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Rice Consumption and Effects of Rice Cake, Seolgitteok, on Human Health

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Rice Consumption and Effects of Rice Cake, *Seolgitteok*, on Human Health

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by

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Abstract

Within the United States type 2 diabetes is an ever growing health epidemic. The prevalence in the adult population has quadrupled over the past 30 years and is expected to continue on a similar path in the coming decades. While the cause of type 2 diabetes is multifactorial, it is considered to be an acquired condition related to environmental contributors including poor diet, obesity, and physical inactivity, which may be managed to alter the course or progression of the disease. Preventative or maintenance measures emphasize nutritional intervention strategies, including encouraging individuals to follow a nutrient-dense, high-fiber diet with ample whole-grains, such as brown rice. A number of scientific studies have determined that regular consumption of brown rice is linked with improved diet quality and adequate fiber intake. Furthermore, researchers have demonstrated the various health properties of brown rice and its nutritional constituents and conclusively shown that brown rice is beneficial and effective in managing blood glucose and insulin levels. However, while the effects on glucose and insulin are well understood, there is limited research regarding its effects on GLP-1 and ghrelin, two satiety hormones which are fundamental in the progression of diabetes. Despite extensive evidence supporting an inverse relationship between regular brown rice consumption and the risk of type 2 diabetes, multiple national-level studies have reported that the majority of Americans seldom consume brown rice. Previously, much focus has been placed on examining rice consumption in the population as a whole; little information is currently available addressing geographical trends. Therefore, the first objective of this research was to provide details on nutrient intake and rice consumption patterns in the Southern U.S., the region where diabetes is most prevalent. Secondly, in the interest of promoting brown rice consumption, the Korean rice cake (*Seolgitteok*) has been suggested as a potential functional food product which could simultaneously increase rice intake and satisfy U.S. consumers' increasing demand for ethnic foods. Thus, the second objective was to investigate the health effects of consuming *Seolgitteok* made with varying ratios of white-to-brown rice flour, in hopes of enhancing the consumption of brown rice among American consumers.

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Dedication

This thesis is dedicated to my kind and wonderful parents, Bonnie and Rory Pottgen, and my fiancé, Jordon Morris, as without them I would not be where I am today.

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Introduction

Diabetes is a major health problem worldwide, especially in the United States where the incidence and prevalence are expected to rise dramatically in the next few decades (CDC, 2014). According to the 2014 National Diabetes Statistics Report, published by the United States Center for Disease Control and Prevention (CDC), 29.1 million Americans have diabetes mellitus (type 1, type 2 or gestational) and 86 million Americans have pre-diabetes (CDC, 2014). Researchers at the National Institute of Health (NIH) estimate that the incidence of diabetes will rise from 14% of Americans in 2010, to somewhere between 21% and 33% of Americans by 2050 (Boyle et al. 2010).

Type 2 diabetes (T2DM) is an acquired and progressive disease characterized by insulin resistance and β-cell failure (NIH, 2014). According to statistics published by the CDC (2014), it is the most common form of diabetes, accounting for 90% to 95% of the diagnosed cases in the United States. Pre-diabetes is defined as a higher than normal fasting blood glucose level, between 100 and 125 mg/dL. Individuals with pre-diabetes have a 15% to 30% increased risk for developing T2DM. Fortunately, the onset of T2DM can be delayed, and in some cases, prevented, by implementing lifestyle changes such as improving food choices and physical activity (CDC, 2014).

Whole grain foods, including brown rice, are inversely related to the risk of T2DM (Fung et al. 2002; Sun et al. 2010; Ye et al. 2012). Brown rice lowers postprandial blood glucose response and improves insulin sensitivity (Ito et al. 2005; Panlasigui and Thompson 2006). These anti-diabetic properties can be partially attributed to the fiber and resistant starch content of brown rice. The fiber found primarily in the bran layer of brown rice, specifically the insoluble fiber, helps lower postprandial blood glucose and insulin responses (Seki et al. 2005). However, brown rice consumption in the United States remains relatively low despite the health and anti-diabetic benefits of brown rice.

Ethnic foods, particularly those with added nutritional value or those containing functional health properties, have been growing in popularity among consumers in the United States (Sloan, 2010). The Korean rice cake, *Seolgitteok*, is of particular interest because the traditional recipe, which calls for white rice flour, may be adjusted by substitution of brown rice flour; thereby improving the micro- and macronutrient content. Furthermore, introducing a new rice-based product, such as *Seolgitteok*, to the U.S. market may promote brown rice consumption. Previously, researchers determined the sensory characteristics of *Seolgitteok* deemed most acceptable by American consumers (Cho et al. 2014; Cho et al. 2016); however, the health effects of consuming *Seolgitteok* made with brown rice have not yet been investigated.

The **goals** of this research were: (I) to determine the dietary and rice consumption patterns of Caucasians in the Southern region of the United States and (II) to determine the anti-diabetic health effects of Korean rice cakes *(Seolgitteok)* made from brown rice. The **hypotheses** were (I) average dietary intake in the Southern region of the United States will be consistent with national data, rice consumption in the region will be relatively low, and regular rice consumption will be associated with improved nutrient intakes, and (II) Korean rice cake made from brown rice will contain more resistant starch and dietary fiber, produce lower postprandial blood glucose, insulin, and ghrelin response, and produce higher GLP-1 and satiation responses compared to rice cakes made with white rice. The **objectives** of part (I) were to (1) assess average micro- and macronutrient intake and frequency of rice consumption in Caucasians in the Southern region of the United States and (2) to evaluate the potential relationship between diet quality and rice intake. The objectives of part (II) were (1) to analyze the functional starch composition and the dietary fiber content in three variations of rice *Seolgitteok* and (2) to determine the effects of consuming *Seolgitteok* on postprandial blood glucose, insulin, GLP-1, and ghrelin response, as well as satiation in healthy (normoglycemic) and pre-diabetic (hyperglycemic) adults.

Literature Review

1. Diabetes Mellitus

Diabetes mellitus is a disease characterized by insufficient or depleted insulin (CDC, 2014; Kahn and Flier, 2000; Muoio and Newgard, 2008). There are three main classifications of diabetes with different etiologies, all evolving around alterations in insulin. Insulin is an anabolic hormone, mainly produced in the β-cells of the pancreas. Type 2 diabetes (T2DM) begins with insulin resistance in the muscle and adipose tissue and progressively leads to β-cell failure (CDC, 2014; Kahn and Flier, 2000; Muoio and Newgard, 2008). In insulin resistance, insulin is able to bind to the receptor on cells, but the cells do not properly respond to the insulin signal. In skeletal muscle, the GLUT4 transporter does not move to the membrane surface after insulin binding, and therefore does not take up glucose from the bloodstream (Kahn and Flier, 2000; Muoio and Newgard, 2008). In adipose tissue, insulin resistance is due to a decrease in the amount of mRNA that codes for the GLUT4 transporter (Kahn and Flier, 2000). When cells don’t properly respond to the binding of insulin the glucose remains in circulation (Kahn and Flier, 2000; Muoio and Newgard, 2008). As a result, the pancreas produces increasing quantities of insulin to meet the growing demand; this leads to progressive β-cell failure (CDC, 2014; Muoio and Newgard, 2008).

Diabetes is a widespread epidemic with a rapidly increasing incidence and prevalence (CDC, 2014). Approximately 29.1 million Americans have diabetes mellitus, which equates to nearly one in every ten people in the United States. In 2012 alone, there were 1.7 million newly diagnosed cases of diabetes in people 20 years of age and older; with a total prevalence of 10.8% in adult females and 14% in adult males (CDC, 2014). Experts have estimated that by 2050, one-fifth to one-third of American adults will have diabetes (Boyle et al. 2010). Currently, T2DM accounts for 90% to 95% of the diagnosed cases (CDC, 2014). The high rate of T2DM in the United States is largely attributed to physical inactivity, excessive intake of energy dense foods and rising obesity rates (CDC, 2014). Risk factors for T2DM include genetics, a family history of T2DM, age, obesity, physical inactivity, hypertension, and ethnicity

(NIH, 2014). High-risk ethnic groups in the United States include American Indians, Alaskan Natives, African Americans, Hispanics, and Asian Americans (NIH, 2014).

Aside from a decreased quality of life, T2DM can lead to serious secondary complications, including: vision loss, kidney failure, heart disease, stroke, and amputations of lower extremities (CDC, 2014). There are several conditions associated with diabetes, some of which include nerve disease, non-alcoholic fatty liver disease, periodontal disease, hearing loss and depression. Diabetes poses an enormous financial burden; it is estimated to have cost the United States 245 billion dollars in 2012 and health care costs for those with diabetes are 2-3 times higher than those without diabetes (CDC, 2014).

Approximately 86 million Americans are pre-diabetic (pre-DM), which equates to more than one-third of the population (CDC, 2014). Pre-diabetes is defined as a higher than normal fasting blood glucose level, more precisely, between 100 and 125 mg/dL. Individuals with pre-diabetes have a 15% to 30% increased risk for developing T2DM within five years (CDC, 2014). Fortunately, physical activity, moderate weight loss and a healthy meal plan can delay and potentially prevent the onset of T2DM (CDC, 2014).

Diet and exercise modifications have proven to be successful in the management of pre-DM. The Diabetes Prevention Program (DPP) (2002) was a lifestyle intervention research study that included over 1,000 participants. Participants received one of two treatments: a lifestyle intervention or pharmaceutical therapy (metformin) (DPP, 2002). The intervention was designed to increase weight loss (7% of initial body weight) and physical activity (150 min moderate physical activity per week), while providing participants with counseling, education and support (DPP, 2002). A substantial part of the intervention focused on improving dietary habits (DPP, 2002). Participants were encouraged to reduce fat consumption (25% of daily energy from fat) and balance energy intake (500-1,000 calories per day less than the estimated calories needed to maintain initial body weight) by making healthier food choices (DPP, 2002). As a result of the intervention, the incidence of diabetes was reduced by fifty-eight percent compared to the control (DPP, 2002). A ten-year follow up study on the Diabetes Prevention Program found that the lifestyle intervention group managed to maintained a lower incidence of T2DM, even compared to participants who were receiving metformin (DPP, 2009).

Research shows that nutritional treatment is an essential part of the prevention and management of T2DM. Currently, the American Diabetes Association's (ADA) dietary recommendations for T2DM focus on reducing total energy intake, while increasing consumption of nutrient dense foods and dietary fiber (ADA, 2016). The current evidence is inconclusive on the exact amount of carbohydrates recommended for T2DM, but individuals are encouraged to consume carbohydrates from fruits, vegetables, whole grains, legumes, and dairy products (ADA, 2016; Evert et al. 2013). In line with these recommendations, a recent study using National Health and Nutrition Examination Survey (NHANES) data from 1991 to 2011, reported that females with a history of gestational diabetes who consumed a low carbohydrate diet, high in protein and fat from animal sources had a greater risk for developing T2DM compared to females who consumed a low carbohydrate diet, high in protein and fat diet from plant sources (Bao et al. 2016). AlEssa and colleagues (2016) reported females with diets high in fiber and low in starch had improved levels of two major biomarkers predicative of T2DM risk, adiponectin and HbA1c. However, only the females who had higher intakes of cereal fiber, which includes brown rice, also had decreased levels of C-reactive protein levels, another indicator of T2DM risk (AlEssa et al. 2016). Further emphasizing the importance of consuming nutrient-dense and high fiber foods rather than simply restricting carbohydrate intake.

2. Rice Consumption in the United States

Rice consumption in the United States is relatively low, especially brown rice, despite the known health benefits. Between 1994 and 1996, 17.4% of American adults reported consuming one-fourth cup of either white rice, brown rice, or rice flour daily (Batres-Marquez et al. 2009). Between 2001 and 2002, that percentage marginally increased to 18.0% (Batres-Marquez et al. 2009). However, despite the increase in the number of people consuming rice, the portion size decreased by 8.0% (Batres-Marquez and Jensen, 2005; Batres-Marquez et al. 2009). A more recent study evaluating NHANES data from 2005 to 2010, reported that approximately 60% of American adults consume less than one-eighth cup of rice daily (Nicklas et al. 2014).

In the former studies on rice consumption, researchers assessed Americans' all-inclusive rice intake, combining white rice, brown rice, and rice flour. Data from adults in the 1994-1996 Continuing Survey of Food Intakes by Individuals (CSFII) (n=9,318) and the 2001-2002 NHANES (n=4,744) was included. Participants were classified as either rice consumers; those who reported consuming at least half of a serving (one-fourth cup) of white rice, brown rice, or rice flour daily, or non-consumers; those who reported consuming less than a half serving of white rice, brown rice, or rice flour daily (Batres-Marquez and Jensen, 2005; Batres-Marquez et al. 2009).

Batres-Marquez and colleagues (2005 and 2009) determined the age groups 20 to 24 years and 60 years and older contained the largest percentage of non-consumers (Batres-Marquez and Jensen, 2005; Batres-Marquez et al. 2009). Of those 20 to 24 years, 78.7% were non-consumers and of those 60 years of age and older, 82.1% were non-consumers. Middle-age adults, between the ages of 25 and 39, contained the largest portion of rice consumers, with 19.9% reporting daily consumption of either white rice, brown rice, or rice flour (Batres-Marquez and Jensen, 2005; Batres-Marquez et al. 2009). Additionally, the authors reported that the vast majority of the rice consumed was white; brown rice only accounted for a mere 1.3% (Batres-Marquez et al. 2009).

Caucasians (white, non-Hispanics) had the least percentage of rice consumers, with 12.4% reporting rice consumption. Caucasians also consumed the smallest portion size compared to other races/ethnicities (Batres-Marquez et al. 2009). There was no significant difference between genders, but females tended to consume more brown rice than males (Batres-Marquez and Jensen, 2005).

Rice consumption varied based on geographical region. Total consumption in the Midwestern region of the United States was 40% less and the portion size was 16% smaller compared to the national averages (Batres-Marquez and Jensen, 2005). Trends in socio-economic status were identified as well: lower income and lower education were both associated with greater rice consumption; all-inclusive of white rice, brown rice, and rice flour (Batres-Marquez et al. 2005).

Americans who consumed rice tended to consume more grains (specifically whole-grains), fruits, vegetables, meat, poultry, and fish. Rice consumers had reduced intakes of total fat, saturated fat and added sugar compared to non-consumers (Batres-Marquez and Jensen, 2005; Batres-Marquez et al.

2009; Nicklas et al. 2014). In the three previous studies, rice consumption was positively associated with greater intakes of fiber, folate, iron, and potassium (Batres-Marquez and Jensen, 2005; Batres-Marquez et al. 2009; Nicklas et al. 2014). Additionally, rice consumers were more likely to have a healthier body mass index (BMI) (Batres-Marquez and Jensen, 2005). In summary, rice consumption has been associated with improved diet quality and health status.

3. Brown Rice and Health Benefits

Americans who consumed high amounts of brown rice, defined as two or more one-half cup servings per week, tended to be leaner and more physically active (Sun et al. 2010). These individuals tended to have an overall healthier diet, with higher intakes of fruits, vegetables and whole grains and lower intakes of red meat and *trans* fat (Sun et al. 2010). Individuals who consumed white rice five or more times per week had a 17% greater risk for developing T2DM. However, those who consumed at least two servings of brown rice per week had an 11% decreased risk of developing T2DM compared to those who ate less than one serving per week (Sun et al. 2010).

Low glycemic index foods are linked to improved metabolic control, while high glycemic foods are positively correlated with T2DM risk. Brown rice elicits only a small, transient rise in postprandial glucose compared to white rice. In-*vitro* starch digestion of brown rice lowered glucose release by 23.7 percent compared to white rice (Panlasigui and Thompson, 2006). Randomized-crossover studies with both healthy and T2DM subjects, found brown rice consumption significantly reduced incremental area under the curve for glucose compared to white rice (Ito et al. 2005; Hsu et al. 2008; Panlasigui and Thompson, 2006).

In brown rice, the outer bran and germ layers remain intact. These layers are rich in key nutrients and phytonutrients, such as protein, fat, B vitamins, α-tocopherol, polyphenols and γ-oryzanol (Babu et al. 2009; Ito et al. 2005; Panlasigui and Thompson, 2006; Shobana et al. 2011; Tian et al. 2004). Additionally, removal of the bran during polishing, results in substantial losses in dietary fiber. This fiber portion serves as a barrier against digestive enzymes, slowing the digestion process and reducing the availability and release of glucose. Nutrients found in the bran layer, including phytic acid and polyphenols, also protect against digestion and lower glucose release (Panlasigui and Thompson, 2006). Brown rice also contains ɣ-aminobutyric acid (GABA), which enhances pancreatic release of insulin (Seki et al. 2005).

Brown rice provides approximately four grams of fiber per cup, while white rice provides less than one gram per cup (USDA, 2016). The recommended amount of fiber per day for adults ranges depending on age: from 28 to 34 grams for males and 22 to 28 grams for females. However, many Americans fall short of the recommendation (Trumbo et al. 2002). A recent report using NHANES data from 2011-2012 found that males over the age of 20 consume an average of 20.3 grams and females over the age of 20 consume an average of 16.1 grams of fiber per day (USDA, 2014). The 2015 Dietary Guidelines for Americans suggested consuming more whole grain foods, like brown rice, daily to increase dietary fiber intake (USDA, 2015).

According to the United States Department of Agriculture (USDA) National Nutrient Database for Standard Reference (2016), raw medium-grain brown rice contains 3.4 grams of fiber per 100 grams of rice and cooked contains about 1.8 grams of dietary fiber per 100 grams of rice. Brown rice flour contains 4.6 grams of dietary fiber per 100 grams of flour. Whereas, dry medium-grain white rice only contains 1.4 grams of dietary fiber and cooked contains 0.3 grams of dietary fiber per 100 grams of rice. White rice flour contains 2.4 grams of dietary fiber per 100 grams of flour (USDA, 2016).

Bednar and colleagues (2001) evaluated the fiber content of dry brown rice and reported that 100 grams of dry brown rice contains 5.7 grams of total fiber, slightly higher than the USDA report. Of the 5.7 grams of dietary fiber, about 75% (4.3 grams) is insoluble fiber and about 25% (1.4 grams) is soluble fiber. Brown rice flour contains 5.1 grams of total dietary fiber per 100 grams of dry weight. In rice flour about 67% (3.4 grams) of the fiber is insoluble, and about 33% (1.7 grams) is soluble (Bednar et al. 2001).

Seki and colleagues (2005) demonstrated the importance of the insoluble fiber portion of the bran in attenuating postprandial glucose and insulin responses. Brown rice was compared to white rice and destarched, defatted rice bran to determine which component is responsible for lowering postprandial glucose and potentiating pancreatic secretion of insulin. The insoluble fiber portion of the bran produced the lowest postprandial blood glucose and insulin levels, as well as the lowest incremental area under the curve. The rice bran itself is 27.0% dietary fiber by weight; 24.5% insoluble and 2.5% soluble fiber (Kahlon and Woodruff, 2003).

4. Satiety Hormones

The satiety hormones ghrelin and glucagon-like peptide-1 (GLP-1) are of specific interest because of their roles in the development and management of T2DM (Broglio et al. 2001; Dezaki et al. 2006; Tong et al. 2010; Tourrel et al. 2002; Xu et al. 1999; Zander et al. 2002). Ghrelin stimulates appetite prior to a meal while GLP-1 promotes satiety after a meal (Austin and Marks, 2009; Baggio and Drucker, 2007; Nakazato et al. 2001; Wren et al. 2001). Levels of both hormones are decreased in persons with insulin resistance, but they remain essential in the regulation and maintenance of glucose and insulin levels (Anderwald et al. 2003; Gagnon et al. 2015; Katsuki et al. 2004; Kjems et al. 2003; Pöykkö et al. 2003; Pulkkinen et al. 2010; Toft-Nielsen et al. 2001; Vilsbøll et al. 2003; Zander et al. 2002).

4.1. Ghrelin

Ghrelin is a potent orexigenic hormone, commonly referred to as the hunger hormone. Ghrelin has several important roles in the body such as regulating appetite, promoting food intake, short and long-term energy balance, and glucose and insulin homeostasis. Ghrelin is produced in the gastric fundus, by the neuroendocrine cells located in the mucosal layer (Khawaja et al. 2012). It can also be produced in other tissues including the pancreas, kidneys, gastrointestinal tract, pituitary, lungs and in smaller quantities in the hypothalamus (Van der Lely et al. 2004).

Ghrelin is primarily released from the fundus of the stomach. It crosses the blood-brain-barrier and binds to receptors in several regions of the brain. Particularly high expression is found in the dentate gyrus, hippocampus, arcuate nucleus, and hypothalamus. Other areas include the piriform cortex, paraventricular nucleus, and the olfactory nerve layer (Nakazato et al. 2001). Once ghrelin binds, it stimulates the activation and release of neuropeptide Y (NPY) and agouti-related protein (AgRP) in the arcuate nucleus (Anderwald et al. 2003; Katsuki et al. 2004; Nakazato et al. 2001). These neuropeptides are responsive to leptin as well, and help regulate appetite and body weight. Ghrelin competes with leptin for these binding sites, and reverses the appetite suppressing effects of leptin (Nakazato et al. 2001).

Ghrelin has two forms, unacylated ghrelin and acylated ghrelin. In acylated ghrelin, the third serine is octanoylated, making it the active form (Pulkkinen et al. 2010; Van der Lely et al. 2004). A higher ratio of acylated ghrelin to unacylated ghrelin is associated with insulin resistance (Pulkkinen et al. 2010). In obesity and T2DM, ghrelin levels are decreased, but the ratio of acylated ghrelin to unacylated ghrelin is higher (Katsuki et al. 2004; Pöykkö et al. 2003; Pulkkinen et al. 2010).

Ghrelin’s primary function is to maintain energy balance by stimulating appetite and food intake. Administration of ghrelin in humans and animals in both the fasting and fed states, increased food consumption regardless of the level of satiation (Nakazato et al. 2001; Wren et al. 2001). Ghrelin treatment resulted in significant body weight increases (Nakazato et al. 2001).

Aside from energy balance, ghrelin is involved in glucose and insulin homeostasis. In healthy subjects, administration of ghrelin impaired insulin and glucose metabolism. Injections resulted in significantly greater fasting and postprandial blood glucose levels. In addition to decreasing glucose tolerance, ghrelin also inhibits insulin secretion (Broglio et al. 2001; Tong et al. 2010). Studies have found that ghrelin and insulin can indirectly influence one another. First, use of an antagonist on the growth hormone receptor, the main receptor for ghrelin, resulted in increased insulin secretion (Dezaki et al. 2004; Dezaki et al. 2006). Second, gene-deletion studies showed removal of the ghrelin gene reversed glucose intolerance induced by a high fat diet (Dezaki et al. 2006).

Insulin is important for reducing ghrelin after food consumption. In healthy persons, insulin directly suppresses ghrelin in insulin-sensitive tissues, such as in the stomach, and indirectly suppresses ghrelin by decreasing the expression of NPY (neuropeptide Y). However, the ability to suppress ghrelin levels is not as profound in individuals with T2DM and it continues to decline with prolonged insulin treatment (Anderwald et al. 2003).

Several factors can influence ghrelin levels, including an individual’s health status and the composition of the meal. In lean and healthy persons, ghrelin will decrease proportional to the caloric content of the meal. However, in persons with insulin resistance, food intake fails to fully suppress ghrelin, resulting in insufficient satiation (Pöykkö et al. 2003).

Ghrelin is also a potent stimulator of gastric emptying. The inability of food intake to appropriately suppress ghrelin, not only decreases satiation, but also increases gastric emptying rate (Levin et al. 2006). This subsequently results in increased food and energy intake, and eventual weight gain.

