebo, demonstrating that CHO ingestion during exercise enhances performance regardless of GI.

During exercise at low to moderate intensity, 50% aerobic capacity, fat provides the major fuel and glycogen levels do not reduce at the same level as high intensity exercise (McArdle et al., 2006). CHO ingestion during exercise is recommended where the total duration of exercise is 60 minutes or more carried out at high intensity, 65% aerobic capacity or higher. This can either be continuous exercise or where exercise is broken up in smaller bouts in sports such as tennis, hockey, soccer, etc. There does not appear to be any benefit in consuming CHO where the exercise is of moderate intensity lasting less than 60 minutes (Coyle, 2004; McArdle et al., 2006).

Moderate to high GI is generally considered to be the best choice during exercise because they are easily digested and absorbed. CHO can be taken on in liquid or solid form. Taking CHO drinks during exercise has the additional benefit of providing fluid and fuel therefore reducing dehydration and fatigue during prolonged exercise (Bean, 2003). Current recommendations suggest that athletes should consume 30-60g CHO per hour and should be consumed in the form of glucose, sucrose, maltodextrin or HGI starches. Fructose intake should be limited to small amounts that do not cause gastrointestinal distress. This amount of CHO can be consumed by drinking 600-1200ml per hour of solutions containing 4 to 8% CHO (Coyle, 2004).

Post exercise nutrition

The amount of available glycogen stored in the muscles and liver and blood glucose directly influences exercise performance and capacity (Bean, 2006). Many of today's athletes and sportspeople participate in exercise and training either more than once a day or during consecutive days. It is therefore essential that muscle glycogen stores are sufficiently restored to facilitate this volume of training. Ingestion of post exercise CHO has been shown to increase muscle glycogen stores during recovery from exercise (Burke et al. 1996; Bowtell et al. 2000). Ingestion of HGI foods promotes high levels of blood glucose and insulin concentrations facilitating rapid absorption and enhanced glycogen re-synthesis (Burke et al. 1996; Bowtell et al., 2000; Stevenson, Williams and Biscoe, 2005).

CHO ingestion post exercise replenishes glycogen stores at a rate of about 5 to 7% per hour. It takes approximately 20 hours to replenish glycogen stores following long bouts of high intensity exercise (McArdle et al., 2006). It is recommended ingesting HGI or LGI recovery meal or snack immediately following high intensity exercise to promote rapid glycogen re-synthesis. Consumption of HGI recovery diet results in higher muscle glycogen levels 24 hours after exercise compared with LGI recovery diet (Burke, Collier and Hargreaves, 1993 as cited by ACSM, 2000). Consumption of a HGI recovery diet may be more important where subsequent exercise is likely to occur within 24 hours.

Immediately following exercise, ingestion of 1 to 1.5g CHO/kg body mass at 2 hourly intervals is recommended, until reaching 7 to 10g CHO/kg body mass. If subsequent exercise is to take place within 24 hours then a HGI recovery diet is recommended to maximise glycogen replenishment but where subsequent exercise takes place more than 24 hours then a LGI recovery diet is recommended (ACSM, 2000; McArdle et al., 2006). Intake of Protein after

exercise assists in the building and repair of muscles, enhances net protein balance and promotes synthesis of new proteins. Therefore athletes should aim to consume a mixed meal containing CHO and protein after high intensity exercise to promote optimal recovery from exercise (ACSM, 2000; Burke et al., 2004). A LGI recovery diet may be more beneficial for promoting fat utilisation during the recovery period particularly in individuals where weight is a concern (Stevenson et al., 2005).

Conclusion

There is confounding evidence that CHO intake before, during and after exercise forms an essential role in the dietary strategy of any recreational or professional athlete.

The main aim of any athlete should be meeting total daily CHO. Each athlete is unique and needs to establish a routine that is suited the individual. Athletes may prefer to take CHO in the form of smaller snacks to avoid any gastrointestinal discomfort or may prefer to take CHO as part of a larger meal (Burke et al., 2004). Prior to exercise athletes should aim to consume a meal that is LGI, particularly if CHO is not taken on board during the exercise bout. During exercise the GI rating does not play a significant role and the athlete should therefore aim to take on CHO in liquid or solid form of either HGI to LGI. The post exercise recovery meal should be HGI if subsequent exercise is less than 24 hours or LGI if subsequent exercise is to take place more than 24 hours.