The composition of the meal is important for regulating ghrelin. In a crossover study by Erdmann et al. (2004), 14 healthy male and female subjects received five test meals: a fat-rich meal (584±96 kcals; 0% of calories from carbohydrate, 14.5% protein, 85.5% fat), a protein-rich meal (551±81 kcals; 0% carbohydrate, 83.0% protein, 17% fat), a carbohydrate-rich meal (658±54 kcals; 79.7% carbohydrate, 12.4% protein, 7.9% fat), a variety of assorted fruits (434±45 kcals; 93.3% carbohydrate, 6.7% protein, 0% fat), and a variety of assorted vegetables (140±11 kcals; 75.0% carbohydrate, 25% protein, 0% fat). The authors found that consumption of the carbohydrate-rich meal was the only treatment that decreased ghrelin (Erdmann et al. 2014). Consumption of the fat-rich, protein-rich, assorted fruit, and assorted vegetable meals all increased postprandial ghrelin levels. However, self-reported feelings of satiation did not differ after the three macronutrient-rich meals. Therefore the relationship between postprandial ghrelin level and feelings of satiety may only apply to carbohydrate-rich meals (Erdmann et al. 2004). In a study by Khawaja et al. (2012), high glycemic index foods decreased postprandial ghrelin levels for sixty minutes while low glycemic index foods decreased ghrelin five times longer (Khawaja et al. 2012).

4.2. Glucagon-like peptide-1

GLP-1 is gastrointestinal satiety hormone. GLP-1 stimulates insulin secretion in a glucose-dependent manner and improves health of pancreatic islet cells. GLP-1 decreases speed of gastric emptying, increases satiety, and reduces food consumption. Because of its powerful effects on insulin response, β-cell health, and satiation, it has potential clinical applications for the treatment of T2DM.

The precursor to GLP-1 is proglucagon, which is found in the α-cells in the pancreas, the L-cells of the gastrointestinal tract, and in the hypothalamus. GLP-1 secretion is highest in the distal ileum and colon. GLP-1 is secreted in response to the presence of nutrients in the gastrointestinal tract (Austin and Marks, 2009; Baggio and Drucker, 2007). Secretion occurs in two phases, the first being ten to fifteen minutes after a meal and a second phase, thirty to sixty minutes after (Austin and Marks, 2009; Baggio and Drucker, 2007).

In addition to direct contact with nutrients, GLP-1 release is regulated by insulin, cholecystokinin, leptin, gastric inhibitory hormone, gastrin releasing peptide and acetylcholine. The GLP-1 receptor (GLP-1R) is found in pancreatic cells, the lungs, heart, kidney, stomach, intestines, pituitary, and in the central nervous system (Baggio and Drucker, 2007).

Postprandial alterations in GLP-1 levels correspond to changes in regional cerebral blood flow to the left dorsolateral prefrontal cortex, particularly in the left-middle and inferior frontal gyri. This area of the brain is associated with satiety. Changes in regional cerebral blood flow also occur in the hypothalamus, the area of the brain responsible for regulating food consumption (Pannacciulli et al. 2007).

GLP-1 response depends on several factors, including the amount of food consumed, the meal composition, and health status (Baggio and Drucker, 2007; Vilsbøll et al. 2003). Nutrient composition of a meal largely determines the GLP-1 response. Raben and associates (2003) compared various macronutrient-rich meals containing similar amounts of energy and fiber. This study reported that the protein-rich meal (32% of calories) produced the greatest GLP-1 response, followed by the carbohydrate-rich meal (65% of calories), and then the fat-rich meal (65% of calories) (Raben et al. 2003).

Dietary fiber (DF) and resistant starch (RS) content of a meal also impact GLP-1. DF and RS are associated with increased satiety; however, satiety levels after high DF and RS meals are inconsistently related to GLP-1. Several studies have found that DF and RS have marginal influence on GLP-1 (Elliott et al. 1993; Karhunen et al. 2010; Klosterbuer et al. 2012; Raben et al. 1994; Willis et al. 2010). In a crossover study, Elliott and colleagues (1993) investigated the effects of consuming a brown rice meal, containing 75 grams of carbohydrate, on postprandial GLP-1 levels in healthy subjects. Over a three hour period, the brown rice meal did not significantly increase GLP-1 levels from the baseline. The control glucose meal, containing 75 grams of glucose, resulted in higher postprandial glucose and insulin levels and significantly increased GLP-1 levels between thirty and sixty minutes after consumption (Elliott et al. 1993).

An individual's health can also influence GLP-1. Levels are decreased in persons with insulin resistance (Gagnon et al. 2015; Kjems et al. 2003; Toft-Nielsen et al. 2001; Vilsbøll et al. 2003). Despite the decrease, GLP-1 still promotes insulin secretion in a glucose-dependent manner. Several studies have found GLP-1 infusions significantly enhanced insulin response and stabilized glucose (Ahrén et al. 2003; Degn et al. 2004; Flint et al. 2001; Kjems et al. 2003; Zander et al. 2002). However, a higher dose of GLP-1 was required to normalize glucose in T2DM (Kjems et al. 2003).

GLP-1 can have beneficial effects on pancreatic islet cells. GLP-1 improves β-cell sensitivity to glucose, *de novo* insulin synthesis, and β-cell function and viability. The β-cells of diabetics are three times less responsive to GLP-1 due to a combination of decreased number of β-cells and decreased β-cell function (Kjems et al. 2003).

Zander and colleagues (2002) found that GLP-1 treatment in T2DM significantly improved β-cell's sensitivity to glucose. In-*vitro* studies on GLP-1 and GLP-1 analogs showed great improvements in pancreatic cell number, neogensis, proliferation and differentiation (Tourrel et al. 2002; Xu et al. 1999). In-*vitro* GLP-1 treatment also resulted in a significantly greater number of insulin-containing islet cells (Farilla et al. 2001; Tourrel et al. 2002; Xu et al. 1999).

GLP-1 is primarily known for its role as a satiety hormone. GLP-1 promotes satiety, in part, by increasing the stomach and upper intestine volume, which slows the rate of gastric emptying. Delgado-Aros and associates (2002) found that GLP-1 treatment in healthy subjects significantly reduced the speed of gastric emptying. Flint and colleagues (2001) found significantly reduced rates of gastric emptying in obese males. Zander and associates (2002) found that six weeks of GLP-1 infusions in T2DM reduced gastric emptying rate by 43 percent. In addition, GLP-1 infusions significantly reduced feelings of hunger and prospective food intake and resulted in significant weight loss.

GLP-1 improves the uptake of glucose, enhances β-cell function and increases insulin synthesis. GLP-1 and derivatives have shown great potential in the management of T2DM. Current therapeutic approaches include use of long-acting GLP-1 receptor agonist, inhibitors of GLP-1 degradation, and GLP-1 derivatives that are resistant to degradation (Degn et al. 2004; Gagnon et al. 2015). The American Diabetes Association (ADA, 2016) recommends including GLP-1 agonist medication for individuals who cannot successfully control their Hemoglobin A1C levels after 3 months of using Metformin or other noninsulin monotherapy methods alone.

It seems plausible that therapeutic approaches would aim to suppress ghrelin activity and enhance GLP-1 activity. Until recently, the relationship, if any, between these two satiety hormones was unknown. However, Gagnon and colleagues (2015) found that ghrelin has a significant role in stimulating postprandial GLP-1 release. Pre-treatment of mice with acylated ghrelin prior to an oral glucose tolerance test (OGTT) resulted in significantly higher postprandial GLP-1 responses. The amount of insulin released was not significantly higher in the ghrelin treated group, but the glucose tolerance significantly improved. When the ghrelin-receptor was blocked, the ability of glucose to stimulate GLP-1 was significantly lower and insulin secretion was significantly reduced. Furthermore, researchers found treatment of human and mice L-cells with ghrelin resulted in a significantly greater release of GLP-1 (Gagnon et al. 2015).

References

Ahren B, Holst JJ, Mari A. Characterization of GLP-1 Effects on β-Cell Function after Meal Ingestion in Humans. Diabetes Care. 2003;26:2860–4.

AlEssa HB, Ley SH, Rosner B, Malik VS, Willett WC, Campos H, Hu FB. High Fiber and Low Starch Intakes Are Associated with Circulating Intermediate Biomarkers of Type 2 Diabetes among Women. J Nutr. 2016;146:306–17.

American Diabetes Association. Standards of Medical Care in Diabetes—2016 Abridged for Primary Care Providers. Clin Diabetes. 2016;34:3–21.

Anderwald C, Brabant G, Bernroider E, Horn R, Brehm A, Waldhausl W, Roden M. Insulin-Dependent Modulation of Plasma Ghrelin and Leptin Concentrations Is Less Pronounced in Type 2 Diabetic Patients. Diabetes. 2003;52:1792–8.

Austin J, Marks D. Hormonal regulators of appetite. Int J Pediatr Endocrinol. 2009; 2009:141753.

Babu PD, Subhasree RS, Bhakyaraj R, Vidhyalakshmi R. Brown rice-beyond the color reviving a lost health food-a review. Magnesium. 2009;187:13-0.

Baggio LL, Drucker DJ. Biology of Incretins: GLP-1 and GIP. Gastroenterology. 2007;132:2131–57.

Bao W, Li S, Chavarro JE, Tobias DK, Zhu Y, Hu FB, Zhang C. Low Carbohydrate–Diet Scores and Long-term Risk of Type 2 Diabetes Among Women With a History of Gestational Diabetes Mellitus: A Prospective Cohort Study. Diabetes Care. 2016;39:43–9.

Batres-Marquez SP, Jensen HH. Rice consumption in the United States: New Evidence from food consumption surveys. Amens: Iowa State University Center for Agricultural and Rural Development; 2005 [cited 2015 August 25].

Batres-Marquez SP, Jensen HH, Upton J. Rice Consumption in the United States: Recent Evidence from Food Consumption Surveys. J Am Diet Assoc. 2009;109:1719–27.

Bednar GE, Patil AR, Murray SM, Grieshop CM, Merchen NR, Fahey GC. Starch and fiber fractions in selected food and feed ingredients affect their small intestinal digestibility and fermentability and their large bowel fermentability in vitro in a canine model. J Nutr. 2001;131:276-86.

Boyle JP, Thompson TJ, Gregg EW, Barker LE, Williamson DF. Projection of the year 2050 burden of diabetes in the US adult population: dynamic modeling of incidence, mortality, and prediabetes prevalence. Popul Health Metr. 2010;8:29-40.

Broglio F, Arvat E, Benso A, Gottero C, Muccioli G, Papotti M, Ghigo E. Ghrelin, a Natural GH Secretagogue Produced by the Stomach, Induces Hyperglycemia and Reduces Insulin Secretion in Humans. J Clin Endocrinol Metab. 2001;86:5083-5.

Centers for Disease Control and Prevention (CDC), National Institute of Diabetes and Digestive and Kidney Diseases. National Diabetes Statistics Report: Estimates of Diabetes and Its Burden in the United States, 2014. 2014 [cited 2016 Jan 21]. Available from: www.diabetes.niddk.nih.gov.

Cho S, Yoon SH, Min J, Lee S, Tokar T, Lee SO, Seo HS. Variations in US Consumers' Acceptability of Korean Rice Cake, Seolgitteok, with respect to Sensory Attributes and Nonsensory Factors. J Food Sci. 2016;81:S199-207.

Cho S, Yoon SH, Min J, Lee S, Tokar T, Lee SO, Seo HS. Sensory characteristics of Seogitteok (Korean rice cake) in relation to the added levels of brown rice flour and sugar. J Sens Stud. 2014;29:371–83.

Degn KB, Juhl CB, Sturis J, Jakobsen G, Brock B, Chandramouli V, Rungby J, Landau BR, Schmitz O. One Week's Treatment With the Long-Acting Glucagon-Like Peptide 1 Derivative Liraglutide (NN2211) Markedly Improves 24-h Glycemia and α- and β-Cell Function and Reduces Endogenous Glucose Release in Patients with Type 2 Diabetes. Diabetes. 2004;53:1187–94.

Delgado-Aros S, Kim DY, Burton DD, Thomforde GM, Stephens D, Brinkmann BH, Camilleri M. 2002. Effect of GLP-1 on gastric volume, emptying, maximum volume ingested, and postprandial symptoms in humans. Am J Physiol Gastrointest Liver Physiol. 2002;28:G424-31.

Dezaki K, Hosoda H, Kakei M, Hashiguchi S, Watanabe M, Kangawa K, Yada T. Endogenous Ghrelin in Pancreatic Islets Restricts Insulin Release by Attenuating Ca2 Signaling in β-Cells: Implication in the Glycemic Control in Rodents. Diabetes. 2004;53:3142–51.

Dezaki K, Sone H, Koizumi M, Nakata M, Kakei M, Nagai H, Hosoda H, Kangawa K, Yada T. Blockade of Pancreatic Islet-Derived Ghrelin Enhances Insulin Secretion to Prevent High-Fat Diet-Induced Glucose Intolerance. Diabetes. 2006;55:3486–93.

Diabetes Prevention Program Research Group. 10-year follow-up of diabetes incidence and weight loss in the Diabetes Prevention Program Outcomes Study. Lancet. 2009;374:1677–86.

Diabetes Prevention Program Research Group. The Diabetes Prevention Program (DPP): Description of lifestyle intervention. Diabetes Care. 2002;25:2165–71.

Elliott RM, Morgan LM, Tredger JA, Deacon S, Wright J, Marks V. Glucagon-like peptide-1(7-36)amide and glucose-dependent insulinotropic polypeptide secretion in response to nutrient ingestion in man: acute post-prandial and 24-h secretion patterns. J Endocrinol. 1993;138:159–66.

Erdmann J, Töpsch R, Lippl F, Gussmann P, Schusdziarra V. Postprandial Response of Plasma Ghrelin Levels to Various Test Meals in Relation to Food Intake, Plasma Insulin, and Glucose. J Clin Endocrinol Metab. 2004;89:3048–54.

Evert AB, Boucher JL, Cypress M, Dunbar SA, Franz MJ, Mayer-Davis EJ, Neumiller JJ, Nwankwo R, Verdi CL, Urbanski P, et al. Nutrition Therapy Recommendations for the Management of Adults With Diabetes. Diabetes Care. 2013;36:3821–42.

Farilla L, Bulotta A, Hirshberg B, Calzi SL, Khoury N, Noushmehr H, Bertolotto C, Mario UD, Harlan DM, Perfetti R. Glucagon-Like Peptide 1 Inhibits Cell Apoptosis and Improves Glucose Responsiveness of Freshly Isolated Human Islets. Endocrinol. 2003;144:5149–58.

Flint A, Raben A, Ersbøll AK, Holst JJ, Astrup A. The effect of physiological levels of glucagon-like peptide-1 on appetite, gastric emptying, energy and substrate metabolism in obesity. Int J Obes Relat Metab Disord. 2001;25:781–92.

Fung TT, Hu FB, Pereira MA, Liu S, Stampfer MJ, Colditz GA, Willett WC. Whole-grain intake and the risk of type 2 diabetes: a prospective study in men. Am J Clin Nutr. 2002;76:535-40.

Gagnon J, Baggio LL, Drucker DJ, Brubaker PL. Ghrelin Is a Novel Regulator of GLP-1 Secretion. Diabetes. 2014;64:1513–21.

Hsu T-F, Kise M, Wang M-F, Ito Y, Yang M-D, Aoto H, Yoshihara R, Yokoyama J, Kunii D, Yamamoto S. Effects of Pre-Germinated Brown Rice on Blood Glucose and Lipid Levels in Free-Living Patients with Impaired Fasting Glucose or Type 2 Diabetes. J Nutr Sci Vitaminol. 2008;54:163–8.

Ito Y, Mizukuchi A, Kise M, Aoto H, Yamamoto S, Yoshihara R, Yokoyama J. Postprandial blood glucose and insulin responses to pre-germinated brown rice in healthy subjects. J Med Invest. 2005;52:159–64.

Kahlon TS, Woodruff CL. In Vitro Binding of Bile Acids by Rice Bran, Oat Bran, Barley and β-Glucan Enriched Barley. Cereal Chem. 2003;80:260–3.

Kahn BB, Flier JS. Obesity and insulin resistance. J Clin Invest. 2000;106:473-81.

Karhunen LJ, Juvonen KR, Flander SM, Liukkonen K-H, Lahteenmaki L, Siloaho M, Laaksonen DE, Herzig K-H, Uusitupa MI, Poutanen KS. A Psyllium Fiber-Enriched Meal Strongly Attenuates Postprandial Gastrointestinal Peptide Release in Healthy Young Adults. J Nutr. 2010;140:737–44.

Katsuki A, Urakawa H, Gabazza E, Murashima S, Nakatani K, Togashi K, Yano Y, Adachi Y, Sumida Y. Circulating levels of active ghrelin is associated with abdominal adiposity, hyperinsulinemia and insulin resistance in patients with type 2 diabetes mellitus. Eur J Endocrinol. 2004;151:573–7.

Khawaja KI, Fatima A, Mian SA, Mumtaz U, Moazzum A, Ghias M, Masud F. Glycaemic, insulin and ghrelin responses to traditional South Asian flatbreads in diabetic and healthy subjects. Br J Nutr. 2012;108:1810–7.

Kjems LL, Holst JJ, Volund A, Madsbad S. The Influence of GLP-1 on Glucose-Stimulated Insulin Secretion: Effects on β-Cell Sensitivity in Type 2 and Nondiabetic Subjects. Diabetes. 2003;52:380–6.

Klosterbuer AS, Thomas W, Slavin JL. Resistant Starch and Pullulan Reduce Postprandial Glucose, Insulin, and GLP-1, but Have No Effect on Satiety in Healthy Humans. J Agric Food Chem. 2012;60:11928–34.

Levin F, Edholm T, Schmidt PT, Grybäck P, Jacobsson H, Degerblad M, Höybye C, Holst JJ, Rehfeld JF, Hellström PM, et al. Ghrelin Stimulates Gastric Emptying and Hunger in Normal-Weight Humans. J Clin Endocrinol Metab. 2006;91:3296–302.

Muoio DM, Newgard CB. Molecular and metabolic mechanisms of insulin resistance and β-cell failure in type 2 diabetes. Nat Rev Mol Cell Biol. 2008;9:193-205.

Nakazato M, Murakami N, Date Y, Kojima M, Matsuo H, Kangawa K, Matsukura S. A role for ghrelin in the central regulation of feeding. Nature. 2001;409:194-8.

National Institute of Health (NIH). Publication No. 14–5164. Causes of Diabetes. 2014 [cited 2015 December 2]. Available from http://diabetes.niddk.nih.gov/dm/pubs/causes/

Nicklas TA, O'Neil CE, Fulgoni VL. Rice Consumption Is Associated with Better Nutrient Intake and Diet Quality in Adults: National Health and Nutrition Examination Survey (NHANES) 2005-2010. Food Nutr Sci. 2014;05:525–32.

Panlasigui LN, Thompson LU. Blood glucose lowering effects of brown rice in normal and diabetic subjects. Int J Food Sci Nutr. 2006;57:151–8.

Pannacciulli N, Le DSN, Salbe AD, Chen K, Reiman EM, Tataranni PA, Krakoff J. Postprandial glucagon-like peptide-1 (GLP-1) response is positively associated with changes in neuronal activity of brain areas implicated in satiety and food intake regulation in humans. NeuroImage. 2007;35:511–7.

Pöykkö SM, Kellokoski E, Hörkkö S, Kauma H, Kesäniemi YA, Ukkola O. Low Plasma Ghrelin Is Associated With Insulin Resistance, Hypertension, and the Prevalence of Type 2 Diabetes. Diabetes. 2003;52:2546–53.

Pulkkinen L, Ukkola O, Kolehmainen M, Uusitupa M. Ghrelin in Diabetes and Metabolic Syndrome. Int J Pept. 2010;2010:1–11.

Raben A, Agerholm-Larsen L, Flint A, Holst JJ, Astrup A. Meals with similar energy densities but rich in protein, fat, carbohydrate, or alcohol have different effects on energy expenditure and substrate metabolism but not on appetite and energy intake. Am J Clin Nutr. 2003;77:91-100.

Raben A, Tagliabue A, Christensen NJ, Madsen J, Holst JJ, Astrup A. 1994. Resistant starch: the effect on postprandial glycemia, hormonal response, and satiety. Am J Clin Nutr. 1994;60:544-51.

Seki T, Nagase R, Torimitsu M, Yanagi M, Ito Y, Kise M, Mizukuchi A, Fujimura N, Hayamizu K, Ariga T. Insoluble Fiber Is a Major Constituent Responsible for Lowering the Post-Prandial Blood Glucose Concentration in the Pre-Germinated Brown Rice. Biol Pharm Bull. 2005;28:1539–41.

Shobana S, Malleshi N, Sudha V, Spiegelman D, Hong B, Hu F, Willett W, Krishnaswamy K, Mohan V. Nutritional and sensory profile of two Indian rice varieties with different degrees of polishing. Int J Food Sci Nutr. 2011;62:800–10.

Sloan EA. Consumer Trends US Consumers Have a Taste for World Cuisines. Food Technol. 2010;64:19.

Sun Q, Spiegelman D, van Dam RM, Holmes MD, Malik VS, Willett WC, Hu FB. White Rice, Brown Rice, and Risk of Type 2 Diabetes in US Men and Women. Arch Intern Med. 2010;170:961-69.

Tian S, Nakamura K, Kayahara H. Analysis of Phenolic Compounds in White Rice, Brown Rice, and Germinated Brown Rice. J Agric Food Chem. 2004;52:4808–13.

Toft-Nielsen MB, Damholt MB, Madsbad S, Hilsted LM, Hughes TE, Michelsen BK, Holst JJ. Determinants of the Impaired Secretion of Glucagon-Like Peptide-1 in Type 2 Diabetic Patients. J Clin Endocrinol Metab. 2001;86:3717–23.

Tong J, Prigeon RL, Davis HW, Bidlingmaier M, Kahn SE, Cummings DE, Tschop MH, D'alessio D. Ghrelin Suppresses Glucose-Stimulated Insulin Secretion and Deteriorates Glucose Tolerance in Healthy Humans. Diabetes. 2010;59:2145–51.

Tourrel C, Bailbe D, Lacorne M, Meile M-J, Kergoat M, Portha B. Persistent Improvement of Type 2 Diabetes in the Goto-Kakizaki Rat Model by Expansion of the β-Cell Mass During the Prediabetic Period With Glucagon-Like Peptide-1 or Exendin-4. Diabetes. 2002;51:1443–52.

Trumbo P, Schlicker S, Yates AA, Poos M. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. J Am Diet Assoc. 2002;102:1621-30.

U.S. Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory. USDA National Nutrient Database for Standard Reference. Release 28; September 2015, revised May 2016 [cited 2016 Jun 6]. Available from: http://www.ars.usda.gov/nea/bhnrc/ndl.

U.S. Department of Agriculture, Agricultural Research Service. Nutrient intakes from food and beverages. Mean amounts consumed per individual, by gender and age. What we eat in America, NHANES 2011–2012. 2014 [cited 2016 Jun 20]. Available from: www.ars.usda.gov/ba/bhnrc/fsrg.

U.S. Department of Agriculture, Health and Human Services. Dietary guidelines for Americans 2015, 8th ed. U.S. Department of Health and Human Services; 2015 [cited 2016 Jun 6]. Available from: http://www.health.gov/dietaryguidelines/dga2005/document/pdf/DGA2005.pdf.

Van Der Lely AJ, Tschop M, Heiman ML, Ghigo E. Biological, physiological, pathophysiological, and pharmacological aspects of ghrelin. Endocr Rev. 2004;25:426-57.

Vilsbøll T, Krarup T, Sonne J, Madsbad S, Vølund A, Juul AG, Holst JJ. Incretin Secretion in Relation to Meal Size and Body Weight in Healthy Subjects and People with Type 1 and Type 2 Diabetes Mellitus. J Clin Endocrinol Metab. 2003;88:2706–13.

Willis HJ, Thomas W, Eldridge AL, Harkness L, Green H, Slavin JL. Increasing doses of fiber do not influence short-term satiety or food intake and are inconsistently linked to gut hormone levels. Food Nutr Res. 2010;53-60.

Wren AM, Seal LJ, Cohen MA, Brynes AE, Frost GS, Murphy KG, Bloom SR. Ghrelin Enhances Appetite and Increases Food Intake in Humans. J Clin Endocrinol Metab. 2001;86:5992–6.

Xu G, Stoffers DA, Habener JF, Bonner-Weir S. Exendin-4 stimulates both beta-cell replication and neogenesis, resulting in increased beta-cell mass and improved glucose tolerance in diabetic rats. Diabetes. 1999;48:2270–6.

Ye EQ, Chacko SA, Chou EL, Kugizaki M, Liu S. Greater Whole-Grain Intake Is Associated with Lower Risk of Type 2 Diabetes, Cardiovascular Disease, and Weight Gain. J Nutr. 2012;142:1304–13.

Zander M, Madsbad S, Madsen JL, Holst JJ. Effect of 6-week course of glucagon-like peptide 1 on glycaemic control, insulin sensitivity, and β-cell function in type 2 diabetes: a parallel-group study. Lancet. 2002;359:824–30.

Nutrient Intake and Rice Consumption in the Southern United States

Abstract

The diabetes belt, identified by the CDC in 2011, spanned across much of the Southern United States, consisting of 644 counties in 15 neighboring states. Within the diabetes belt, the prevalence of diabetes was at least 11.7%, while the, while the rest of the country had an average rate of 8.5%. Consumption of fiber-rich whole grains, including brown rice, is inversely related to type 2 diabetes. However, the majority of Americans fall short of consuming adequate fiber. The purpose of this research was to determine the average nutrient intake and rice consumption of Caucasians in the Southern U.S. and to evaluate the potential relationship between diet quality and frequency of rice consumption. A 7-day food frequency questionnaire was administered and data from 60 males and 106 females, with a mean age of 30.8±14.3 (SD) (18-30yoa, n=111; 31-50yoa, n=30; 51-70yoa, n=25) were included. Participants who consumed white rice, brown rice, or both, two or more times in a seven day period were classified as rice consumers (RC) (n=39). Mean energy intake was 1930±47 kilocalories/day (43.7±0.5% carbohydrate, 16.5±0.5% protein, 36.5±0.4% lipid, energy percent). Mean dietary fiber intake was 22.1±0.8 grams/day, surpassing the national average of 15.6 grams, but short of the recommendation. Ages 18-30 consumed more protein (%) than ages 31-50 ($P<0.05$). Ages 51-70 consumed more fat (%) than those 18-30yoa ($P<0.05$). Ages 31-50 consumed more dietary fiber than ages 18-30 and 51-70, and more polyunsaturated fat than ages 18-30 ($P<0.05$). The majority reported consuming white rice one-to-three times per month (34.9%) and brown rice less than one time per month (54.6%). Ages 31-50 were the most frequent consumers of both white- and brown rice. Compared to non-rice consumers (NRC), RC had higher daily intakes of energy, dietary fiber, polyunsaturated fat, vitamins A, C, E, thiamin, niacin, folate, potassium, calcium, iron, phosphorus, magnesium, copper, manganese, and selenium ($P<0.05$). Key findings include that rice, brown rice in particular, is consumed infrequently and that regular consumption, regardless of whether it is white- or brown rice, is associated with adequate nutrient intakes, most notably dietary fiber, and improved diet quality.

Introduction

Diabetes is a major health epidemic worldwide and especially here in the United States. In 2010, it was reported that approximately one in ten people in the U.S. had been diagnosed with diabetes (CDC, 2014). That number is estimated to increase to as many as one in three adults by 2050 (Boyle et al. 2010). Type 2 diabetes (T2DM) accounts for 90-95% of the diagnosed cases of diabetes (CDC, 2014).

Based on analysis of county-level data, experts at the CDC identified a portion of the U.S. with a very highly concentrated prevalence of diabetes, now termed the “diabetes belt.” The diabetes belt consists of 15 states, primarily in the Southern U.S., where diabetes affects more than 11.7% of the population. Researchers attributed the heightened prevalence of diabetes to the high obesity rate and physical inactivity (Barker et al. 2011; CDC, 2014).

Recommendations for T2DM include consuming carbohydrates from nutrient- and fiber dense sources, such as brown rice. Brown rice provides dietary fiber, vitamins, minerals, phytic acid, polyphenols, and ɣ-aminobutyric acid (GABA), each of which have been found to contain some level of anti-diabetic properties (Ito et al. 2005; Panlasigui and Thompson, 2006; Seki et al. 2005; Tian et al. 2004). Despite the documented health benefits rice consumption, most especially brown rice, remains consistently low in the U.S.

The majority of U.S. adults reportedly consume less than one-eighth cup of rice daily (Nicklas et al. 2014). Rice consumption patterns tend to vary based on demographic characteristics: Caucasians (white, non-Hispanic) and ages 20 to 24 years and 60 years and older tend to consume rice the least (Batres-Marquez and Jensen, 2005; Batres-Marquez et al. 2009).

Regular rice consumption has been linked to better diet quality; consumption is positively associated with the intake of whole-grains, fruits, vegetables, meat, poultry, fish, fiber, folate, iron and potassium (Batres-Marquez and Jensen, 2005; Batres-Marquez et al. 2009; Nicklas et al. 2014; Sun et al. 2010). Additionally, consumption is negatively associated with the intake of fat (total), saturated fat, and added sugar (Batres-Marquez and Jensen, 2005; Batres-Marquez et al. 2009; Nicklas et al. 2014; Sun et al. 2010). Furthermore, Sun et al. (2010) determined that adults who consumed one-half cup serving of brown rice two or more times per week, were more likely to be physically active and have a lower body mass index (BMI).

The purpose of this research was to better understand the current dietary intake and the average frequency of rice consumption of the white, non-Hispanic (Caucasian) population in the Southern U.S. and identify any trends between regular rice consumption and improved nutrient intakes. The objectives were to (1) assess the average micro- and macronutrient intakes and frequency of rice consumption in the target population and compare and contrast major findings by gender and age and (2) to evaluate the potential relationship between average nutrient intake and rice consumption.

Materials and Methods

Participant Profile

The Institute of Research Board at the University of Arkansas approved this human study to be conducted at the University of Arkansas Food Science Department (IRB approval #13-07-024, Appendix C-I). A sample of 166 adult male and female volunteers, with an average age of 30.8±14.3 (SD) years old, completed a Food Frequency Questionnaire (FFQ). Inclusion criteria included white, non-Hispanics, 18 to 70 years old and currently residing in the South. In order to identify any trends or patterns in dietary intake and rice consumption, two variables were used to categorize responses. Participants were grouped by gender (female, n=106; male, n=60) and also by age (young adults, 18-30 years, n=111; middle-age adults, 31-50 years, n=30; older adults, 51-70 years, n=25). For the purpose of this study, participants were classified as rice consumers (RC) (n=39) if they reported consuming white rice, brown rice, or both, two or more times per week.

Food Frequency Questionnaire Analysis

A seven-day food frequency questionnaire (FFQ) was distributed at the University of Arkansas' main campus and in the surrounding area (Fayetteville, Arkansas, USA) (Appendix A). The FFQ provided an exhaustive list of food items and asked participants to report the quantity and frequency of consumption for each. FFQ responses were analyzed using Axxya System Nutritionist Pro™ software version 4.3.0 (Stafford, Texas, USA) based on USDA References. The questionnaire included additional questions intended to assess average frequency of white and brown rice consumption. Participants' were instructed to specify their gender and age on the questionnaire as well.

Statistical Analysis

SAS 9.4© (SAS Institute Inc. Cary, NC, USA) was used to analyze data and determine statistical significance. Values are expressed as means ± standard error of the mean (SEM) unless otherwise specified as standard deviation (SD). Significant differences were computed using analysis of variance (ANOVA), and a P-value of less than 0.05 was considered significant.

Results and Discussion

The 2015 Dietary Guidelines for Americans reported, based on evidence from National Health and Nutrition Examination Surveys (NHANES) conducted from 1999-2010, that the average adult, 19 years of age (yoa) and older, consumes between 1,765 and 2,514 kilocalories per day depending on gender (USDA, 2015). The mean energy intake for the participants in this study (n=166) was 1930±47 kilocalories, falling within the average range reported by the USDA (Table 1). According to the 2015 Dietary Guidelines, it is recommended that adult (19yoa and older) males consume between 2,000 and 3,000 kilocalories per day and females consume between 1,600 and 2,400 kilocalories per day depending on physical activity level and other health factors (USDA, 2015). In the present study, the average energy intake for both genders fell within the recommended ranges (Table 1).

Participants' combined daily energy intake from protein (16.5±0.5%) (n=166) was within the acceptable macronutrient distribution range (AMDR) of 10-35% (Trumbo et al. 2002; USDA, 2015). This finding is consistent with the national average for adults (19yoa and older) of approximately 16.0% (USDA, 2015). Daily energy intake from carbohydrate was 43.7±0.5%, slightly less than the AMDR of 45-65% (Trumbo et al. 2002; USDA, 2015) and below the national average of 49.0% (USDA, 2014).

The 2015 Dietary Guidelines reported that nearly all Americans do not meet the recommendation for dietary fiber and listed fiber as a nutrient considered to be of substantial public health concern in the U.S. (USDA, 2015). The recommended amount of fiber for adult males is between 28 and 34 grams depending on age (19-30yoa, 33.6 g; 31-50yoa, 30.8 g; 51+yoa, 28 g), however, the national average for adult males is 18.2 grams per day (USDA, 2015). The recommended amount of fiber for adult females is 22 to 28 grams depending on age (19-30yoa, 28 g; 31-50yoa, 25.2 g; 51+yoa, 22.4 g) and the national average is 14.8 grams per day, also short of the recommendation (USDA, 2015). In the present study, the average fiber intake was 22.1±0.8 grams; higher than the national average of 15.6 grams, but still below the recommendation (USDA, 2015). Combined averages for both males (total, 23.6±1.6 g; 18-30yoa, 22.4±1.9 g; 31-50yoa, 29.1±4.7 g; 51-70yoa, 21.0±1.9 g, per day) and females (total, 21.3±0.9 g; 18-30yoa, 20.2±0.9 g; 31-50yoa, 25.7±3.6 g; 51-70yoa, 21.6±2.3 g, per day) fell short of the recommendations (Table 1). The USDA recommends increasing intake of whole grains, such as brown rice, to boost daily fiber intake (USDA, 2015).

In the present study, energy intake from lipid was 36.5±0.4%, above the AMDR of 20-35% (Trumbo et al. 2002; USDA, 2015) and above the national average of 33.0% (USDA, 2015). The average daily fat intake was 79.7±2.3 grams. Males consumed an average of 89.3±4.5 grams of fat daily, less than the national average for adult males of 94.5±1.2 grams (USDA, 2015). Females consumed an average of 74.3±2.4 grams of total fat daily, greater than the national average for adult females of 66.4±0.7 (USDA, 2015).

Solid fats, such as *trans*-fat and saturated fat, are consumed in excessive amounts in the U.S. Adults consume, on average, 16% of daily energy from solid fats and 11% of that is from saturated fat (USDA, 2015). The average daily saturated fat intake for participants in this study was 25.4±0.8 grams, or approximately 8.4% of daily energy intake, below the national average. The Dietary Guidelines recommend not consuming more than 10% of calories from saturated fat (USDA, 2015). Experts recommend further decreasing intake to less than 7.0% to reduce the risk of cardiovascular disease (USDA, 2015).

In this study, 3.3% of energy intake was from alcohol, or approximately 64 kilocalories (data not shown). The Dietary Guidelines reported that alcohol is one of the top contributors to energy intake in adults, accounting for 3.8% of the daily energy intake (USDA, 2015).

Average cholesterol intake in males was previously considered excessive, with the major contributors being eggs, egg products, chicken, and beef (USDA, 2010). The USDA previously recommended cholesterol intake be below 300 mg per day (USDA, 2010). However, more recent evidence has failed to link cholesterol intake to serum cholesterol levels, therefore no recommendations were included in the most recent version of the Dietary Guidelines and cholesterol was no longer listed as a nutrient of concern for over-consumption (USDA, 2015). The national average for males is 348 mg and 225 mg for females (USDA, 2015). Mean intake in this study was 274.7±10.7 mg, below the previously recommended amount. The average for males (301.3±16.8 mg) was marginally over the previous USDA recommendation, but still well below the national average for males. Interestingly, females consumed an average of approximately 260 mg of cholesterol, which is lower than the previously recommended amount, but higher than the national average for females.

In the present study, middle-age adults had a significantly larger portion of energy intake from carbohydrates (45.6±1.1%) compared to older adults (43.1±1.3%) ($P<0.05$) (Figure 1). Both the young and older adult groups did not meet the AMDR of 45-65% for carbohydrate. Young adults consumed a significantly larger portion of energy from protein (16.9±0.3%) compared to middle-age adults (15.2±0.4%) ($P<0.05$). Finally, older adults consumed a significantly larger portion of energy from lipid (38.5±1.0%) when compared to young adults (36.0±0.5%) ($P<0.05$) (Figure 1).

In addition to macronutrient composition, fiber and polyunsaturated fat intake also varied between age groups. Middle-age adults consumed significantly more fiber (27.2±2.8 g) compared to the young adults (21.0±0.9 g) and older adults (21.3±1.6 g) ($P<0.05$). Middle-age adults consumed significantly more polyunsaturated fat (19.0±2.1 g) than young adults (16.0±0.6 g) ($P<0.05$), but did not differ from the older adults (17.3±1.2 g).

The majority of participants (34.9%) reported consuming white rice 1 to 3 times per month, followed by less than once per month (34.3%). The remaining 30.8% of participants reported consuming white rice at least once weekly (Figure 2A). More than half of participants reported consuming brown rice less than once a month (54.6%) and exactly one-third reported consuming brown rice between 1 and 4 times per month (Figure 2B). Only a small number of respondents reported consuming brown rice at least two times per week (12.1%).

The recommended amount of refined grains for a 2,000-calorie diet is 3.0 ounces per day, however, approximately 70% of Americans consume more than that (USDA, 2015). The USDA suggests replacing at least half of refined grains with whole-grains, and recommends adults consume at least 3-4 ounces of whole gains daily depending on gender (USDA, 2015). Recent research revealed that nearly all Americans do not meet the recommendation for whole grains; however, consumption significantly increased between 2001-2004 and 2007-2010 for adults (19-70yoa) (USDA, 2015). The USDA mentions that a diet with adequate whole grains, will partially fulfill daily requirements of other short-fall nutrients, including 32% fiber, 42% iron, 35% folic acid, 29% magnesium, and 16% of vitamin A (USDA, 2015).

In the U.S., 4.4% of all grains consumed are from rice or rice dishes (USDA, 2010). The present study found rice consumption to be low and white rice, a refined grain, was consumed more frequently than brown rice, a whole grain. Only a small number of participants reported consuming brown rice two or more times weekly. This finding is consistent with prior research by Kennedy and Luo (2015) which reported that, based on analyses of the 2007-2008 NHANES and the Food Commodity Intake Database, the vast majority of U.S. adults do not consume brown rice regularly.

In order to equally evaluate white and brown rice consumption, responses were grouped into three categories: <1x per month, 1-4x per month, or ≥2x per week (Table 2). One response was missing from the young adult group for frequency of brown rice consumption (n=110). For all age categories, the majority reported consuming white rice 1-4x per month, and the second highest number reporting white rice consumption <1x per month. For brown rice, the majority in each age category reported consuming brown rice <1x per month, followed by 1-4x per month.

Participants were considered rice consumers (RC) if they reported consumption at least two times per week, and those who consumed rice less frequently or not at all were considered non-rice consumers (NRC). RCs were further categorized by the type of rice consumed: white rice-only consumers (WRC, n=19), brown rice-only consumers (BRC, n=16), and white and brown rice consumers (WRC+BRC, n=4); who consumed both white and brown rice separately at least twice a week.

Middle-age adults had the greatest percentage of RC for both white (20.0%) and brown (20.0%) rice. For young adults, the number of RC decreased from white rice (15.3%) to brown rice (11.8%). None of the older adults were WRC, but one participant in that age group was a BRC (Table 2).

As previously mentioned, Batres-Marquez and associates reported that individuals in their early twenties and individuals over the age of sixty greatest number of non-consumers, consistent with the present study (Batres-Marques and Jensen, 2005; Batres-Marquez 2009).

Several significant differences were found when comparing nutrient intakes of NRC (n=127) to RC (n=39) (Table 3). RC had significantly higher daily energy intake than NRC (P<0.05); consistent with several previous studies (Batres-Marques and Jensen, 2005; Batres-Marquez 2009; Fulgoni et al. 2010; Kennedy and Luo, 2015). Fiber intake was also significantly greater for RC than NRC (P<0.05); also in agreement with previous findings (Batres-Marques and Jensen, 2005; Batres-Marquez 2009; Fulgoni et al. 2010; Nicklas et al. 2014). In addition, RC also had a significantly higher polyunsaturated fatty acid intake ($P<0.05$).

An inverse relationship between rice consumption and fat (total) and saturated fat intake has been reported previously by multiple authors (Batres-Marques and Jensen, 2005; Batres-Marquez 2009; Fulgoni et al. 2010; Kennedy and Luo, 2015). However, the above study found no difference in fat (total) or saturated fat between RC and NRC.

RC had significantly greater intakes of several micronutrients, including: vitamins A, C, and E, thiamin, niacin, folate, potassium, calcium, iron, phosphorus, magnesium, copper, manganese and selenium (Table 3) ($P<0.05$). Improved intakes for vitamins A and C, thiamin, niacin, and folate have been reported in previous work (Fulgoni et al. 2010; Kennedy and Luo, 2015). Intakes of riboflavin, pyridoxine (vitamin B6), and cobalamin (vitamin B12) were greater in RC, however, not significantly as seen in prior studies (Fulgoni et al. 2010; Kennedy and Luo, 2015). RC had significantly greater intakes of numerous minerals, including: potassium, iron, phosphorus, magnesium, copper, manganese, and selenium, also supported by findings of previous research (Batres-Marques and Jensen, 2005; Batres-Marquez 2009; Kennedy and Luo, 2015; Fulgoni et al. 2010; Nicklas et al. 2014). It is important to note that the formerly mentioned studies may have used different methodology or included different populations and the criteria for determining a “rice consumer” may vary.

Several differences were found when NRC and RC were analyzed based on gender (Table 3). Average intakes of calories, sugar, calcium, phosphorus, magnesium, and copper remained significantly greater for RC compared to NRC for females ($P<0.05$), but not for males. Average intakes of vitamin C, vitamin E, niacin, folate, and iron remained significantly greater for RC compared to NRC for males ($P<0.05$), but not females. Male RC also had a significantly greater intake of pyridoxine and cobalamin compared to male NRC ($P<0.05$). Both male and female RC had significantly higher intakes of fiber, manganese, and selenium compared to NRC of the same gender ($P<0.05$).

The nutrient intake of rice consumers was further analyzed based on the type of rice consumed. All three categories of rice consumers (WRC, BRC, WRC+BRC) had greater intakes of calories compared to NRC (Table 4). BRC and WRC+BRC had a slightly higher percentage of daily energy intake from protein compared to NRC and WRC. All three categories of rice consumers had a lower intake of calories from lipids compared to NRC. Both BRC and WRC+BRC had significantly higher intakes of fiber than NRC ($P<0.05$).

BRC had significantly higher intakes of several nutrients compared to NRC, including: fiber, vitamin A, vitamin C, phosphorus, magnesium, copper, and selenium. Interestingly, BRC did not consume significantly higher amounts of any nutrient compared to WRC. WRC+BRC had significantly higher intakes of fiber, beta-carotene, and vitamin C than WRC and NRC ($P<0.05$).

As stated, BRC and WRC+BRC both had significantly higher intakes of fiber, and several vitamins and minerals compared to non-consumers. While WRC had negligible differences compared to NRC. No significant difference in nutrient intake was found between brown rice-only consumers and white rice-only consumers, indicating that the improved nutrient intake seen in rice consumers may not be reliant on the variety of rice. The frequency used to evaluate rice consumption (rice consumers defined by consumption 2 or more times per week) may not be sufficient to produce significant differences in nutrient intake.

Much of the white rice consumed in the United States is enriched providing important B-vitamins, including thiamin, riboflavin, niacin, and fortified, providing folic acid (USDA, 2016). White rice also provides iron and zinc (USDA, 2016). Brown rice contains fiber, magnesium, phosphorus and other important micronutrients (USDA, 2016). Despite the nutrients present in rice, whether the nutrients are naturally occurring and/or added via enrichment or fortification processes, it is unlikely that rice consumption in this study was directly or solely responsible for the significant increases in nutrient consumption seen in RC.

Batres-Marquez and colleagues reported that rice consumers generally have diets that are higher in grains, vegetables, meat, poultry, and fish (Batres-Marquez et al. 2009). Further, rice is a dish that is typically prepared with vegetables or meat, rather than alone, providing even more fiber, vitamins, and minerals.

While there may not be a direct correlation, the current evidence supports that there is an important link between rice consumption and diet adequacy. As stated, when compared to non-consumers, rice consumers had significantly greater intakes of vitamin A, vitamin C, vitamin E, folate, and magnesium, all of which are on the USDA's list of largely under-consumed nutrients, referred to as "shortfall nutrients." Additionally, rice consumers had significantly greater intakes of calcium, potassium, and fiber, which the USDA has classified as under-consumed nutrients of substantial public health concern because inadequate intake is associated with adverse health conditions (USDA, 2015).

There are several limitations to this study. Primarily limitations stem from use of a seven-day food frequency questionnaire, which require volunteers to rely on memory to recall food intake accurately and honestly. Food recalls are also often associated with underreporting of calorie intake. A second limitation to this study was the sample characteristics; there was a much higher response rate from females and younger adults. Another limitation to this study is that the survey included questions about frequency of rice consumption, but the survey did not include questions on serving size/portion. Finally, it would have been beneficial to include questions on respondent's health status, including BMI, physical activity level, or lifestyle. Additionally, information on education level and household income would have been beneficial in assessing dietary patterns and rice consumption trends.

Conclusion

This study provides detailed information on the dietary habits of Caucasians in the Southern region of the United States. Energy intake from fat tended to increase with age. Middle-age adults had higher intakes of carbohydrate and fiber. Compared to national averages, there were a few minor discrepancies. Average energy intake from fat was higher than the national average, but saturated fat was lower. Dietary fiber intake was above the national intake. Frequency of rice consumption was consistently low, with white rice being the more preferred. Some unfavorable trends were also identified; rice consumption was positively associated with higher daily energy intake. Overall, rice consumers had substantially improved intakes of dietary fiber and several vitamins and minerals. Differences in nutrient intake and diet quality were even more apparent when brown rice was consumed, as opposed to white rice alone. These findings suggest that there are potential benefits to including regular rice consumption, as part of a healthy, adequate diet.

References

Barker LE, Kirtland KA, Gregg EW, Geiss LS, Thompson TJ. Geographic distribution of diagnosed diabetes in the US: a diabetes belt. Am J Prev Med. 2011;40:434-9.

Batres-Marquez SP, Jensen HH. Rice consumption in the United States: New Evidence from food consumption surveys. Amens: Iowa State University Center for Agricultural and Rural Development; 2005 [cited 2015 August 25].

Batres-Marquez SP, Jensen HH, Upton J. Rice Consumption in the United States: Recent Evidence from Food Consumption Surveys. J Am Diet Assoc. 2009;109:1719–27.

Boyle JP, Thompson TJ, Gregg EW, Barker LE, Williamson DF. Projection of the year 2050 burden of diabetes in the US adult population: dynamic modeling of incidence, mortality, and prediabetes prevalence. Popul Health Metr. 2010;8:29-40.