The consumption of HGI foods is associated with increased risk of type 2 diabetes, coronary heart disease, obesity and cancer. Consumption of LGI diet results in improved glucose tolerance and promotes additional health benefits therefore a diet consisting predominantly of LGI CHO may be advisable in the long term in either trained or untrained individuals (Stevenson et al., 2005c).

References

American College Sports Medicine (2000)

Position Stand: Nutrition and Athletic Performance

Medicine and Science in Sports and Exercise

Bean, A. (2003)

The Complete guide to Sports Nutrition: How to eat for maximum performance
(3rd Edition).

A & C Black – London

Bowtell, J.L., Gelly, K., Jackman, M.L., Patel, A., Simeoni, M., and Rennie, M.J.

(2000)

Effect of different carbohydrate drinks on whole body carbohydrate storage after
exhaustive exercise.

Journal of Applied Physiology, 88, 1529-1536

Brand-Miller, J.C., Holt, , Pawlak, , and McMillan, J. (2002)

Glycemic index and obesity.

American Journal of Clinical Nutrition, 76, 218S-5S

Burke, L.M., Claassen, A., Hawley, J.A., and Noakes, T.D. (1998)

Carbohydrate intake during prolonged cycling minimizes effect of glycemic index
of preexercise meal.

Journal of Applied Physiology, 85(6), 2220-2226

Burke, L.M., Collier, G.R., Davis, P.G, Fricker, P.A., Sanigorski, A.J., and Hargreaves, M. (1996)

Muscle glycogen storage after prolonged exercise: effect of the frequency of carbohydrate feedings.

American Journal of Clinical Nutrition, 64, 115-9

Burke, L.M., Kiens, B., and Ivy, J.L. (2004)

Carbohydrates and fat for training and recovery.

Journal of Sports Sciences, 22, 15-30

Coyle, E.F. (2004)

Fluid and fuel intake during exercise.

Journal of Sports Sciences, 22, 39-55

Crombie, I.K. (2006)

The Pocket Guide to Critical Appraisal.

BMJ Books

DeMarco, H., Sucher, K.P., Cisar, C.J., and Butterfield, G.E. (1999)

Pre-exercise carbohydrate meals: application of glycemic index.

Journal of Medicine and Science in Sports and Exercise, 31(1), 164-170

Earnest, C.P., Lancaster, S.L., Rasmussen, C.J., Kerksick, C.M., Lucia, A.,

Greenwood, M.C., Almada, A.L, Cowan, P.A., and Kreider, R.B. (2004)

Low vs high glycemic index carbohydrate gel ingestion during simulated 64-km cycling time trial performance.

Journal of Strength and Conditioning, 18(3), 466-472

Eberle, S.G. (2000)

Endurance Sports Nutrition.

Human Kinetics

Erith, S., Williams, C., Stevenson, E., Chamberlain, S., Crews, P., and Rushbury, I. (2006)

The effect of high carbohydrate meals with different glycemic indices on recovery of performance during prolonged intermittent high-intensity shuttle running.

International Journal of Sports Nutrition and Exercise Metabolism, 16, 393-404

Erlenbusch, M., Haub, M., Munoz, K., MacConnie, S., and Stillwell, B. (2005)

Effect of high-fat or high-carbohydrate diets on endurance exercise: A meta-analysis.

International Journal of Sports Nutrition and Exercise Metabolism, 15, 1-14

Febbraio, M.A., Chiu, A., Angus, D.J., Arkinstall, M.J., and Hawley J.A. (2000)

Affects of carbohydrate ingestion before and during exercise on glucose kinetics and performance.

Journal of Applied Physiology, 89, 2220-2226

Febbraio, M.A., Keenan, J., Angus, D.J., Campbell, S.E., and Garnham, A.P.

(2000b)

Preexercise carbohydrate ingestion, glucose kinetics, and muscle glycogen use: effect of the glycemic index.