Centers for Disease Control and Prevention (CDC), National Institute of Diabetes and Digestive and Kidney Diseases. National Diabetes Statistics Report: Estimates of Diabetes and Its Burden in the United States, 2014. 2014 [cited 2016 Jan 21]. Available from: www.diabetes.niddk.nih.gov.

Fulgoni VL, Fulgoni SA, Upton JL, Moon M. Diet Quality and Markers for Human Health in Rice Eaters Versus Non-Rice Eaters. NutrToday. 2010;45:262–72.

Ito Y, Mizukuchi A, Kise M, Aoto H, Yamamoto S, Yoshihara R, Yokoyama J. Postprandial blood glucose and insulin responses to pre-germinated brown rice in healthy subjects. J Med Invest. 2005;52:159–64.

Kennedy E, Luo H. Association between Rice Consumption and Selected Indicators of Dietary and Nutritional Status using National Health and Nutrition Examination Survey 2007–2008. Ecol Food Nutr. 2015;54:224–39.

Nicklas TA, O'Neil CE, Fulgoni VL. Rice Consumption Is Associated with Better Nutrient Intake and Diet Quality in Adults: National Health and Nutrition Examination Survey (NHANES) 2005-2010. Food Nutr Sci. 2014;05:525–32.

Panlasigui LN, Thompson LU. Blood glucose lowering effects of brown rice in normal and diabetic subjects. Int J Food Sci Nutr. 2006;57:151–8.

Seki T, Nagase R, Torimitsu M, Yanagi M, Ito Y, Kise M, Mizukuchi A, Fujimura N, Hayamizu K, Ariga T. Insoluble Fiber Is a Major Constituent Responsible for Lowering the Post-Prandial Blood Glucose Concentration in the Pre-Germinated Brown Rice. Biol Pharm Bull. 2005;28:1539–41.

Sun Q, Spiegelman D, van Dam RM, Holmes MD, Malik VS, Willett WC, Hu FB. White Rice, Brown Rice, and Risk of Type 2 Diabetes in US Men and Women. Arch Intern Med. 2010;170:961-69.

Tian S, Nakamura K, Kayahara H. Analysis of Phenolic Compounds in White Rice, Brown Rice, and Germinated Brown Rice. J Agric Food Chem. 2004;52:4808–13.

Trumbo P, Schlicker S, Yates AA, Poos M. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. J Am Diet Assoc. 2002;102:1621-30.

U.S. Department of Agriculture, Agricultural Research Service. Nutrient intakes from food and beverages. Mean amounts consumed per individual, by gender and age. What we eat in America, NHANES 2011–2012. 2014 [cited 2016 Jun 20]. Available from: www.ars.usda.gov/ba/bhnrc/fsrg.

U.S. Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory. USDA National Nutrient Database for Standard Reference. Release 28; September 2015, revised May 2016 [cited 2016 Jun 6]. Available from: http://www.ars.usda.gov/nea/bhnrc/ndl.

U.S. Department of Agriculture, Health and Human Services. USDA Dietary guidelines for Americans 2010, 7th ed. U.S. Department of Health and Human Services; 2010 [cited 2016 Jun 6]. Available from: http://www.health.gov/dietaryguidelines/dga2010/document/pdf/DGA2010.pdf.

U.S. Department of Agriculture, Health and Human Services. USDA Dietary guidelines for Americans 2015, 8th ed. U.S. Department of Health and Human Services; 2015 [cited 2016 Jun 6]. Available from: http://www.health.gov/dietaryguidelines/dga2005/document/pdf/DGA2005.pdf.

Tables and Figures

Table 1. Dietary Intake Information

	Total (n=166)	**Males** (n=60)	**Females** (n=106)
Calories (kcals)	1930.9 ± 46.8	2130.7 ± 88.9^{a}	1817.8 ± 50.2^{b}
CHO (%)	43.7 ± 0.5	42.7 ± 0.8	44.3 ± 0.7
PRO (%)	16.5 ± 0.2	17.1 ± 0.4	16.2 ± 0.3
Lipid (%)	36.5 ± 0.4	36.6 ± 0.6	36.4 ± 0.6
Fiber (g)	22.1 ± 0.8	23.6 ± 1.6	21.3 ± 0.9
Total Fat (g)	79.7 ± 2.3	89.3 ± 4.5^{a}	74.3 ± 2.4^{b}
SFA[1] (g)	25.4 ± 0.8	28.8 ± 1.4^{a}	23.4 ± 0.8^{b}
MUFAS[2] (g)	31.2 ± 1.0	35.6 ± 2.1^{a}	28.7 ± 1.0^{b}
PUFAS[3] (g)	16.7 ± 0.6	17.6 ± 1.3	16.2 ± 0.6
Cholesterol (mg)	274.7 ± 10.7	301.3 ± 16.8	259.7 ± 13.7

Values reflect means ± standard error of the mean (SEM). Superscripts not sharing a common letter within the same row are significantly different between genders at P<0.05; absence of a superscript implies means are not significantly different from each other. 1) Saturated Fatty Acid 2) Monounsaturated Fatty Acid 3) Polyunsaturated Fatty Acid.

Table 2. Frequency of White and Brown Rice Consumption by Age Group

White Rice Consumption			
Frequency	**Young Adults** (n=111)	**Middle-age Adults** (n=30)	**Older Adults** (n=25)
<1 per month	30.6%	36.7%	48.0%
1-4 per month	54.1%	43.3%	52.0%
≥ 2 per week	15.3%	20.0%	0.0%
Brown Rice Consumption			
Frequency	**Young Adults** (n=110)	**Middle-age Adults** (n=30)	**Older Adults** (n=25)
<1 per month	55.5%	50.0%	56.0%
1-4 per month	32.7%	30.0%	40.0%
≥ 2 per week	11.8%	20.0%	4.0%

Young adults- 18-30yoa; Middle-Age Adults- 31-50yoa; Older Adults 51-70yoa.

Table 3. Key Nutrient Intakes for Non-Rice Consumers and Rice-Consumers

	Total		Male		Female	
Nutrient	**NRC$^{1)}$**	**RC$^{2)}$**	**NRC**	**RC**	**NRC**	**RC**
Calories (kcals)	1863.4 ± 47.9^{b}	2150.7 ± 118.6^{a}	2090.2 ± 88.1	2225.2 ± 216.8	1751.3 ± 53.2^{b}	2086.9 ± 122.2^{a}
Protein %	16.4 ± 0.3	16.8 ± 0.5	16.8 ± 0.5	17.6 ± 0.7	16.2 ± 0.3	16.2 ± 0.6
Carbohydrate %	43.3 ± 0.6	44.9 ± 1.3	42.1 ± 0.9	44.3 ± 1.2	44.0 ± 0.7	45.5 ± 2.3
Lipid %	36.9 ± 0.5	35.2 ± 0.9	37.1 ± 0.8	35.4 ± 1	36.8 ± 0.6	35.0 ± 1.4
Fiber (g)	20.6 ± 0.8^{b}	27.2 ± 2.3^{a}	21.0 ± 1.5^{b}	29.7 ± 3.6^{a}	20.4 ± 0.9^{b}	24.9 ± 2.9^{a}
Total Fat (g)	77.9 ± 2.5	85.8 ± 5.3	88.5 ± 4.7	91.3 ± 10.4	72.6 ± 2.8	81.0 ± 4.3
SFA$^{3)}$ (g)	24.8 ± 0.8	27.1 ± 1.6	29.2 ± 1.5	27.9 ± 2.9	22.7 ± 1	26.4 ± 1.6
MUFA$^{4)}$ (g)	30.7 ± 1.2	32.8 ± 2.1	35.8 ± 2.5	35.2 ± 4.2	28.2 ± 1.1	30.7 ± 1.7
PUFA$^{5)}$ (g)	16.1 ± 0.5^{b}	18.8 ± 1.8^{a}	16.2 ± 0.9	20.7 ± 3.5	16.0 ± 0.7	17.2 ± 1.3
Cholesterol (mg)	264.5 ± 12.0	308.0 ± 23.2	294.9 ± 16.5	316.3 ± 41.5	249.5 ± 15.8	300.9 ± 25.3
Sugar (g)	85.2 ± 3.4^{b}	103.2 ± 9.3^{a}	98.2 ± 7.2	105.3 ± 13.9	78.9 ± 3.4^{b}	101.3 ± 12.9^{a}
Vitamin A (RE)	1013.5 ± 55.3^{b}	1258.2 ± 126.1^{a}	1142.5 ± 107.7	1390.7 ± 226.2	949.7 ± 62.4	1144.7 ± 131.9
Beta-Carotene (µg)	1192.2 ± 99.2	1514.6 ± 194.9	1345.8 ± 213.3	1675.3 ± 290.3	1116.3 ± 104.3	1376.9 ± 265.7
Vitamin C (mg)	121.9 ± 6.6^{b}	158.6 ± 15.6^{a}	122.1 ± 12.3^{b}	173.6 ± 22.2^{a}	121.7 ± 7.8	145.7 ± 21.9
Vitamin D (µg)	2.7 ± 0.2	3.2 ± 0.3	3.6 ± 0.3	3.9 ± 0.6	2.3 ± 0.2	2.7 ± 0.4
Vitamin E (mg)	5.8 ± 0.3^{b}	8.0 ± 1.2^{a}	5.9 ± 0.6^{b}	9.6 ± 2.4^{a}	5.7 ± 0.4	6.6 ± 0.7
Thiamin (mg)	1.6 ± 0.1^{b}	1.9 ± 0.2^{a}	1.7 ± 0.1	2.1 ± 0.3	1.5 ± 0.1	1.8 ± 0.2
Riboflavin (mg)	2.3 ± 0.1	2.7 ± 0.2	2.6 ± 0.1	3.0 ± 0.3	2.2 ± 0.1	2.4 ± 0.2
Niacin (mg)	24.1 ± 1.2^{b}	28.9 ± 2.2^{a}	26.2 ± 1.5^{b}	32.5 ± 3.1^{a}	23 ± 1.6	25.8 ± 3
Pyridoxine (mg)	2.2 ± 0.1	2.6 ± 0.2	2.3 ± 0.1^{b}	2.9 ± 0.3^{a}	2.1 ± 0.2	2.4 ± 0.3
Folate (µg)	398.5 ± 22.8^{b}	521.4 ± 49.0^{a}	415.4 ± 30.1^{b}	588.3 ± 77.3^{a}	390.2 ± 30.8	464 ± 61.3
Cobalamin (µg)	7.2 ± 0.5	9.1 ± 0.8	7.5 ± 0.7^{b}	10.4 ± 1.3^{a}	7.1 ± 0.7	8.0 ± 0.9
Biotin (µg)	15.9 ± 0.8	19.1 ± 1.7	18.5 ± 1.7	21.9 ± 3.2	14.6 ± 0.8	16.6 ± 1.6
Sodium (mg)	2027.1 ± 67.9	2258.2 ± 128.6	2279.8 ± 132	2347.8 ± 198	1902.2 ± 74.7	2181.5 ± 170.8
Potassium (mg)	2799.3 ± 88.2^{b}	3363.7 ± 218.7^{a}	3093.8 ± 177.9	3666.6 ± 352.7	2653.8 ± 95.1	3104.0 ± 266.2
Calcium (mg)	790.6 ± 29.2^{b}	937.5 ± 66.6^{a}	952.2 ± 57	996.3 ± 120.7	710.7 ± 30^{b}	887.2 ± 69.0^{a}
Iron (mg)	16.8 ± 1.0^{b}	21.2 ± 1.9^{a}	17.3 ± 1.2^{b}	23.2 ± 2.9^{a}	16.5 ± 1.3	19.6 ± 2.5
Phosphorus (mg)	1294.7 ± 36.6^{b}	1559.7 ± 89.9^{a}	1476.9 ± 67.6	1688.2 ± 159.2	1204.8 ± 40.2^{b}	1449.6 ± 93.4^{a}
Magnesium (mg)	299.5 ± 8.9^{b}	370 ± 25.9^{a}	325.5 ± 17.6	397.6 ± 42.8	286.7 ± 9.7^{b}	346.5 ± 31.2^{a}
Zinc (mg)	14.8 ± 0.8	17.4 ± 1.5	16.0 ± 1	19.7 ± 2.4	14.2 ± 1.2	15.5 ± 1.8
Copper (mg)	1.3 ± 0.0^{b}	1.6 ± 0.1^{a}	1.4 ± 0.1	1.7 ± 0.2	1.2 ± 0.0^{b}	1.5 ± 0.1^{a}
Manganese (mg)	3.3 ± 0.1^{b}	4.5 ± 0.4^{a}	3.3 ± 0.2^{b}	4.7 ± 0.6^{a}	3.3 ± 0.1^{b}	4.3 ± 0.5^{a}
Selenium (µg)	58.6 ± 2.1^{b}	75.8 ± 6.3^{a}	65.9 ± 3.8^{b}	86.2 ± 11.1^{a}	55 ± 2.5^{b}	66.8 ± 6.6^{a}

Values are expressed as mean ± SEM. Superscripts not sharing a common letter within the same nutrient for each subgroup (total, male, female) are significantly different at P<0.05; absence of a superscript implies means are not significantly different from each other. $^{1)}$ NRC: Non-Rice Consumer; participants who reported not consuming rice two or more times per week (total n=127; male n=42; female n=85); $^{2)}$ RC: Rice-Consumer; participants who reported consuming rice two or more times per week (total n=39; male n=18; female n=21); $^{3)}$ Saturated Fatty Acid; $^{4)}$ Monounsaturated Fatty Acid; $^{5)}$ Polyunsaturated Fatty Acid.

Table 4. Key Nutrient Intakes for Non-Rice Consumers and Rice Consumers Based on Rice Type

Nutrient	NRC1)	WRC2)	BRC3)	WRC + BRC4)
Calories (kcals)	1863.4 ± 47.9	2133.8 ± 184.4	2171.5 ± 181.2	2147.5 ± 331.4
Protein %	16.4 ± 0.3	16.2 ± 0.6	17.4 ± 0.7	17.6 ± 2.5
Carbohydrate %	43.3 ± 0.6	45.2 ± 2.3	43.3 ± 1.6	49.8 ± 1.9
Lipid %	36.9 ± 0.5	35.6 ± 1.4	35.9 ± 1.2	30.1 ± 1.5
Fiber (g)	20.6 ± 0.8^{c}	23.8 ± 3.3^{bc}	29.2 ± 3.6^{ab}	34.9 ± 6.3^{a}
Total fat (g)	77.9 ± 2.5	85.9 ± 8.3	88.2 ± 8.0	75.4 ± 14.9
SFA5) (g)	24.8 ± 0.8	27.5 ± 2.0	27.3 ± 2.8	23.8 ± 4.2
MUFA6) (g)	30.7 ± 1.2	32.4 ± 3.3	34.5 ±3.2	27.6 ± 5.5
PUFA7) (g)	16.1 ± 0.5	18.8 ± 3.0	19.2 ± 2.3	16.9 ± 4.8
Cholesterol (mg)	264.5 ± 12.0	298.0 ± 26.3	305.6 ± 32.3	365.5 ± 156.3
Sugar (g)	85.2 ± 3.4	105.8 ± 15.6	100.3 ± 12.5	102.4 ± 26.7
Vitamin A (RE)	1013.5 ± 55.3^{b}	1032 ± 109.6^{ab}	1454.6 ± 224.3^{a}	1547.3 ± 673.6^{ab}
Beta-Carotene (µg)	1192.2 ± 99.2^{b}	1105.1 ± 197.5^{b}	1746.5 ± 339.2^{ab}	2532.7 ± 772.3^{a}
Vitamin C (mg)	121.9 ± 6.6^{c}	133.8 ± 19.2^{bc}	167.6 ± 23.3^{ab}	240 ± 72.5^{a}
Vitamin D (µg)	2.7 ± 0.2	3.7 ± 0.5	2.5 ± 0.4	3.9 ± 1.8
Vitamin E (mg)	5.8 ± 0.3	8.7 ± 2.1	8 ± 1.6	5.2 ± 1.3
Thiamin (mg)	1.6 ± 0.1	2 ± 0.3	1.7 ± 0.2	2.4 ± 0.8
Riboflavin (mg)	2.3 ± 0.1	2.8 ± 0.3	2.4 ± 0.2	3.1 ± 1.1
Niacin (mg)	24.1 ± 1.2	29.5 ± 3.4	27.1 ± 2.6	33 ± 10.4
Pyridoxine (B6) mg	2.2 ± 0.1	2.7 ± 0.3	2.4 ± 0.2	3.3 ± 1.1
Folate (µg)	398.5 ± 22.8^{b}	523.3 ± 74.7^{ab}	472.3 ± 60.1^{ab}	708.7 ± 224.9^{a}
Cobalamin (µg)	7.2 ± 0.5	9.4 ± 1.3	8.6 ± 0.9	9.3 ± 3.8
Biotin (µg)	15.9 ± 0.8	17.8 ± 2.1	18.7 ± 1.9	26.9 ± 12.4
Pantothenic acid (mg)	8.2 ± 0.5	10.5 ± 1.6	8.2 ± 1.0	12.2 ± 5.3
Sodium (mg)	2027.1 ± 67.9	2156.5 ± 162.8	2431.8 ± 197.0	2047.1 ± 662.8
Potassium (mg)	2799.3 ± 88.2	3109.2 ± 311.6	3498.7 ± 348.6	4032.1 ± 659.4
Calcium (mg)	790.6 ± 29.2	882.7 ± 78.8	1009.2 ± 129.6	911.2 ± 152.5
Iron (mg)	16.8 ± 1.0	22.8 ± 2.9	18.4 ± 2.0	24.8 ± 9.3
Phosphorus (mg)	1294.7 ± 36.6^{b}	1477.8 ± 130.1^{ab}	1619.8 ± 149.1^{a}	1708.8 ± 220.0^{ab}
Magnesium (mg)	299.5 ± 8.9^{b}	337.5 ± 35.5^{ab}	391.7 ± 44.4^{a}	438 ± 62.0^{a}
Zinc	14.8 ± 0.8	18.7 ± 2.3	15.4 ± 1.6	19.5 ± 8.0
Copper (mg)	1.3 ± 0.0^{b}	1.5 ± 0.2^{ab}	1.7 ± 0.2^{a}	1.7 ± 0.2^{ab}
Manganese (mg)	3.3 ± 0.1^{b}	4.1 ± 0.6^{a}	4.7 ± 0.6^{a}	5.5 ± 1.0^{a}
Selenium (µg)	58.6 ± 2.1^{b}	71 ± 10.3^{ab}	79.9 ± 9.0^{a}	82.3 ± 15.1^{ab}

Values are expressed as mean ± SEM. Superscripts not sharing a common letter within the same nutrient are significantly different among groups at P<0.05; absence of a superscript implies means are not significantly different from each other. 1) NRC: Non-rice consumer; consume rice less than two times per week (n=127); 2) WRC: White rice-consumer; consume only white rice on two or more times per week (n=19); 3) BRC: Brown rice-consumer; consume only brown rice on two or more times per week (n=16); 4) WRC + BRC: White and brown rice consumers; consume white and brown rice separately 2 or more times per week (n=4); 5) Saturated Fatty Acid; 6) Monounsaturated Fatty Acid; 7) Polyunsaturated Fatty Acid.

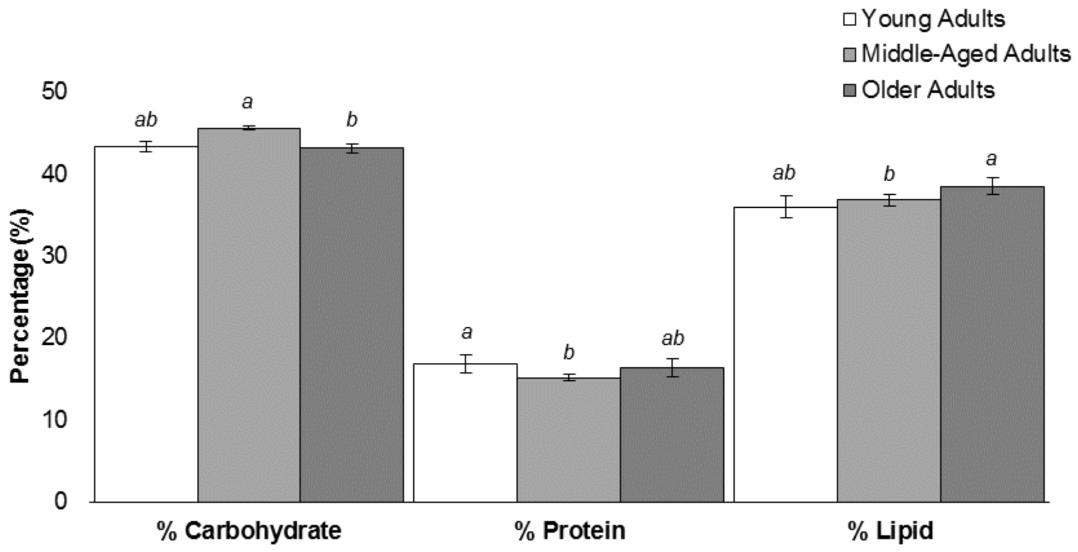


Figure 1. Macronutrient Composition by Age Group; (Young adults: 18-30yoa, n=111; middle-age: 31-50yoa, n=30; older adults: 51-70yoa, n=25). Values reflect means ± standard error of the mean (SEM); Bars marked with different superscriptions within the same macronutrient are significantly different at $P<0.05$.

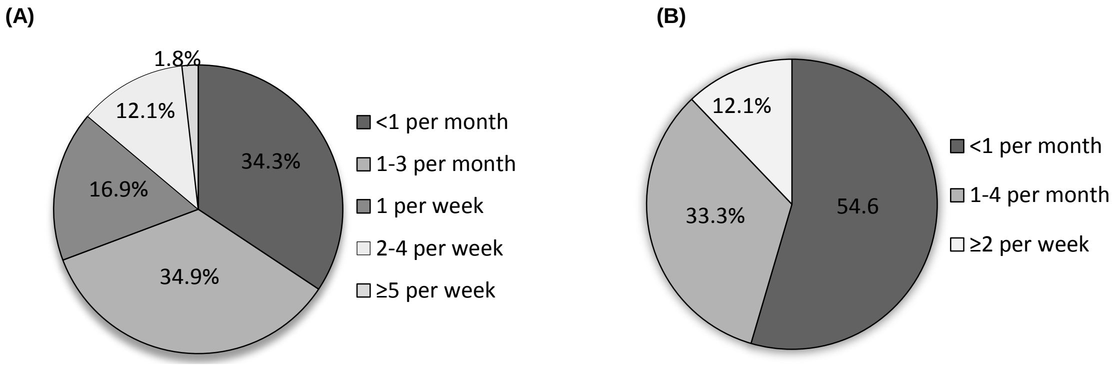


Figure 2. Average Frequency of White and Brown Rice Consumption; **(A)** Frequency of white rice consumption, n=166; **(B)** frequency of brown rice consumption, n=165.

Effect of Korean Rice Cakes on Blood Glucose, Insulin, and Satiety Hormone Levels

Abstract

A human research study was conducted in order to determine the effects of Korean rice cake (*Seolgitteok*) on postprandial glucose, insulin, satiety hormones, and appetite in healthy (normoglycemic) and pre-diabetic (hyperglycemic) persons. Using a randomized-crossover design, 23 participants consumed one of three rice cakes (white rice, WRC; brown rice, BRC; and mixture of equal parts white and brown rice, MRC) with a one-week washout period between. Each *Seolgitteok* contained 50 g of total starch based on rice flour analysis, and additional ingredients remained consistent. Blood samples were collected intravenously at 15 minutes prior to and 0, 30, 60, 90, 120, and 180 minutes after consumption and self-reported feelings of satiety were collected at each time interval using a visual analog scale (VAS). The BRC contained significantly more insoluble fiber (3.3±0.3 g/100 g) compared to the MRC (1.6±0.3 g/100 g) and WRC (0.8±0.3 g/100 g) ($P<0.05$). Average postprandial blood glucose response was significantly lower at time point 60 for the BRC compared to the MRC and WRC ($P<0.05$). Glucose net incremental area under the 0-3 h curve (niAUC) for the BRC (1941±341 $\text{mg}\cdot(3\text{h})\cdot\text{dL}^{-1}$) was significantly lower than the WRC (3487±550 $\text{mg}\cdot(3\text{h})\cdot\text{dL}^{-1}$) ($P<0.05$), but not the MRC (2970±427 $\text{mg}\cdot(3\text{h})\cdot\text{dL}^{-1}$). Insulin niAUC for the BRC (2968±493 $\mu\text{U}\cdot(3\text{h})\cdot\text{L}^{-1}$) was reduced by approximately 13% and 18% compared to the MRC (3407±607 $\mu\text{U}\cdot(3\text{h})\cdot\text{L}^{-1}$) and WRC (3595±633 $\mu\text{U}\cdot(3\text{h})\cdot\text{L}^{-1}$) respectively, but the difference was not statistically significant. No differences were observed between treatments for the satiety hormones, GLP-1 and ghrelin, and plasma concentrations remained predominately unaffected by consumption of the test meals. Based on participants' subjective appetite responses, the BRC was reportedly 10-15% more satiating over the 3 hour postprandial time period compared to the WRC and MRC. These findings suggest that *Seolgitteok* made from brown rice has a potential for use as functional food to improve postprandial hyperglycemia and promote satiety.

Introduction

Diabetes mellitus is the seventh leading cause of death in the United States, making it a significant health concern for the population (CDC, 2014). Upwards of 29 million U.S. adults age 20 years and older have diabetes and another 86 million are at risk for developing diabetes (CDC, 2014). It is estimated that by 2050, diabetes could affect as many as one in three U.S. adults (Boyle et al. 2010).

Pre-diabetes is a condition defined as a fasting blood glucose level between 100 and 125 mg/dL. Pre-diabetic (pre-DM) persons are at a 15% to 30% increased risk for developing type 2 diabetes (T2DM) within five years (CDC, 2014). In 2012, it was estimated that one-third of Americans over the age of 20 had pre-diabetes and over half of adults 65 years and older had pre-diabetes (CDC, 2014).

The onset of T2DM can be delayed or prevented through lifestyle modifications (CDC, 2014). The Diabetes Prevention Program (DPP) Research Group (2009) reported that implementing a lifestyle intervention, which promoted a healthy diet and regular physical activity, reduced the incidence of T2DM by 58% compared to the control group and maintained the lower incidence over a ten year time period (DPP, 2009). For the prevention and management of T2DM, it is recommended that individuals consume carbohydrates from nutrient dense sources such as fruits, vegetables, whole grains, and legumes, as well as consume adequate dietary fiber (American Diabetes Association, 2016; Evert et al. 2013). Diets high in whole-grains and cereal fiber have been found to improve major biomarkers associated with the development of T2DM (AlEssa et al. 2016; Giacco et al. 2014; Yu et al. 2014).

Consumption of brown rice, an unrefined whole grain, is inversely associated with the risk of T2DM and may be beneficial for the management of hyperglycemia (Fung et al. 2002; Sun et al. 2010). The outer bran and germ layers, which provide protection against enzymatic digestion and encompass vital nutrients and phytonutrients, remain intact in brown rice, while only the starchy endosperm remains in white rice. These two layers reduce the portion of available carbohydrate and provide dietary fiber, slowing the digestion and absorption of the rice, thus improving the postprandial metabolic response (Babu et al. 2009; Shobana et al. 2011). Furthermore, refining, or polishing, results in substantial losses of nutrient including protein, fat, B vitamins, vitamin E, phytic acid, polyphenols and γ-oryzanol (Babu et al. 2009; Shobana et al. 2011). Much of the dietary fiber in brown rice is insoluble. Insoluble fiber improves glycemic control and insulin sensitivity (Seki et al. 2005). Further, Sun et al. (2010) reported that individuals who consumption of two or more half-cup servings of brown rice weekly, reduced their risk of T2DM by 11% when compared to those who consumed less than one serving weekly (Sun et al. 2010).

There are two satiety hormones important for the development and management of T2DM: ghrelin and glucagon-like peptide-1 (GLP-1). Ghrelin, referred to as the “hunger hormone,” is typically highest prior to a meal, stimulating appetite and promoting food intake. In normoglycemic persons and persons with a BMI<25 kg/m^2, levels decrease proportional to a meal’s caloric content (Pöykkö et al. 2003). However, because insulin is required to counter-regulate circulating ghrelin levels, the ability to suppress ghrelin in the fed state is less effective for individuals with insulin resistance (Anderwald et al. 2003).

Ghrelin treatment in normoglycemic subjects decreased fasting and fed glucose tolerance and decreased postprandial insulin secretion (Broglio et al. 2001; Tong et al. 2010). Deletion of the ghrelin gene reportedly improved insulin responsiveness and reversed glucose intolerance induced by a high fat diet (Broglio et al. 2001; Dezaki et al. 2004; Dezaki et al. 2006; Tong et al. 2010).

GLP-1 is a gastrointestinal satiety hormone that stimulates pancreatic secretion of insulin in a glucose-dependent manner, reduces food intake, lowers gastric emptying rate, and improves pancreatic islet cell health. GLP-1 secretion is stimulated by direct contact with nutrients in the gastrointestinal tract. Secretion is biphasic, occurring at 10-15 and then 30-60 minutes post-meal (Austin and Marks, 2009; Baggio and Drucker, 2007). GLP-1 response depends on the amount of food consumed, macronutrient composition of a meal, and a person’s health status (Baggio and Drucker, 2007; Vilsbøll et al. 2003).

Similar to ghrelin, insulin is necessary for the regulation of GLP-1 and insulin resistance is associated with reduced GLP-1 (Gagnon et al. 2015; Kjems et al. 2003; Vilsbøll et al. 2003; Toft-Nielsen et al. 2001). Despite this reduction, GLP-1 remains essential for promoting appropriate insulin secretion after food intake. Several studies have reported that therapeutic GLP-1 treatment significantly improves glucose control and insulin response (Ahrén et al. 2003; Degn et al. 2004; Flint et al. 2001; Kjems et al. 2003; Zander et al. 2002).

Gagnon et al. (2015) reported that ghrelin has a substantial role in the regulation of postprandial GLP-1 secretion. Ghrelin treatment prior to food consumption resulted in significantly higher levels of post-meal GLP-1 and significantly enhanced glucose clearance. Moreover, blocking the ghrelin receptor was found to lessen post-meal GLP-1 release and insulin secretion (Gagnon et al. 2015).

Recently, there has been a growing interest among U.S. consumers for ethnic foods that contain added health benefits, such as the Korean rice cake (Sloan, 2010). The traditional Korean rice cake, *Seolgitteok*, is made by steaming a mixture of milled white rice flour, salt, sugar, and water. However, researchers previously reported that Americans tended to dislike the chewy consistency and modest flavor profile of the traditional recipe (Lee, 2010; Lee et al. 2010; Yoon, 2005). In order to increase consumer acceptance in the U.S., Cho et al. (2014) tested partial and full replacement of white rice flour with brown rice flour and adjusted the amount of sugar added. These modifications were found to enhance consumers' perception of and preference for *Seolgitteok*, specifically in regards to flavor and texture characteristics (Cho et al. 2014). More in-depth sensory analyses found that full substitution of white-for-brown rice was deemed acceptable by consumers and could be marketable in the U.S. (Cho et al. 2016).

The purpose of this study was to assess the health effects of 3 different Korean rice cakes (*Seolgitteok*) (white rice, brown rice, and mixture of equal parts white and brown rice). The objectives of this research were (1) to determine the nutrient composition of *Seolgitteok* and (2) to evaluate the overall effects of consuming *Seolgitteok* on postprandial blood glucose, insulin, ghrelin, GLP-1 and satiation and the effects in healthy (normoglycemic) and pre-diabetic (hyperglycemic) adults.

Materials and Methods

Participant Profile

The Institute of Research Board (IRB) at the University of Arkansas approved this human study to be conducted at the University of Arkansas Food Science Department (IRB #14-09-086, Appendix C-II). Participants were recruited from the University of Arkansas and the surrounding Fayetteville area (Fayetteville, Arkansas, USA). Subjects were screened to determine eligibility and to ensure they were non-smokers, had no diagnosed illnesses, did not take any medications, and did not consume two or more servings of alcohol per week. Subjects were asked to fast for ten to twelve hours prior to the screening in order to measure subjects' fasting blood glucose (FBG). FBG levels were determined in duplicate using a lancing device and Accu-Chek® Aviva Blood Glucose Meter (Roche Diabetes Care, Inc, Indianapolis, Indiana, USA). Healthy (normoglycemic; FBG<100 mg/dL) and pre-DM (hyperglycemic; 100≤FBG≤125 mg/dL) subjects were selected to participate.

Anthropometric measurements were taken at the time of the screening using a Seca® digital measuring and weighing station (Chino, California, USA) with participants barefoot, in the free-standing position. Body height was measured to the nearest 0.01 cm and body weight was measured in the fasting state to the nearest 0.01 kg. Body mass index (BMI) was calculated as weight (in kilograms) divided by height (in meters) squared.

Subjects signed consent forms prior to the start of the study. In total, 23 subjects between the ages of 21 and 45 completed the study. There were twelve male and eleven female subjects included. Five of the males and 7 of the females were healthy (normoglycemic) and 7 of the males and 4 of the females were pre-DM (hyperglycemic).

Study Design

The study was a randomized-crossover design. There was a washout period between treatments of at least one week. Subjects received three treatments: a control treatment consisting of white rice (WRC), and two experimental treatments, one consisting of a mixture of white and brown rice (1:1) (MRC) and one consisting of brown rice (BRC). Subjects fasted for a minimum of ten hours prior to the treatment.

Subjects were allowed five minutes to consume the entire rice cake (containing 50 g of starch) and drink all of the water (250 mL) provided. Blood samples were collected intravenously at seven time points.

Treatment Preparation

Rice and Rice Flour

A short grain rice variety was used for this study. Both white and brown rice was purchased from a Korean market in Dallas, Texas (HMART, Dallas, Texas, USA). Prior to making the rice flour, 1 kilogram of white rice and 1 kilogram of brown rice were soaked separately in 3 liters of water (1:3 rice-to-water ratio). The white rice was soaked for a period of 3 hours at 20°C and the brown rice was soaked for a period of 24 hours at 4°C. After soaking, the rice drained for 1 hour at 20°C in a colander. After the rice was soaked and drained, 1 kilogram of rice was weighed and 12 g of unrefined sea salt (RHEE BROS., Inc., Hanover, Maryland, USA) was added. Then, rice was milled in a rice miller (Model: Small Stainless Roller machine #283, Korea Food Machine Union Co., Daegu, Republic of Korea). The gap between the two stainless rollers was 2 mm. After the rice had been milled one time, 100 mL of water was added to the white rice and 130 mL of water was added to the brown rice and sufficiently mixed into the flour. Rice flours were then milled two additional times under the same conditions. The rice flour was then stored in a double zip-lock bag at 4°C until preparation of the Korean rice cakes (*Seolgitteok*). Flour was stored for a maximum period of 24 hours prior to use.

Seolgitteok Preparation

Prior to steaming, 500 g of white rice flour, 500 g of brown rice flour, and a mixture of 250 g of white rice flour and 250 g of brown rice flour was weighed. Each of the 3 rice flours was sieved in a U.S. standard testing sieve, No. 12 with 1.70-mm opening (VWR International, LLC. Radnor, Pennsylvania, USA) to ensure equal size flour particles. Next, 50 g of generic table sugar was added to each of the three rice flours. A white, cotton Mainstays™ flour sack towel (Wal-Mart Inc., Bentonville, AR, USA) was used to line the inner portion of the first tier of the digital steamer (Hamilton Beach Digital Two-Tier Food Steamer #37537, Hamilton Beach Brands, Inc., Southern Pines, North Carolina, USA). The rice and sugar mixtures were added to the cloth-lined digital steamer. The rice cakes were steamed for 25 minutes and cooled at room temperature for 5 minutes. After the rice cakes are cooled, the cake was removed from the cloth and the entire rice cake was weighed (*due to the fact that various factors can influence the starch content of rice cakes, including weather conditions, researcher error, etc., the individual Seolgitteok portion size was calculated for all treatments on every study dat*e.) Once the rice cakes were weighed, an exact serving size was calculated for each rice cake to ensure subjects were consuming a serving containing exactly 50 g of starch.

Starch and Dietary Fiber Analysis

Total starch content was determined in duplicate for the three rice flours (dry weight) using a Megazyme kit and a modified KOH method (Wicklow, Ireland). The mean total starch content of each rice flour was then used to calculate the portion size of the three rice *Seolgitteok* (post-steaming) on each date of the human study. Additionally, for each treatment date, all rice *Seolgitteok* samples were analyzed after steaming for total starch content using the same materials and methods described above. The Englyst in-*vitro* starch digestion method was used to determine the functional starch fractions for the flour and for the control and treatment samples in duplicates on each date of the human study (Englyst, 1992).

Dietary fiber content of the three rice flours and rice *Seoligtteok* was analyzed in duplicates using a Megazyme kit (Wicklow, Ireland).

Food Frequency Questionnaire

A seven-day food frequency questionnaire (FFQ), containing a comprehensive list of foods followed by serving size, was provided to each of the subjects during the study period. The FFQ asked the quantity and frequency of consumption for each item. Subjects’ responses were analyzed using Axxya System Nutritionist Pro™ software version 4.3.0 (Stafford, Texas, USA) based on USDA References.

Subjective Appetite Response

Self-reported appetite ratings were measured using a visual analog scale (VAS) at each time interval of the study (Appendix B). Subjects were instructed to place an “X” along a line with opposing anchors, from “extremely hungry” to “extremely full.” Subject responses were later given a corresponding numerical value (extremely hungry=0, hungry=10, semi-hungry=20, no particular feeling=30, semi-satisfied=40, satisfied=50, extremely full=60). Net incremental area under the curve (niAUC) was calculated for responses using the trapezoidal approximation (Matthews et al. 1990).

Blood Collection and Analysis

Approximately 7.0 mL of blood was collected intravenously at each time interval into a BD vacutainer coated with EDTA (Becton, Dickinson and Company©, Franklin Lakes, New Jersey, USA). A baseline fasting blood sample was taken (time point -15) prior to consuming the rice cake. Immediately following consumption of the rice cake, the first postprandial blood collection (time point 0) occurred, and subsequent collections occurred at 30, 60, 90, 120, and 180 minutes.

Blood samples were centrifuged at 3000 revolutions per minute (rpm) for 10 minutes at 4°C in an Allegra™ X-22R Centrifuge (Beckman Coulter, Inc., Brea, California, USA). Plasma was then collected and stored at -20°C. Plasma glucose concentrations were determined using an ACE Alera™ Clinical Analyzer (West Caldwell, New Jersey, USA). Plasma insulin concentrations were measured using an enzyme-linked immunosorbent assay (ELISA) kit from Mercodia (Uppsala, Sweden). Plasma GLP-1 concentrations were determined using an enzyme immunoassay (EIA) kit (Sigma-Aldrich, Co. LLC. St. Louis, Missouri, USA). Ghrelin concentrations were also determined using an EIA kit (RayBiotech, Inc., Norcross, Georgia, USA). Incremental area under the curve was calculated for glucose and insulin using the trapezoidal rule (Matthews et al. 1990).

Statistical Analysis

Subjects were randomly assigned to one of three sequence groups (WRC-MRC-BRC, n=8; MRC-BRC-WRC, n=7; BRC-WRC-MRC, n=8) to control for possible treatment carryover effects.

Summary statistics were calculated for all data and expressed as sample means and sample standard deviation or standard error of the mean, as specified below. Two sample independent t-test were used to analyze descriptive participant characteristics by genders and FBG levels. One-way analysis of variance (ANOVA) was used to compare nutrient composition (starch and fiber) between treatments and to analyze energy and micronutrient intake from the seven-day FFQs. Additionally, one-way ANOVA was used to compare differences in treatment effects at independent time points and 0-3 h net incremental change from baseline (iAUC) for plasma glucose, insulin, and satiety responses and used to compare differences in iAUC within and between subject groups. One-way ANOVA was also used to determine differences for baseline and postprandial plasma ghrelin and GLP-1 at independent time intervals. Where significance was found, Tukey's studentized range test (HSD) post hoc test was conducted to determine significant differences among the means.

Multiple-factor, cross-over, repeated measures analysis of variance (ANOVA) was used to examine significant differences between and within subjects and subject groups for the treatments over time for the plasma measurements and appetite ratings. Gender, FBG levels and rice type were treated as fixed effects having a factorial treatment structure. The carryover effect between visits in the cross-over portion of the model was considered negligible. Time was treated as a repeated measure for each subject's plasma and appetite measurements. Means were compared using a protected least significant difference (LSD) procedure where appropriate.

Values are expressed as means ± standard deviation (SD) in reference to participant profile and nutrient content of the treatments (starch and dietary fiber data). All remaining values are expressed as means ± standard error of the mean (SEM), unless otherwise specified. Statistical analyses were performed using Statistical Analysis System (SAS, Release 9.4, SAS Institute, Inc. Cary, North Carolina, USA). A P-value of less than 0.05 was considered statistically significant.

Results

Participant Profile

After screening and subject selection, data from 23 individuals was included: 12 males and 11 females with a mean age of 28.8±1.2 years (Table 1). The mean fasting blood glucose (FBG) for the subjects was 99.3±1.5 mg/dL and the average body mass index (BMI) was 28.4±1.3 kg/m^2. Eight subjects were normal weight (BMI 18.5-24.9), 6 were overweight (BMI 25.0-29.9) and 9 were obese (BMI ≥30.0). Of the subjects, 19 were Caucasian, 2 Latino or Hispanic, and 1 Asian from India.

Starch and Dietary Fiber Analysis

The WR flour contained significantly more total starch compared to the MR and BR flours (P<0.05) (Table 2). The BR flour contained significantly more total dietary fiber and insoluble fiber compared to the WR and MR flours (P<0.05).

Based on starch analysis of the rice cake samples from separate study days, the total starch content (per serving) was 52.2±2.8 g, 51.6±2.1 g, and 51.4±5.0 g for the WRC, MRC, and BRC respectively (Table 3). The BRC contained a greater amount of dietary fiber compared to the WRC and MRC (P<0.05). Both the MRC and BRC had similar amounts of soluble fiber, while the WRC contained a lesser amount. The BRC also contained more insoluble fiber compared to both the WRC and MRC (P<0.05) (Table 3).

Food Frequency Questionnaire (FFQ)

The analysis of the seven-day FFQ is presented in Table 4. There were no significant differences in daily energy, carbohydrate, protein, lipid, and dietary fiber intake based on gender. In addition, there were no significant differences between the FFQ results of the healthy and pre-DM subject groups (data not shown).

Subjective Appetite Response

Based on the subjects' self-reported appetite ratings, measured at each time interval using a VAS, responses did not differ between treatments (Figure 1). Overall there was a significant effect of time ($P<0.0001$), but there was no effect of treatments over time. There was a marginal effect of fasting blood glucose ($P<0.09$) and FBG over time ($P<0.08$) for VAS responses.

Comparison of the niAUC revealed the BRC was 10-15% more satiating (WRC, 3044±504; MRC, 2902±355; BRC, 3360±408). The healthy participants reported feeling ~20-40% fuller after consumption of the BRC and WRC when compared to the pre-DM participants (Figure 2).

Postprandial Blood Glucose, Insulin, and Satiety Hormone Response

Postprandial Glucose Response

The BRC significantly reduced glucose levels at 60 m compared to the WRC and MRC ($P<0.05$) (Figure 3). Mean niAUC was significantly reduced after consumption of BRC compared to the WRC (WRC, 3487±550; MRC, 2970±427; BRC, 1941±341 $mg\cdot(3h)\cdot dL^{-1}$) ($P<0.05$). Glucose responses did not differ between males and females (data not shown).

Plasma glucose responses did not differ within the healthy subject group (n=12); glucose reached concentration maximum (C_{max}) at 30 m and promptly returned to near-baseline values by 2 h following all treatments (Figure 4A). There was no significant difference in niAUC among treatments (WRC, 2470±466; MRC, 2261±435; BRC, 1588±343 $mg\cdot(3h)\cdot dL^{-1}$).

For the pre-DM group (n=11), glucose responses differed more conspicuously (Figure 4B). For the WRC and MRC, there was a plateau at 30 m, thereafter glucose remained considerably elevated and did not return to baseline until 3 h indicating protracted glucose clearance. The BRC response curve was similar to that of the healthy participants', however, glucose did not reach near-baseline values until the 3 h mark. Within the pre-DM subject group, the niAUC for the BRC was significantly decreased compared to the WRC (WRC, 4597±947; MRC, 3743±705; BRC, 2326±604 $mg\cdot(3h)\cdot dL^{-1}$) ($P<0.05$).

Compared to the healthy subjects, the pre-DM subjects had a significantly greater spike in glucose immediately upon consuming the WRC (time point 0) ($P<0.04$). Their glucose was significantly elevated again at 60 m and decreased much more gradually thereafter (P<0.04) (Figure 5A). Comparatively, MRC responses were similar at 30 m, but the rate of glucose clearance differed drastically between the groups in the subsequent 2 h period (Figure 5B). In contrast, the BRC responses were more similar, with the exception of time interval 90 (P<0.02) (Figure 5C). The niAUC of glucose response for healthy group was approximately 46, 40 and 25 percent lower for the white, mixed and brown rice treatments respectively, compared to the pre-DM group.

Postprandial Insulin Response

None of the treatments resulted in a significant difference for plasma insulin responses (Figure 6). Overall there was a significant effect of time (P<0.0001) on insulin, but no significant effect treatment over time. The BRC reduced the niAUC by an average of 15% compared with the other rice cakes, but the difference was not significant (WRC, 3595±633; MRC, 3407±607; BRC, 2968±493 μU·(3h)·L^{-1}).

Insulin responses did not differ between genders (data not shown). Insulin responses also did not differ within the healthy group (niAUC for WRC, 3166±811; MRC, 2699±628; BRC, 3105±768 μU·(3h)·L^{-1}) or within the pre-DM group (niAUC for WRC, 4063±1006; MRC, 4181±1051; BRC, 2818±638 μU·(3h)·L^{-1}) (Figure 7).

Postprandial GLP-1 Response

Plasma GLP-1 responses did not significantly change in response to the different test meals (Figure 8). Postprandial GLP-1 concentrations fluctuated sparingly and never rose above baseline values for the white- and mixed rice cakes (Figure 8). The BRC tended to steadily increase GLP-1 concentrations, resulting in concentrations above fasting at latter time intervals.

GLP-1 concentrations did not vary within the two subject groups, nor did they vary based on gender (data not shown). Baseline and postprandial GLP-1 concentrations varied to a small degree between subject groups for the WRC, but responses to the MRC and BRC were nearly indistinguishable (Figure 9).

Postprandial Ghrelin Response

Likewise, the test meals did not elicit any significant changes in plasma ghrelin concentrations (Figure 10). Overall, there was a significant effect of treatment over time ($P<0.04$). The BRC tended to maintain postprandial ghrelin concentrations marginally below baseline, but the responses were still comparable for all 3 rice cakes. The healthy subjects had consistently higher fasting and postprandial ghrelin concentrations, but ghrelin levels remained unchanged for both subject groups (Figure 11).