Journal of Applied Physiology, 89, 1845-1851

Horowitz, J.F., Mora-Rodriguez, R., Byerley, L.O., and Coyle, E.F. (1999)

Substrate metabolism when subjects are fed carbohydrate during exercise

American Journal of Physiology

Jenkins, D.J.A, Kendall, C.W.C., Augustin, L.S.A., Franceschi, S., Hamidi, M.,
Marchie, A., Jenkins, A.L., and Axelsen, M. (2002)

Glycemic Index: overview of implications in health and disease.

American Journal of Clinical Nutrition, 76, 266S-73S

Kirwan, J.P., O’Gorman, D.J., Cyr-Campbell, D., Campbell, W.W., Yarasheski, K.E.,
and Evans, W.J. (2001)

Effects of a moderate glycemic meal on exercise duration and substrate utilization.

Journal of Medicine and Science in Sports and Exercise, 33(9), 1517-1523

Kirwan, J.P., O’Gorman, D., and Evans, W.J. (1998)

A moderate glycemic meal before endurance exercise can enhance performance.

Journal of Applied Physiology, 84(1), 53-59

Kovacs, M.S. (2006)

Carbohydrate intake and tennis: are there benefits?

British Journal of Sports Medicine, 40, 1-5

Mc Ardle, W.D., Katch, F.I., and Katch, V.L. (2006)

Exercise Physiology: Energy, Nutrition & Human Performance (6th Edition)

Lippincott Williams & Wilkins

Noakes, T. (2001)

Lore of Running (4th Edition)

Human Kinetics

Stannard, S.R., Thompson, M.W., and Brand-Miller J.C. (2000)

The effect of glycemic index on plasma glucose and lactate levels during incremental exercise.

International Journal of Sport Nutrition and Exercise metabolism, 10, 51-61

Stevenson, E., Williams, C., and Biscoe, H., (2005)

The metabolic responses to high carbohydrate meals with different glycemic indices consumed during recovery from prolonged strenuous exercise.

International Journal of Sport Nutrition and Exercise Metabolism, 15, 291-307

Stevenson, E.J., Williams, C., McComb, G., and Oram, C. (2005a)

Improved recovery from prolonged exercise following the consumption of low glycaemic index carbohydrate meals.

International Journal of Sport Nutrition and Exercise Metabolism, 15, 333-349

Stevenson, E., Williams, C., and Nute, M. (2005b)

The influence of the glycaemic index of breakfast and lunch on substrate utilisation during the postprandial periods and subsequent exercise.

British Journal of Nutrition, 93, 885-893

Stevenson, E., Williams, C., Nute, M., Swaile, P., and Tsui, M. (2005c)

The effect of the glycemic index of an evening meal on the metabolic responses to a standard high glycemic index breakfast and subsequent exercise in men.

Internation Journal of Sports Nutrition and Exercise Metabolism, 15, 308-322

Wee, S., Williams, C., Gray, S., and Horabin, J. (1999)

Influence of high and low glycemic index meals on endurance running capacity.

Journal of Medicine and Science in Sports and Exercise, 31(3), 393-399

Wee, S., Williams, C., Tsintzas, K., and Boobis, L. (2005)

Ingestion of a high-glycemic index meal increases muscle glycogen storage at rest but augments its utilization during subsequent exercise.

Journal of Applied Physiology, 99, 707-714

Wu, C., Nicholas, C., Williams, C., Took, A., and Hardy, L. (2003)

The influence of high-carbohydrate meals with different glycaemic indices on substrate utilisation during subsequent exercise.

British Journal of Nutrition, 90, 1049-1056

Wu, C., and Williams, C. (2006)

A low glycemic index meal before exercise improves endurance running capacity in men.

Journal of Sport Nutrition and Exercise Metabolism, 16, 510-527

Secondary References

Burke, L.M., Collier, G.R., and Hargreaves, M. (1993)

Muscle glycogen storage after prolonged exercise: Effect of the glycemic index of carbohydrate feeding.

Journal of Applied Physiology, 75, 1019-1023

Thomas, D.E., Brotherhood, and Miller (1991)

Carbohydrate feeding before exercise: effect of glycemic index.

International Journal of Sports Medicine, 12, 180-186