Discussion

The present study was conducted in 23 healthy (normoglycemic) and pre-diabetic (hyperglycemic) adults to assess the effects of consuming 3 Korean *Seolgitteok* variations on major plasma indicators of T2DM, including postprandial blood glucose, insulin, ghrelin, and GLP-1. It was hypothesized that the BRC would improve postprandial metabolic responses, relative to the WRC. The primary finding was that modifying the traditional *Seolgitteok* recipe by substituting white rice- for brown rice significantly lowered post-meal blood glucose levels. The overall insulin demand was reduced by an average of 15% following the brown rice *Seolgitteok*. It is worth mentioning that a partial substitution with brown rice (mixture of equal parts white and brown rice) was not sufficient to cause considerable improvements in the metabolic response, with regards to glucose and insulin. Plasma GLP-1 and ghrelin remained unchanged in response to the different treatments and neither satiety hormone appeared to be susceptible to, or correspond with fluctuations in plasma glucose or insulin in this study.

The favorable effects of brown rice on the metabolic response have been attributed to its physical properties, structure, and nutrient content. Using various methods including static soaking, gastric simulators and magnetic resonance imaging, Kong et al. (2011) provided evidence on the significant role of the fiber-rich bran layer in altering digestion and absorption. The bran layer acts as a protective coat, blocking moisture and gastric secretions from being absorbed by the rice, thereby preventing starch hydrolysis and impeding gastric emptying (Kong et al. 2011).

Aside from the physicochemical properties, several constituents present in the bran layer such as, lipids, polyphenolic compounds and phytic acid, have all been investigated for their suggested role in restoring glucose tolerance and insulin sensitivity. However, human-based research conducted by Seki et al. (2005) determined that dietary fiber, notably the insoluble fraction, is the predominant component in the rice bran responsible for such improvements. The study emphasized the synergistic effects of dietary fiber on pancreatic secretion of insulin, subsequently lowering the quantity required to stabilize plasma glucose (Seki et al. 2005). Research findings by Mofidi et al. (2012) also points towards insoluble fiber as the primary constituent involved in reducing the glycemic response.

In the present study, the BRC contained 2.5-fold more dietary fiber (total) per serving compared to the WRC. Furthermore, the BRC contained roughly 4-fold more insoluble fiber per serving. Accordingly, the improved postprandial glucose and insulin levels in response to the BRC can be reasonably attributed to the differences fiber content.

It is important to also address the resistant starch content, which could have contributed to the results as well. The crystalline structure of resistant starch prevents amylases from hydrolyzing starch into glucose thus inhibiting digestion as it travels the length of the gastrointestinal tract (Englyst et al. 1992; Syihus et al. 2005). Resistant starch is known to decrease postprandial glucose and enhance insulin sensitivity (Behall et al. 2006; García-Rodríguez et al. 2013; Nilsson et al. 2008; Robertson et al. 2003; Sanz et al. 2010). Based on portion size, the BRC contained more resistant starch compared to the WRC, but the difference was less than a gram. Consequently, it can be assumed that dietary fiber was predominately responsible for the change in glucose.

The BRC markedly decreased glucose throughout the duration of the study and significantly reduced the niAUC, indicating that the BRC has a lower glycemic index than the other treatments. Consumption of the BRC tended to potentiate insulin as well when compared to white rice, but to a lesser degree than observed with glucose. After intake of the BRC, levels of both plasma biomarkers rapidly descended upon reaching C_{max} at 30 m, evidence of an immediate and effective insulin response.

The healthy (normoglycemic) participants were able to maintain normal plasma glucose concentrations consistently regardless of rice type, while glucose clearance after the white- and mixed rice cakes progressed at a lesser rate and over a longer duration for the pre-DM participants, indicating impaired glucose metabolism. By contrast, the brown rice proved to be highly effective in reducing glucose regardless of subjects' fasting blood glucose level. However, there was a considerable variation in the glucose responses of the white- and brown rice for the pre-DM subjects; the BRC reduced the niAUC by nearly half compared with the WRC. These results indicate that the improved glucose response to the brown- as opposed to the white rice *Seolgitteok*, is amplified in subjects with disordered or impaired metabolism.

Within the healthy group, insulin responses from intervals 60 to 180 m differed sparingly between the treatments, and there was a <2% difference in niAUC of the white- and brown rice meals. The insulin response of the pre-DM subjects was approximately 25% greater than that of the healthy subjects following the WRC, suggesting a larger requirement for insulin to reduce blood glucose in response to a high glycemic index food. As observed with glucose, there was a considerable reduction in insulin between treatments for the pre-DM participants; niAUC was approximately 30% less for the brown rice treatment compared with the white rice.

Ito et al. (2005) conducted comparable research in adults with fasting blood glucose levels below 110 mg/dL (7 female, 12 male). Subjects consumed test meals containing equal loads of carbohydrate in a randomized order. Incremental glucose responses did not differ within the first hour, but the 0-2 h iAUC was significantly reduced for the brown rice compared with the white rice (Ito et al. 2005). The authors also found no significant variation in insulin between the white and brown rice (Ito et al. 2005).

The present findings are also consistent with research by Panlasigui and Thompson (2006), which investigated glycemic responses to white and brown rice meals, in healthy persons (n=10) and type 2 diabetics (n=9). The authors reported that brown rice lessened the glucose response for all subjects. Moreover, the impact of brown rice was more substantial for the hyperglycemic subjects when compared with their response to white rice (Panlasigui and Thompson, 2006).

Somewhat similar results were found in a recent cross-over study that evaluated the acute effects of consuming brown versus white rice meals in males with and without metabolic syndrome (Shimabukuro et al. 2014). Within the healthy group, differences in the glucose and insulin responses to the 2 treatments were insignificant. However, for the subjects with metabolic syndrome, iAUC (0-4 h) glucose and insulin responses were significantly reduced in response to the brown rice (Shimabukuro et al. 2014). These results are consistent with the above study: larger variations in glucose and insulin following the white- versus brown rice meals were more apparent in subjects with disordered or impaired metabolism.

This is also consistent with a study by Jenkins et al. (1981), which concluded that brown rice did not evoke any measurable changes on the glucose responses of healthy subjects compared to white rice containing equivalent portions of available carbohydrate. However, research by Karupaiah et al. (2011)

showed that significant differences can exist, albeit findings are somewhat contradictory. Normoglycemic subjects' postprandial blood glucose responses to white- versus brown rice differed significantly at several time intervals, but differences in iAUC (0-3 h) for glucose and insulin were insignificant (Karupaiah et al. 2011).

Studies have suggested that meals rich in dietary fiber have minimal impact on glucose and insulin metabolism in healthy persons, despite the significant improvements noted in those with impaired glucose tolerance. In a cross-over, Ullrich and Albrink (1982) reported little variation in the postprandial glucose and insulin responses of healthy males following carbohydrate meals either high (41.0 g) or low (12.4 g) in dietary fiber. After the initial investigation, researchers further increased the fiber content of the high-fiber meal by one-third, yet the even-higher fiber meal failed to alter the plasma biomarkers (Ullrich and Albrink 1982). Cara et al. (1992) found similar results, stating that 3 meals enriched with 10 grams of dietary fiber from oat bran, rice bran, or wheat fiber failed to improve glucose or insulin over the low-fiber (2.8 g) control in normolipidemic, normoglycemic males. Frost et al. (2003) reported dietary fiber-enriched pasta induced no change in healthy subjects either, although it should be taken into consideration that less than 2 g of fiber was added in that specific study.

However, it was later shown that a dietary fiber-enriched cereal meal with close to 15 g of total dietary fiber significantly lowered AUC for glucose in type 2 diabetics (n=15) compared with a conventional cereal meal containing under 3 g of dietary fiber (Kim et al. 2016). Similar results were obtained in two separate studies by Mofidi et al. (2012) and Tucker et al. (2014) that examined the glucose-lowering effects of various bread-type products, ranging in dietary fiber, in overweight/obese and type 2 diabetic males.

In terms of satiety hormone responses, the effects of the different rice treatments on GLP-1 were insignificant. The incretin hormones, GLP-1 and glucose-dependent insulinotropic peptide (GIP), are responsible for upwards of 50% of postprandial insulin secretion (Burcelin, 2005; Drucker, 2006; Gautier et al. 2005; Holst and Gromada, 2004). However, in the present study, insulin responses did not appear to correspond with changes in GLP-1.

Additionally, for nearly half of the study participants, post-meal GLP-1 concentrations failed to increase above baseline for one or more of the treatments. The inconsistent GLP-1 responses may be attributed to a number of variables. Factors such as the time of intake, the meal composition, and a participant's health status can alter postprandial GLP-1 levels (Baggio and Drucker, 2007; Raben et al. 2003; Vilsbøll et al. 2003).

Previous research by Elliott et al. (1993) showed that postprandial GLP-1 was unaffected after a brown rice meal, while a glucose meal matched for available carbohydrate content (75 g), resulted in significantly higher GLP-1 concentrations accompanied by elevations in plasma glucose and insulin. Consistent with the above findings, a study conducted by Kim et al. (2016) found that a dietary fiber-enriched meal reduced postprandial hyperglycemia in type 2 diabetics, but failed to significantly alter gut hormone levels, including GLP-1, compared to the control (Kim et al. 2016). Several other studies support that foods high in dietary fiber and/or resistant starch have minimal influence on GLP-1, offering an explanation as to why no effects on net concentrations were evident in the current study (Elliott et al. 1993; Karhunen et al. 2010; Klosterbuer et al. 2012; Raben et al. 1994; Willis et al. 2010). According to these data, the acute effects of *Seolgitteok* on GLP-1 are limited, therefore further research is warranted to investigate the potential effects of repeated consumption.

Similarly, ghrelin was not significantly changed from baseline upon ingestion of the rice cakes. The brown rice was the sole treatment that tended to consistently suppress ghrelin below fasting level, but nonetheless, the differences in postprandial responses between treatments were insignificant.

There is limited research currently available comparing the effects of brown and white rice consumption on ghrelin levels in humans, but somewhat comparable research has been carried out using other carbohydrate-based meals. Khawaja et al. (2012) examined the effects of various flatbreads on glucose, insulin, and ghrelin responses in persons with and without type 2 diabetes. The low-glycemic index bran flatbread reduced 0-5 h glucose and insulin responses overall, with a more pronounced effect in the participants with hyperglycemia when compared with their respective response to the high-glycemic index flatbread. The low-glycemic bran flatbread was able to significantly reduce postprandial plasma ghrelin, inconsistent with the current results (Khawaja et al. 2012).

Gruendel et al. (2006) determined that fiber-enriched meals, derived from carob pulp, which is abundant in polyphenols and contains insoluble fiber, significantly reduced acylated ghrelin levels in 20 healthy individuals, but had no impact on total ghrelin or insulin. The authors elaborated further, stating that acylated ghrelin was significantly reduced 1 h after ingestion of 3 meals enriched with either 5-, 10-, or 20-grams. However, only the two higher doses of fiber (10 and 20 g) significantly reduced the ratio of acylated to total ghrelin, indicating that the postprandial effects of insoluble fiber on ghrelin are dose-dependent (Gruendel et al. 2006). This former study offers potential explanations as to why no variation was observed in the current study. First, the dose of fiber was likely insufficient to elicit significant changes in ghrelin. Secondly, plasma levels of biologically active acylated ghrelin may have been altered by the meals, but the present study did not measure the concentrations of acylated ghrelin.

In a cross-over study published by Weickert et al. (2006), healthy females (n=14) consumed isocaloric meals consisting of either low-fiber white bread or high-insoluble fiber bread enriched using 10.5 g of either wheat- or oat cereal fiber. According to the researchers, only the wheat fiber-enriched bread significantly suppressed ghrelin levels, but the authors were unable to provide a definitive explanation as to why the wheat, but not oat-fiber elicited a lower ghrelin response (Weickert et al. 2006). Thus, more in-depth research is necessary to assess the impact of cereal fibers from varying plant sources on regulating postprandial ghrelin.

Furthermore, Weickert et al. (2006) stated that subjects' 0-5 h self-reported feelings of satiety were unaffected regardless of plasma ghrelin concentrations or fiber content, consistent with the results of the present study. Research by Karhunen et al. (2010) also observed that a psyllium fiber-rich meal, which significantly reduced postprandial glucose, insulin and GLP-1 levels in healthy individuals, had limited influence on satiation responses. The results of the mentioned studies were contradicted by Blom et al. (2005) who provided evidence of a significant correlation between ghrelin levels in healthy subjects and satiation following carbohydrate-based meals. Therefore, additional research needs to be explored to understand the relationship between satiety hormones and subjective feelings of satiation.

Conclusion

In conclusion, substitution with brown rice flour decreased postprandial glucose response and tended to mitigate insulin demand compared to the traditional *Seolgitteok* made from white rice flour. The benefits from using brown over white rice were much more pronounced in participants with impaired glucose tolerance, as oppose to the healthy participants. Postprandial GLP-1 and ghrelin remained considerably unchanged and the differences in postprandial concentrations between the rice cakes were equivocal, indicating that a larger dose of fiber is necessary to elicit significant effects. Taken together, these data suggest that *Seolgitteok* made with brown rice has beneficial effects on glucose and insulin metabolism, and may be a particularly useful functional food for individuals with impaired glucose metabolism to prevent or delay the onset of type 2 diabetes.

References

Ahren B, Holst JJ, Mari A. Characterization of GLP-1 Effects on β-Cell Function after Meal Ingestion in Humans. Diabetes Care. 2003;26:2860–4.

AlEssa HB, Ley SH, Rosner B, Malik VS, Willett WC, Campos H, Hu FB. High Fiber and Low Starch Intakes Are Associated with Circulating Intermediate Biomarkers of Type 2 Diabetes among Women. J Nutr. 2016;146:306–17.

American Diabetes Association. Standards of Medical Care in Diabetes—2016 Abridged for Primary Care Providers. Clin Diabetes. 2016;34:3–21.

Anderwald C, Brabant G, Bernroider E, Horn R, Brehm A, Waldhausl W, Roden M. Insulin-Dependent Modulation of Plasma Ghrelin and Leptin Concentrations Is Less Pronounced in Type 2 Diabetic Patients. Diabetes. 2003;52:1792–8.

Austin J, Marks D. Hormonal regulators of appetite. Int J Pediatr Endocrinol. 2009; 2009:141753.

Babu PD, Subhasree RS, Bhakyaraj R, Vidhyalakshmi R. Brown rice-beyond the color reviving a lost health food-a review. Magnesium. 2009;187:13-0.

Baggio LL, Drucker DJ. Biology of Incretins: GLP-1 and GIP. Gastroenterology. 2007;132:2131–57.

Behall KM, Scholfield DJ, Hallfrisch JG, Liljeberg-Elmståhl HG. Consumption of both resistant starch and β-glucan improves postprandial plasma glucose and insulin in women. Diabetes Care. 2006;29:976–81.

Blom WA, Stafleu A, de Graaf C, Kok FJ, Schaafsma G, Hendriks HF. Ghrelin response to carbohydrate-enriched breakfast is related to insulin. Am J Clin Nutr. 2005;81:367-75.

Boyle JP, Thompson TJ, Gregg EW, Barker LE, Williamson DF. Projection of the year 2050 burden of diabetes in the US adult population: dynamic modeling of incidence, mortality, and prediabetes prevalence. Popul Health Metr. 2010;8:29-40.

Broglio F, Arvat E, Benso A, Gottero C, Muccioli G, Papotti M, Ghigo E. Ghrelin, a Natural GH Secretagogue Produced by the Stomach, Induces Hyperglycemia and Reduces Insulin Secretion in Humans. J Clin Endocrinol Metab. 2001;86:5083-5.

Burcelin R. The incretins: a link between nutrients and well-being. Br J Nutr. 2005;93:S147–56.

Cara L, Dubois C, Borel P, Armand M, Senft M, Portugal H, Lairon D. Effects of oat bran, rice bran, wheat fiber, and wheat germ on postprandial lipemia in healthy adults. Am J Clin Nutr. 1992;55:81-8.

Centers for Disease Control and Prevention (CDC), National Institute of Diabetes and Digestive and Kidney Diseases. National Diabetes Statistics Report: Estimates of Diabetes and Its Burden in the United States, 2014. 2014 [cited 2016 Jan 21]. Available from: www.diabetes.niddk.nih.gov.

Cho S, Yoon SH, Min J, Lee S, Tokar T, Lee SO, Seo HS. Variations in US Consumers' Acceptability of Korean Rice Cake, Seolgitteok, with respect to Sensory Attributes and Nonsensory Factors. J Food Sci. 2016;81:S199-207.

Cho S, Yoon SH, Min J, Lee S, Tokar T, Lee SO, Seo HS. Sensory characteristics of Seogitteok (Korean rice cake) in relation to the added levels of brown rice flour and sugar. J Sens Stud. 2014;29:371–83.

Degn KB, Juhl CB, Sturis J, Jakobsen G, Brock B, Chandramouli V, Rungby J, Landau BR, Schmitz O. One Week's Treatment With the Long-Acting Glucagon-Like Peptide 1 Derivative Liraglutide (NN2211) Markedly Improves 24-h Glycemia and α- and β-Cell Function and Reduces Endogenous Glucose Release in Patients with Type 2 Diabetes. Diabetes. 2004;53:1187–94.

Dezaki K, Hosoda H, Kakei M, Hashiguchi S, Watanabe M, Kangawa K, Yada T. Endogenous Ghrelin in Pancreatic Islets Restricts Insulin Release by Attenuating Ca2 Signaling in β-Cells: Implication in the Glycemic Control in Rodents. Diabetes. 2004;53:3142–51.

Dezaki K, Sone H, Koizumi M, Nakata M, Kakei M, Nagai H, Hosoda H, Kangawa K, Yada T. Blockade of Pancreatic Islet-Derived Ghrelin Enhances Insulin Secretion to Prevent High-Fat Diet-Induced Glucose Intolerance. Diabetes. 2006;55:3486–93.

Diabetes Prevention Program Research Group. 10-year follow-up of diabetes incidence and weight loss in the Diabetes Prevention Program Outcomes Study. Lancet. 2009;374:1677–86.

Drucker DJ. The biology of incretin hormones. Cell Metab. 2006;3:153–65.

Elliott RM, Morgan LM, Tredger JA, Deacon S, Wright J, Marks V. Glucagon-like peptide-1(7-36)amide and glucose-dependent insulinotropic polypeptide secretion in response to nutrient ingestion in man: acute post-prandial and 24-h secretion patterns. J Endocrinol. 1993;138:159–66.

Englyst HN, Kingman SM, Cummings JH. Classification and measurement of nutritionally important starch fractions. Eur J Clin Nutr. 1992;46:S33-50.

Evert AB, Boucher JL, Cypress M, Dunbar SA, Franz MJ, Mayer-Davis EJ, Neumiller JJ, Nwankwo R, Verdi CL, Urbanski P, et al. Nutrition Therapy Recommendations for the Management of Adults With Diabetes. Diabetes Care. 2013;36:3821–42.

Flint A, Raben A, Ersbøll AK, Holst JJ, Astrup A. The effect of physiological levels of glucagon-like peptide-1 on appetite, gastric emptying, energy and substrate metabolism in obesity. Int J Obes Relat Metab Disord. 2001;25:781–92.

Frost GS, Brynes AE, Dhillo WS, Bloom SR, McBurney MI. The effects of fiber enrichment of pasta and fat content on gastric emptying, GLP-1, glucose, and insulin responses to a meal. Eur J Clin Nutr. 2003;57:293-8.

Fung TT, Hu FB, Pereira MA, Liu S, Stampfer MJ, Colditz GA, Willett WC. Whole-grain intake and the risk of type 2 diabetes: a prospective study in men. Am J Clin Nutr. 2002;76:535-40.

Gagnon J, Baggio LL, Drucker DJ, Brubaker PL. Ghrelin Is a Novel Regulator of GLP-1 Secretion. Diabetes. 2014;64:1513–21.

García-Rodríguez CE, Mesa MD, Olza J, Buccianti G, Pérez M, Moreno-Torres R, Gil Á. Postprandial glucose, insulin and gastrointestinal hormones in healthy and diabetic subjects fed a fructose-free and resistant starch type IV-enriched enteral formula. Eur J Nutr. 2013;52:1569-78.

Gautier JF, Fetita S, Sobngwi E, Salaun-Martin C. Biological actions of the incretins GIP and GLP-1 and therapeutic perspectives in patients with type 2 diabetes. Diabetes Metab. 2005;31:233-42.

Giacco R, Costabile G, Della Pepa G, Anniballi G, Griffo E, Mangione A, Pacini G. A whole-grain cereal-based diet lowers postprandial plasma insulin and triglyceride levels in individuals with metabolic syndrome. Nutr Metab Cardiovasc Dis. 2014;24:837-44.

Gruendel S, Garcia AL, Otto B, Mueller C, Steiniger J, Weickert MO, Koebnick C. Carob pulp preparation rich in insoluble dietary fiber and polyphenols enhances lipid oxidation and lowers postprandial acylated ghrelin in humans. J Nutr. 2006;136:1533-8.

Holst JJ, Gromada J. 2004. Role of incretin hormones in the regulation of insulin secretion in diabetic and nondiabetic humans. Am J Physiol Endocrinol Metab. 2004;287:E199-206.

Ito Y, Mizukuchi A, Kise M, Aoto H, Yamamoto S, Yoshihara R, Yokoyama J. Postprandial blood glucose and insulin responses to pre-germinated brown rice in healthy subjects. J Med Invest. 2005;52:159–64.

Jenkins DJ, Wolever TM, Taylor RH, Barker HM, Fielden H, Gassull MA. Lack of effect of refining on the glycemic response to cereals. Diabetes Care. 1981;4:509-13.

Karhunen LJ, Juvonen KR, Flander SM, Liukkonen K-H, Lahteenmaki L, Siloaho M, Laaksonen DE, Herzig K-H, Uusitupa MI, Poutanen KS. A Psyllium Fiber-Enriched Meal Strongly Attenuates Postprandial Gastrointestinal Peptide Release in Healthy Young Adults. J Nutr. 2010;140:737–44.

Karupaiah T, Aik CK, Heen TC, Subramaniam S, Bhuiyan AR, Fasahat P, Ratnam W. A transgressive brown rice mediates favourable glycaemic and insulin responses. J Sci Food Agric. 2011;91:1951-6.

Khawaja KI, Fatima A, Mian SA, Mumtaz U, Moazzum A, Ghias M, Masud F. Glycaemic, insulin and ghrelin responses to traditional South Asian flatbreads in diabetic and healthy subjects. Br J Nutr. 2012;108:1810–7.

Kim EK, Oh TJ, Kim L, Cho YM. Improving effect of the acute administration of dietary fiber-enriched cereals on blood glucose levels and gut hormone secretion. J Korean Med Sci. 2016;31:222-230.

Kjems LL, Holst JJ, Volund A, Madsbad S. The Influence of GLP-1 on Glucose-Stimulated Insulin Secretion: Effects on β-Cell Sensitivity in Type 2 and Nondiabetic Subjects. Diabetes. 2003;52:380–6.

Klosterbuer AS, Thomas W, Slavin JL. Resistant Starch and Pullulan Reduce Postprandial Glucose, Insulin, and GLP-1, but Have No Effect on Satiety in Healthy Humans. J Agric Food Chem. 2012;60:11928–34.

Kong F, Oztop MH, Singh RP, McCarthy MJ. Physical changes in white and brown rice during simulated gastric digestion. J Food Sci. 2011;76:E450-7.

Lee JY. The effects of Korean food globalization on foreigners' perception of wellbeing value and experience with Korean food. J Korean Society Food Cult. 2010;25:487-98.

Lee JY, Kim KJ, Park YH, Kim HR. Preference and perception of Korean foods of foreign consumers by nationality. J Korean Society Food Cult. 2010;25:9-16.

Matthews JS, Altmann DC, Campbell MJ, Royston P. Analysis of serial measurements in medical research. Br Med J. 1990;300:230-35.

Mofidi A, Ferraro ZM, Stewart KA, Tulk HM, Robinson LE, Duncan AM, Graham TE. The acute impact of ingestion of sourdough and whole-grain breads on blood glucose, insulin, and incretins in overweight and obese men. J Nutr Metab. 2012;2012:1-9.

National Institute of Health (NIH). Publication No. 14–5164. Causes of Diabetes. 2014 [cited 2015 December 2]. Available from http://diabetes.niddk.nih.gov/dm/pubs/causes/

Nilsson AC, Östman EM, Holst JJ, Björck IM. Including indigestible carbohydrates in the evening meal of healthy subjects improves glucose tolerance, lowers inflammatory markers, and increases satiety after a subsequent standardized breakfast. J Nutr. 2008;138:732-9.

Panlasigui LN, Thompson LU. Blood glucose lowering effects of brown rice in normal and diabetic subjects. Int J Food Sci Nutr. 2006;57:151–8.

Pöykkö SM, Kellokoski E, Hörkkö S, Kauma H, Kesäniemi YA, Ukkola O. Low Plasma Ghrelin Is Associated With Insulin Resistance, Hypertension, and the Prevalence of Type 2 Diabetes. Diabetes. 2003;52:2546–53.

Raben A, Agerholm-Larsen L, Flint A, Holst JJ, Astrup A. Meals with similar energy densities but rich in protein, fat, carbohydrate, or alcohol have different effects on energy expenditure and substrate metabolism but not on appetite and energy intake. Am J Clin Nutr. 2003;77:91-100.

Raben A, Tagliabue A, Christensen NJ, Madsen J, Holst JJ, Astrup A. 1994. Resistant starch: the effect on postprandial glycemia, hormonal response, and satiety. Am J Clin Nutr. 1994;60:544-51.

Robertson MD, Currie JM, Morgan LM, Jewell DP, Frayn KN. Prior short-term consumption of resistant starch enhances postprandial insulin sensitivity in healthy subjects. Diabetologia. 2003;46:659-65.

Sanz T, Martínez-Cervera S, Salvador A, Fiszman SM. Resistant starch content and glucose release of different resistant starch commercial ingredients: effect of cooking conditions. Eur Food Res Technol. 2010;31:655-62.

Seki T, Nagase R, Torimitsu M, Yanagi M, Ito Y, Kise M, Mizukuchi A, Fujimura N, Hayamizu K, Ariga T. Insoluble Fiber Is a Major Constituent Responsible for Lowering the Post-Prandial Blood Glucose Concentration in the Pre-Germinated Brown Rice. Biol Pharm Bull. 2005;28:1539–41.

Shimabukuro M, Higa M, Kinjo R, Yamakawa K, Tanaka H, Kozuka C, Masuzaki H. Effects of the brown rice diet on visceral obesity and endothelial function: the BRAVO study. Br J Nutr. 2014;111:310-20.

Shobana S, Malleshi N, Sudha V, Spiegelman D, Hong B, Hu F, Willett W, Krishnaswamy K, Mohan V. Nutritional and sensory profile of two Indian rice varieties with different degrees of polishing. Int J Food Sci Nutr. 2011;62:800–10.

Sloan EA. Consumer Trends US Consumers Have a Taste for World Cuisines. Food Technol. 2010;64:19.

Sun Q, Spiegelman D, van Dam RM, Holmes MD, Malik VS, Willett WC, Hu FB. White Rice, Brown Rice, and Risk of Type 2 Diabetes in US Men and Women. Arch Intern Med. 2010;170:961-69.

Svihus B, Uhlen AK, Harstad OM. (2005). Effect of starch granule structure, associated components and processing on nutritive value of cereal starch: A review. Anim. Feed Sci. Technol. 2005;122:303-20.

Toft-Nielsen MB, Damholt MB, Madsbad S, Hilsted LM, Hughes TE, Michelsen BK, Holst JJ. Determinants of the Impaired Secretion of Glucagon-Like Peptide-1 in Type 2 Diabetic Patients. J Clin Endocrinol Metab. 2001;86:3717–23.

Tong J, Prigeon RL, Davis HW, Bidlingmaier M, Kahn SE, Cummings DE, Tschop MH, D'alessio D. Ghrelin Suppresses Glucose-Stimulated Insulin Secretion and Deteriorates Glucose Tolerance in Healthy Humans. Diabetes. 2010;59:2145–51.

Tucker AJ, Vandermey JS, Robinson LE, Graham TE, Bakovic M, Duncan AM. Effects of breads of varying carbohydrate quality on postprandial glycaemic, incretin and lipidaemic response after first and second meals in adults with diet-controlled type 2 diabetes. J Funct Foods. 2014;6:116-25.

Ullrich IH, Albrink MJ. Lack of effect of dietary fiber on serum lipids, glucose, and insulin in healthy young men fed high starch diets. Am J Clin Nutr. 1982;36:1-9.

Vilsbøll T, Krarup T, Sonne J, Madsbad S, Vølund A, Juul AG, Holst JJ. Incretin secretion in relation to meal size and body weight in healthy subjects and people with type 1 and T2DM mellitus. J Clin Endocrinol Metab. 2003;88:2706-13.

Weickert MO, Spranger J, Holst JJ, Otto B, Koebnick C, Möhlig M, Pfeiffer AF. Wheat-fibre-induced changes of postprandial peptide YY and ghrelin responses are not associated with acute alterations of satiety. Br J Nutr. 2006;96:795-8.

Willis HJ, Thomas W, Eldridge AL, Harkness L, Green H, Slavin JL. Increasing doses of fiber do not influence short-term satiety or food intake and are inconsistently linked to gut hormone levels. Food Nutr Res. 2010;53-60.

Yoon HR. A study on recognition and preference of Korean foods for foreigners in different nationality. Korean J Food Cult. 2005;20:367–33.

Yu K, Ke MY, Li WH, Zhang SQ, Fang XC. The impact of soluble dietary fibre on gastric emptying, postprandial blood glucose and insulin in patients with type 2 diabetes. Asia Pac J Clin Nutr. 2014;23:210-8.

Zander M, Madsbad S, Madsen JL, Holst JJ. Effect of 6-week course of glucagon-like peptide 1 on glycaemic control, insulin sensitivity, and β-cell function in type 2 diabetes: a parallel-group study. Lancet. 2002;359:824–30.

Tables and Figures

Table 1. Subject Characteristics

	Age (years)	**BMI**[1] (kg/m^2)	**FBG**[2] (mg/dL)
Total (n=23)	28.8 ± 1.2	28.4 ± 1.3	99.3 ± 1.5
Healthy (n=12)	26.3 ± 1.0	25.6 ± 1.2	94.2 ± 1.2
Male (n=5)	27.4 ± 0.7	26.2 ± 2.2	96.4 ± 1.6
Female (n=7)	25.5 ± 1.5	25.2 ± 1.5	92.7 ± 1.6
Pre-Diabetic (n=11)	31.5 ± 2.0	31.5 ± 2.1	104.8 ± 1.7
Male (n=7)	30.5 ± 2.3	31.5 ± 1.9	106.0 ± 2.5
Female (n=4)	33.3 ± 4.3	31.3 ± 5.1	102.6 ± 0.8

Values reflect means ± standard error of the mean (SEM). 1) Body Mass Index (kilograms body weight/meters^2). 2) Fasting Blood Glucose (milligrams/deciliter).

Table 2. Starch and Dietary Fiber Composition of Rice *Seolgitteok* Flour

Components g/100g	**WR Flour**	**MR Flour**	**BR Flour**
Total Starch	90.0 ± 1.3^a	84.7 ± 2.1^b	82.2 ± 1.6^b
RDS$^{1)}$	39.0 ± 3.3	34.7 ± 0.7	34.4 ± 0.0
SDS$^{2)}$	40.7 ± 4.0	48.1 ± 0.9	48.5 ± 1.0
RS$^{3)}$	20.3 ± 0.7	18.4 ± 1.2	17.8 ± 0.1
Total Dietary Fiber	1.9 ± 0.7^c	3.5 ± 0.7^b	5.7 ± 0.7^a
Soluble Fiber	0.9 ± 0.6	0.8 ± 0.6	1.2 ± 0.4
Insoluble Fiber	1.0 ± 0.3^c	2.7 ± 0.9^b	4.4 ± 0.7^a

Values reflect means (dry weight basis) $\underline{+}$ standard deviation (SD). Total starch and functional starch analyses were performed in quadruplicate and dietary fiber analyses were performed in sextuplicate. Superscripts not sharing a common letter within the same row are significantly different at P<0.05; values not followed by a superscript indicate means are not significantly different from each other. WR: white rice; MR: mixed rice; BR: brown rice. $^{1)}$ Rapidly digestible starch $^{2)}$ slowly digestible starch $^{3)}$ resistant starch.

Table 3. Starch and Dietary Fiber Composition of Rice Cake *(Seolgitteok*, g/serving*)*

	WRC	**MRC**	**BRC**
Serving Size (g)	102.4 ± 2.5	110.3 ± 0.9	115.8 ± 1.4
Total Starch	52.2 ± 2.8	51.6 ± 2.1	51.4 ± 5.0
RDS[1)]	42.9 ± 3.6	42.7 ± 5.2	42.5 ± 4.3
SDS[2)]	6.3 ± 2.9	5.7 ± 1.5	5.3 ± 1.3
RS[3)]	3.0 ± 2.6	3.2 ± 5.1	3.6 ± 2.7
Total Dietary Fiber	1.6 ± 0.4^{c}	3.3 ± 0.7^{b}	5.6 ± 0.6^{a}
Soluble Fiber	0.8 ± 0.5^{b}	1.5 ± 0.7^{ab}	1.7 ± 0.2^{a}
Insoluble Fiber	0.8 ± 0.7^{b}	1.8 ± 0.8^{b}	3.8 ± 0.6^{a}

Values reflect means ± standard deviation (SD). Serving sizes represent the portion of the total weight containing 50 g of total starch based on rice flour analyses. Total and functional starch analyses were performed for on samples for each treatment date (WRC, n=17; MRC, n=17; BRC, n=16); dietary fiber analyses were performed in sextuplicate. Superscripts not sharing a common letter within the same row are significantly different at $P<0.05$; values not followed by a superscript indicate means are not significantly different from each other. WRC: white rice cake; MRC: mixed rice cake; BRC: brown rice cake. 1) Rapidly digestible starch 2) slowly digestible starch 3) resistant starch.

Table 4. Subject Food Frequency Questionnaire (FFQ) Data

	Total (n=23)	**Males** (n=12)	**Females** (n=11)
Calories (kcals)	2089.0 ± 179.9	1997.5 ± 290.4	2188.8 ± 213.7
CHO (%)	41.2 ± 2.2	37.5 ± 3.3	45.2 ± 2.5
PRO (%)	17.4 ± 0.9	18.3 ± 1.5	16.4 ± 1.0
Lipid (%)	38.8 ± 1.7	40.9 ± 2.6	36.5 ± 1.9
Fiber (g)	24.7 ± 2.4	22.0 ± 3.8	27.6 ± 2.9
Total Fat (g)	90.1 ± 7.8	89.0 ± 11.2	91.3 ± 11.5
SFA[1] (g)	29.1 ± 3.0	29.2 ± 4.4	29.1 ± 4.4
MUFAS[2] (g)	34.8 ± 3.1	34.2 ± 4.2	35.5 ± 4.9
PUFAS[3] (g)	18.4 ± 1.5	17.9 ± 2.1	19.1 ± 2.1
Sugar (g)	103.1 ± 13.8	95.4 ± 22.8	111.4 ± 15.4

Values reflect means ± standard error of the mean (SEM). No significant difference in nutrient intake was found for males v. females. 1) Saturated fatty acid 2) monounsaturated fatty acid 3) polyunsaturated fatty acid.

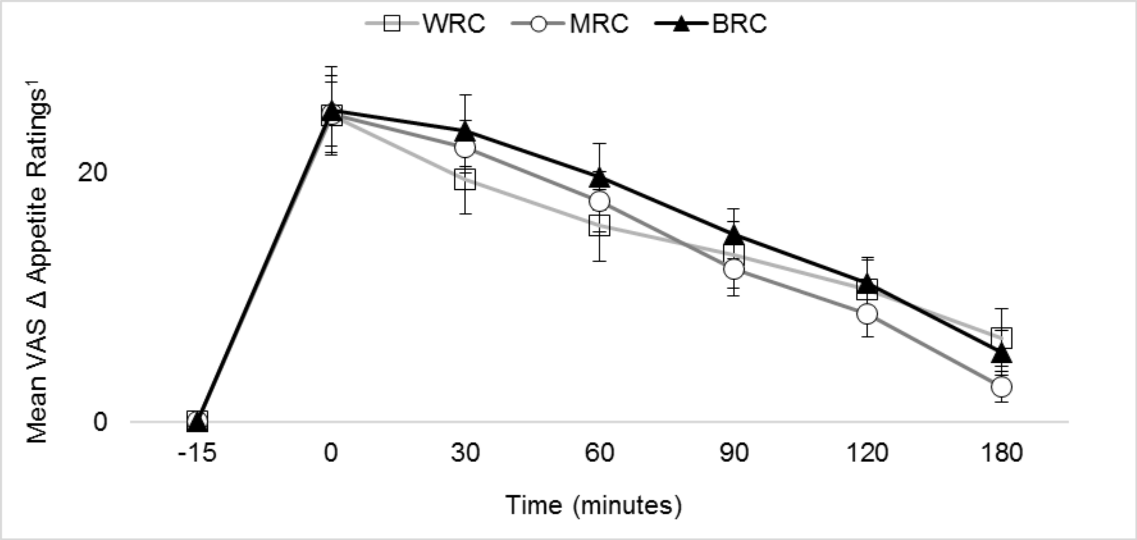


Figure 1. Mean Incremental Δ in Self-Reported Feelings of Satiation Determined From Subject Responses on Visual Analog Scale (n=23). Values reflect means ± SEM. ¹⁾ VAS scale: extremely hungry=0, hungry=10, semi-hungry=20, no particular feeling=30, semi-satisfied=40, satisfied=50, extremely full=60. WRC, white rice cake; MRC, mixed rice cake; BRC, brown rice cake.

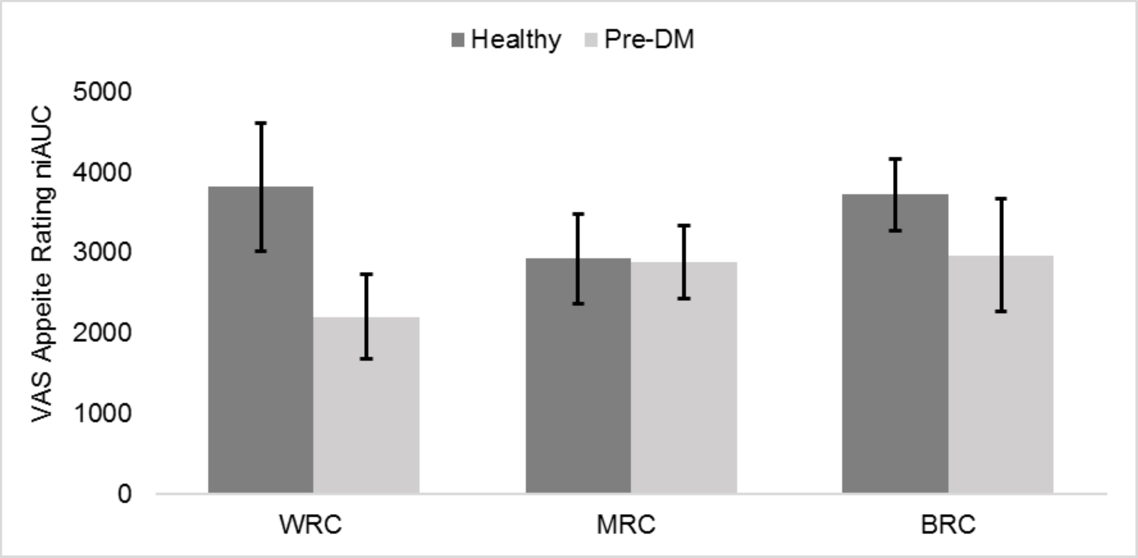


Figure 2. Mean Incremental AUC of Self-Reported Feelings of Satiation Determined from Subject Responses on Visual Analog Scales (n=23); healthy (n=12) v. pre-DM (n=11). Values reflect means ± SEM. WRC, white rice cake; MRC, mixed rice cake; BRC, brown rice cake; pre-DM, pre-diabetic; niAUC, net incremental area under the curve.

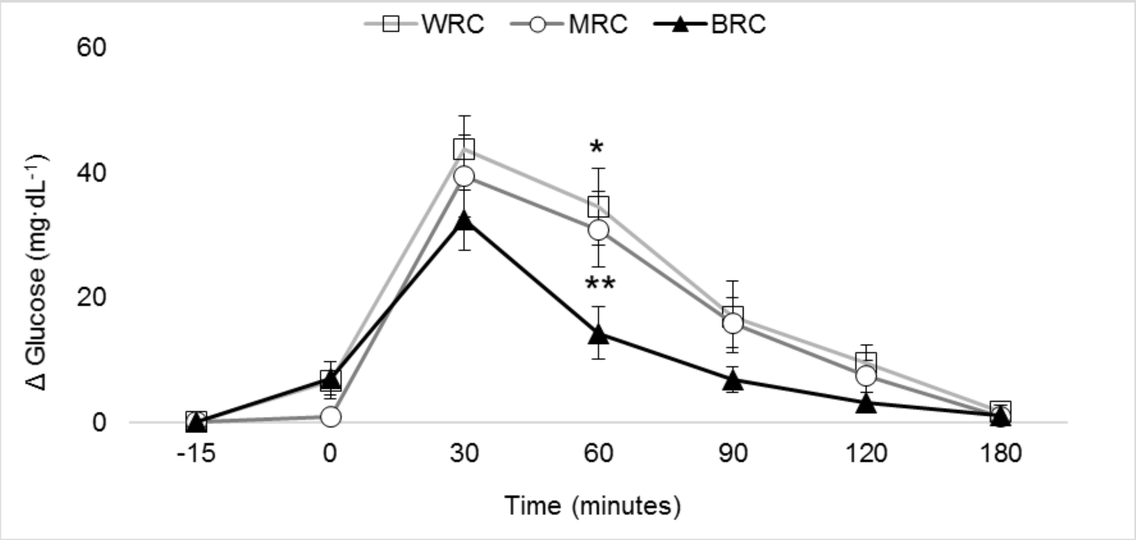


Figure 3. Mean Incremental Δ in Plasma Glucose Concentrations (n=23). Values reflect means ± SEM. *Difference between WRC and BRC at 60 m, P<0.01. **Difference between MRC and BRC at 60 m, P<0.03. WRC, white rice cake; MRC, mixed rice cake; BRC, brown rice cake.

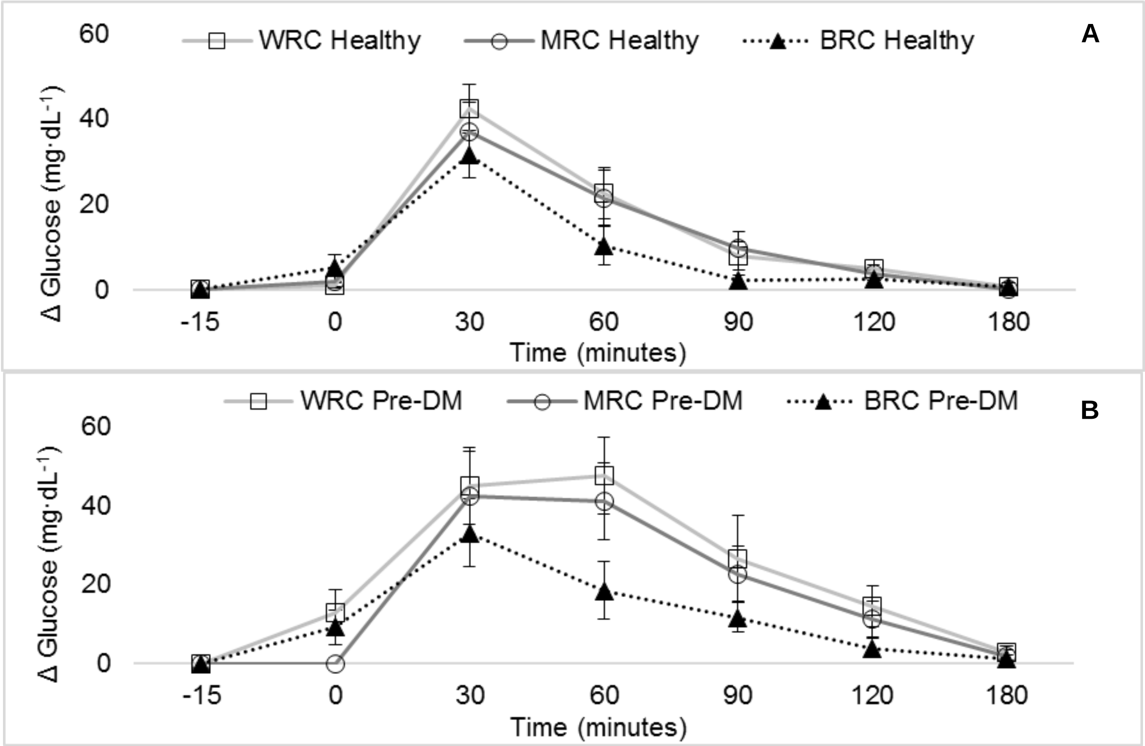


Figure 4. Mean Incremental Δ in Plasma Glucose Concentration for Healthy and Pre-Diabetic Subjects; **A)** healthy subjects with a normal fasting blood glucose (FBG < 100 mg/dL^{-1}) (n=12); **B)** pre-DM subjects with a high fasting blood glucose levels 100 ≤ FBG ≤ 125 mg/dL^{-1}) (n=11). Values reflect means ± SEM. WRC, white rice cake; MRC, mixed rice cake; BRC, brown rice cake; pre-DM, pre-diabetic.

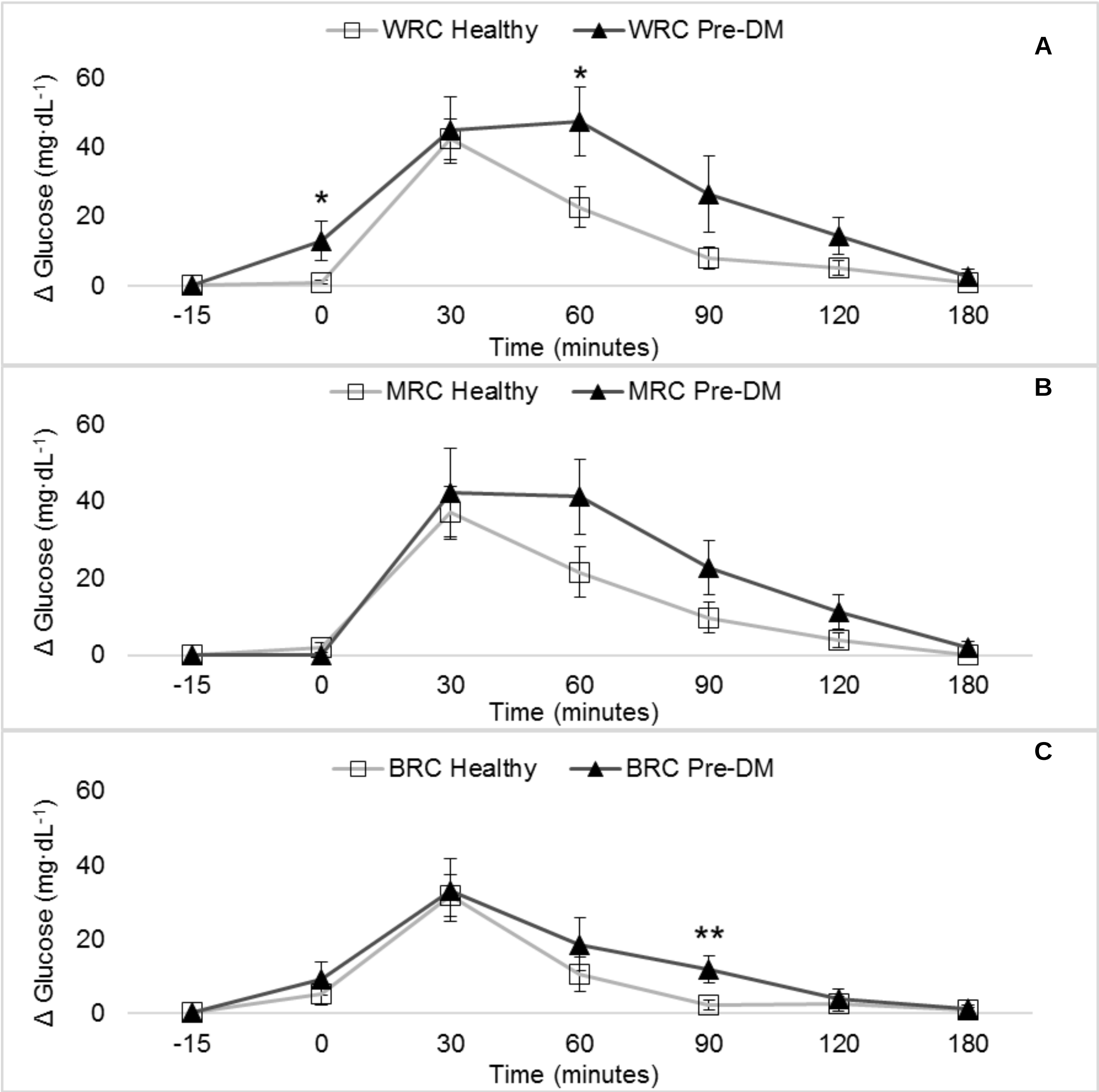


Figure 5. Comparison of Mean Incremental Δ in Plasma Glucose Concentration Based on Fasting Blood Glucose; subjects with healthy fasting blood glucose (FBG < 100 mg/dL^{-1}) (n=12) v. subjects with high fasting blood glucose levels 100 ≤ FBG ≤ 125 mg/dL^{-1}) (n=11); **A)** white rice cake; **B)** mixed rice cake; **C)** brown rice cake. Values reflect means ± SEM. *Difference between healthy and pre-DM at 0 m and 60 m, $P<0.05$. **Difference between healthy and pre-DM at 90 m, $P<0.02$. WRC, white rice cake; MRC, mixed rice cake; BRC, brown rice cake; pre-DM, pre-diabetic.

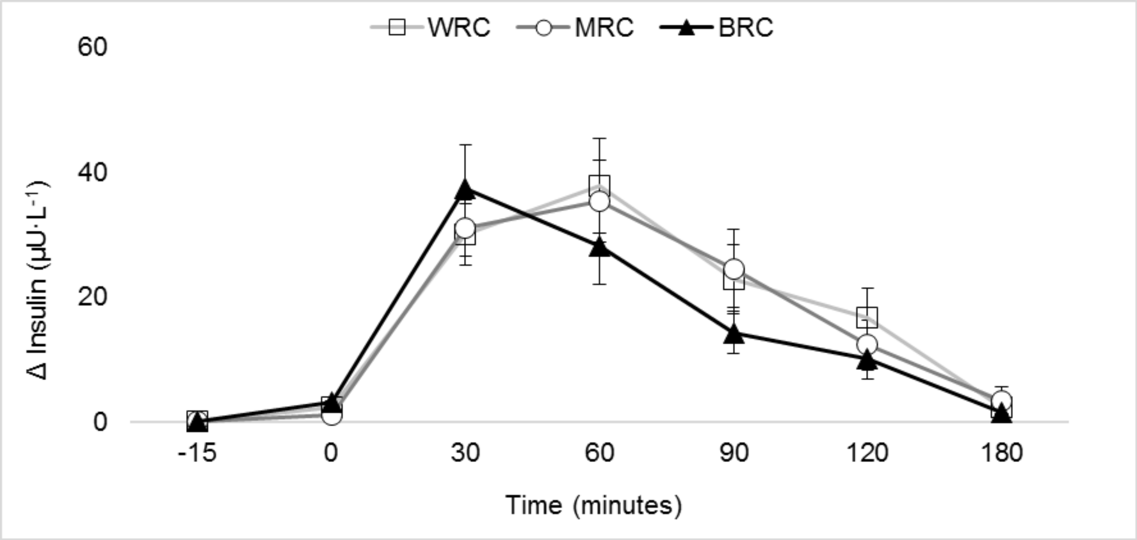


Figure 6. Mean Incremental Δ in Plasma Insulin Concentrations (n=23). Values reflect means ± SEM. WRC, white rice cake; MRC, mixed rice cake; BRC, brown rice cake.

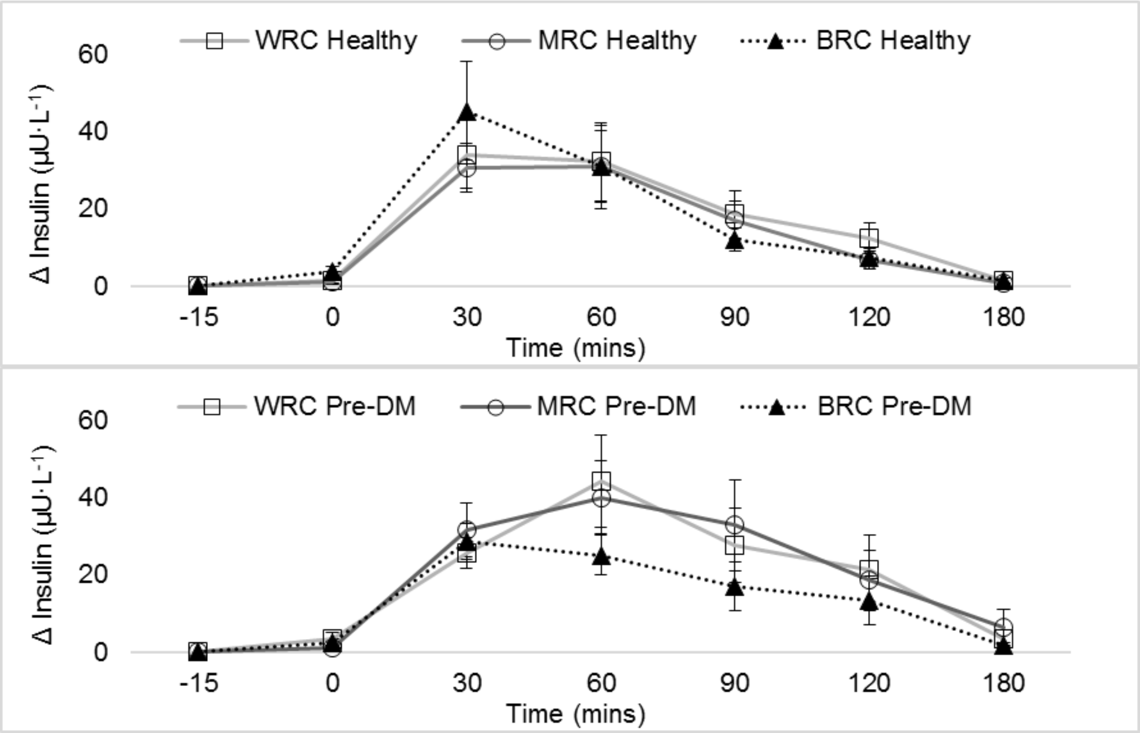


Figure 7. Mean Incremental Δ in Plasma Insulin Concentration for Healthy and Pre-Diabetic Subjects; **A)** healthy subjects with a normal fasting blood glucose (FBG < 100 mg/dL^{-1}) (n=12); **B)** pre-DM subjects with a high fasting blood glucose levels 100 $\leq$ FBG $\leq$ 125 mg/dL^{-1}) (n=11). Values reflect means ± SEM. WRC, white rice cake; MRC, mixed rice cake; BRC, brown rice cake; pre-DM, pre-diabetic.

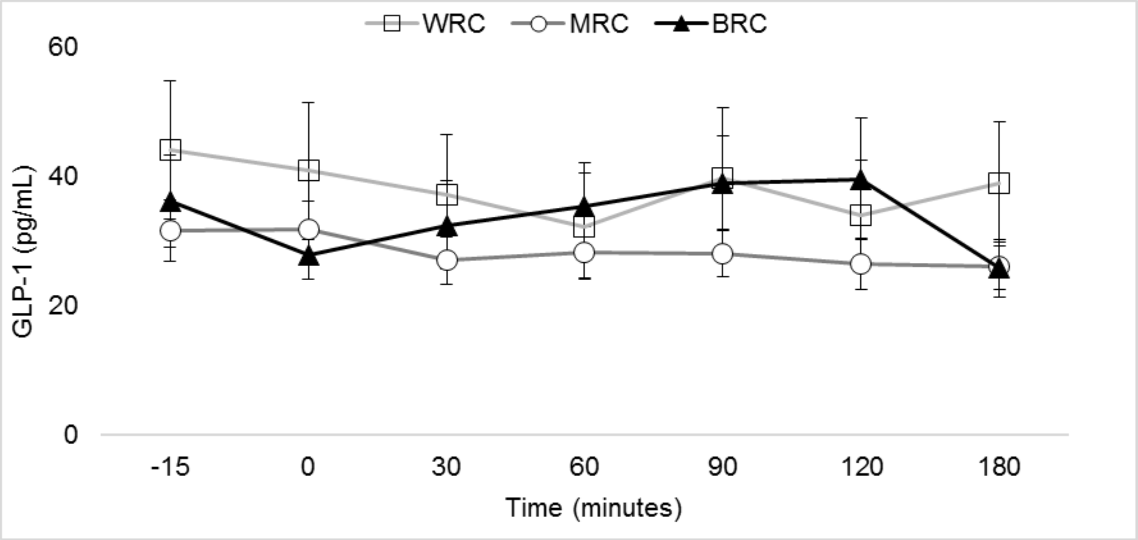


Figure 8. Mean Plasma GLP-1 Concentrations (n=23). Values reflect means ± SEM. WRC, white rice cake; MRC, mixed rice cake; BRC, brown rice cake.

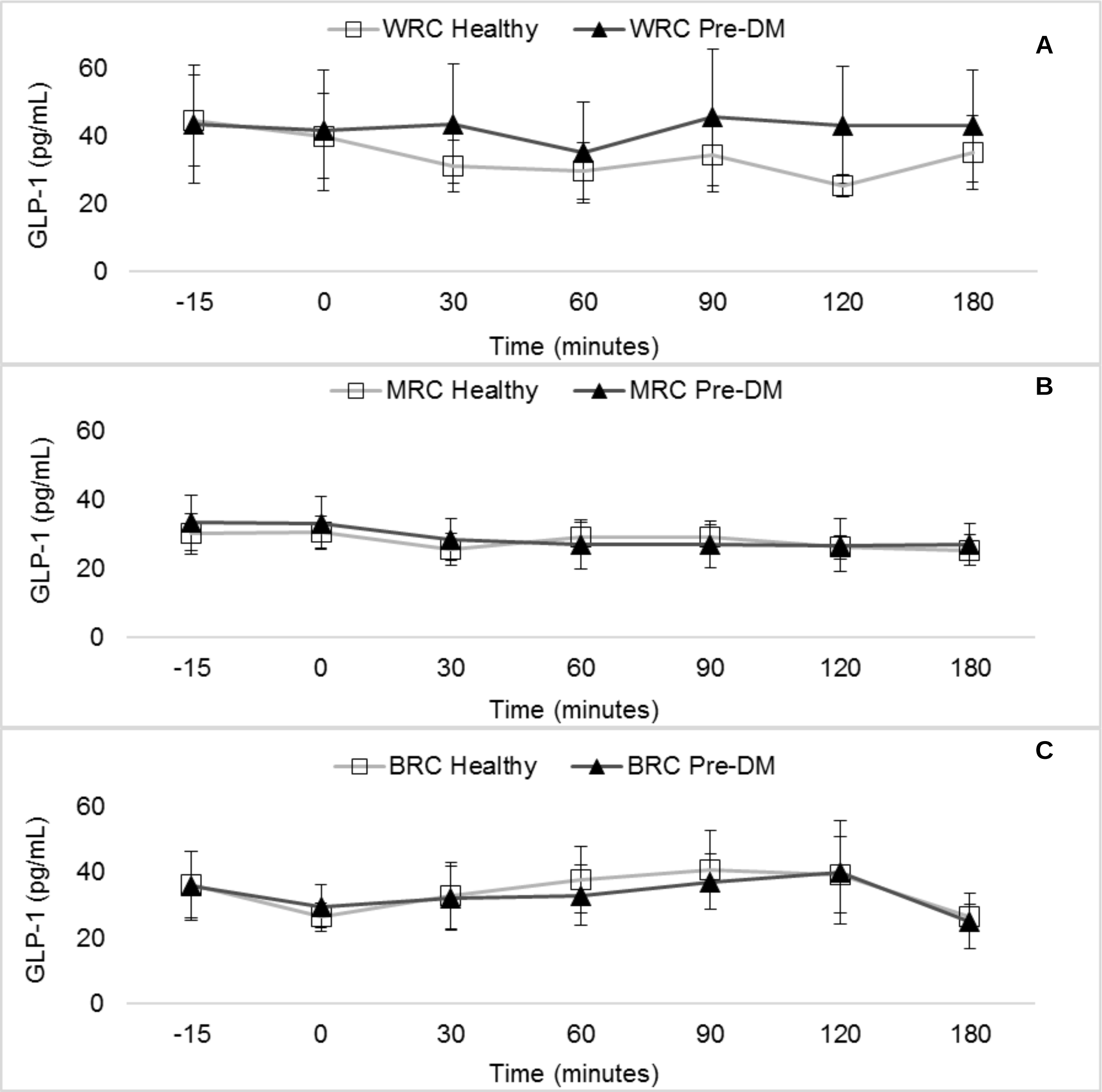


Figure 9. Comparison of Plasma GLP-1 Concentrations Based on Fasting Blood Glucose; subjects with healthy fasting blood glucose (FBG < 100 mg/dL^{-1}) (n=12) v. subjects with high fasting blood glucose levels 100 $\leq$ FBG $\leq$ 125 mg/dL^{-1}) (n=11); **A)** white rice cake; **B)** mixed rice cake; **C)** brown rice cake. Values reflect means ± SEM. WRC, white rice cake; MRC, mixed rice cake; BRC, brown rice cake; pre-DM, pre-diabetic.

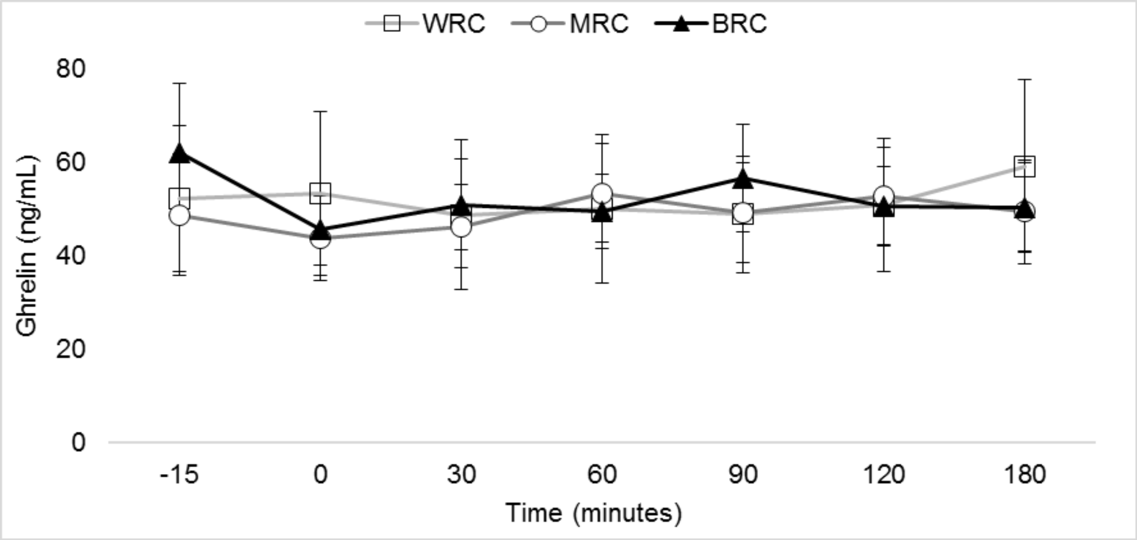


Figure 10. Mean Plasma Ghrelin Concentrations (n=23). Values reflect means ± SEM. WRC, white rice cake; MRC, mixed rice cake; BRC, brown rice cake.

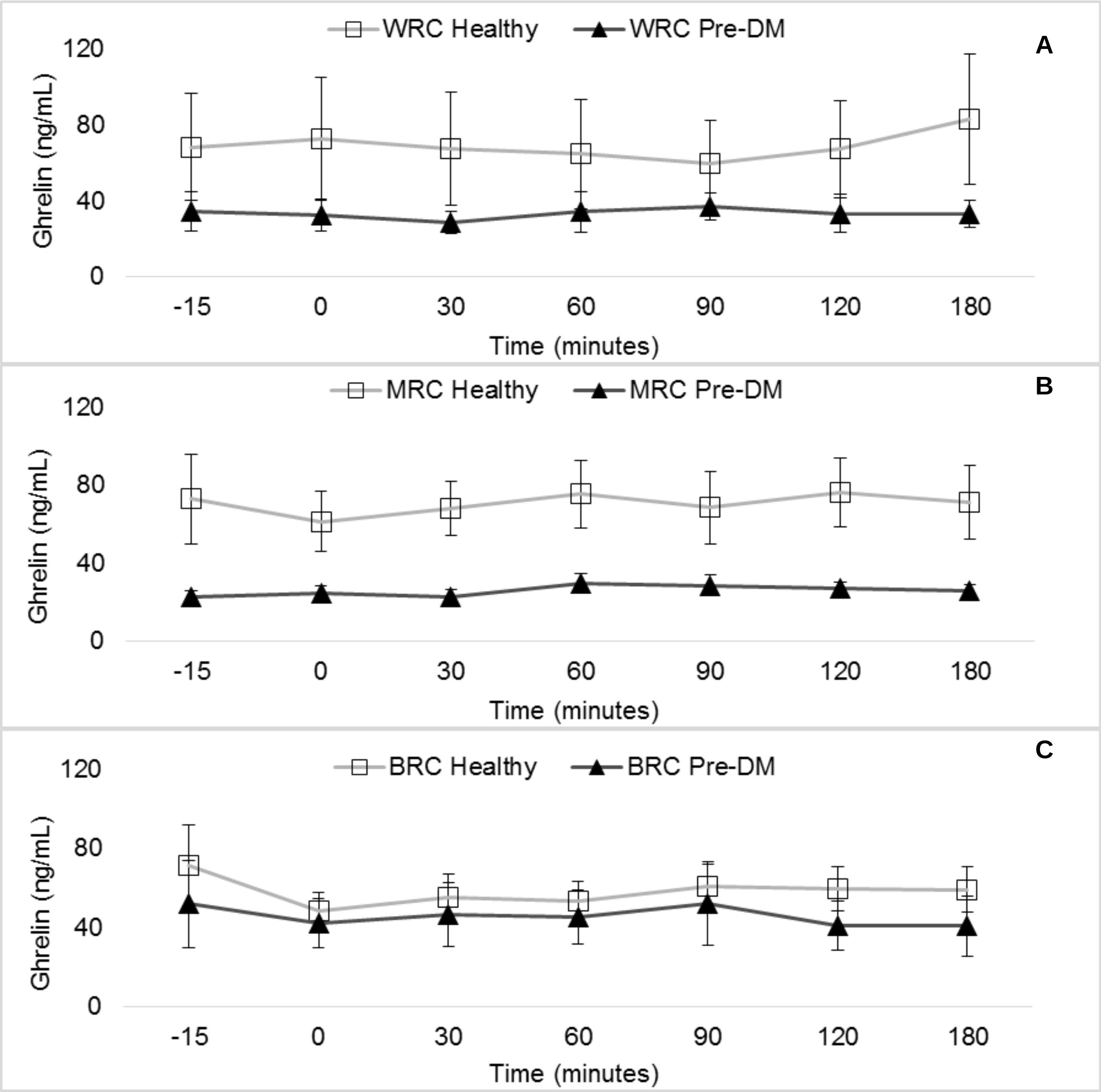


Figure 11. Comparison of Plasma Ghrelin Concentration Based on Fasting Blood Glucose; subjects with healthy fasting blood glucose (FBG < 100 mg/dL^{-1}) (n=12) v. subjects with high fasting blood glucose levels 100 ≤ FBG ≤ 125 mg/dL^{-1}) (n=11); **A)** white rice cake; **B)** mixed rice cake; **C)** brown rice cake. Values reflect means ± SEM. WRC: white rice cake; MRC: mixed rice cake; BRC: brown rice cake; pre-DM, pre-diabetic.

Conclusion

In conclusion rice, predominately brown rice, is consumed infrequently in the Southern region of the United States, where type 2 diabetes is most prevalent. In addition, regular rice consumption, regardless of rice type, is associated with improved diet quality and more adequate intake of numerous shortfall nutrients, including, dietary fiber. Further, *Seolgitteok* made using brown rice has proven to be beneficial in lowering postprandial blood glucose and insulin responses in humans and improved appetite response. This research demonstrates that *Seolgitteok* may be beneficial for promoting rice consumption and contains anti-diabetic properties.

Appendices

Appendix A:

Food Frequency Questionnaire for Nutrient Intake and Rice Consumption Survey

Gender: Female or Male Age: ___________ Subject ID number ___________

Food Frequency Questionnaire

This questionnaire asks you about your eating patterns over the past week, which includes the time from exactly one week ago until the last meal you had before you fill out this questionnaire. For each food item listed, respond by indicating your usual intake of that food per day or week. Check "X" on the Day/Week column if you don't eat the food or if you have it once or twice a year. This questionnaire will take about 15 minutes to complete.

Description	Amt	Unit	Quantity	Day/Week
Breads Cereals and Grain Products				
Whole grain breads (whole wheat, rye, pumpernickel)	1.00	slice		
White breads (burger/hot dog bun-1/2 item, French bread-1 slice)	1.00	serving		
English muffin, bagel, pita bread	0.50	item		
Whole grain crackers: Triscuits, Wheat Thins, etc. (4-6 each)	5.00	item		
Other crackers: Saltines, Ritz, etc. (4-6 each)	5.00	item		
Tortilla, corn, 6 inch diameter (medium)	1.00	item		
Muffins	1.00	item		
Pancakes (2), waffles (1-7 inch diameter)	1.00	serving		
Whole grain hot cereal: rolled oats, rolled wheat	0.50	cup		
Instant or quick hot cereal: cream of wheat, cream of rice	0.50	cup		
Cold cereals: shredded wheat, raisin bran, or bran flakes	0.75	cup		
Cold cereals: Frosted Flakes, Sugar Smacks, etc.	0.75	cup		
Rice, cooked	0.50	cup		
Pasta, cooked	0.50	cup		

Fruits and Juices				
Apple or pear, fresh, medium	1.00	item		
Banana, medium	1.00	item		
Orange (1 item) or grapefruit (1/2 item)	1.00	serving		
Peach (1), nectarine (1/2) or apricots (2)	1.00	serving		
Berries (in season)	0.75	cup		
Cantaloupe, medium (in season)	0.25	cup		
Other melon (watermelon, honeydew, casaba)	1.00	cup		
Pineapple, fresh	0.50	cup		
Dried fruits: raisins (2 Tbsp), dates (2), prunes (2), dried apricots (4)	0.25	cup		
Canned fruit or frozen fruit	0.50	cup		

Orange or grapefruit juice	0.50	cup		
Tomato juice or vegetable juice	0.50	cup		
Other juices: apple, grape, pineapple, or cranberry	0.50	cup		
Fruit drinks: lemonade, punch, Koolaid	0.50	cup		

Fats and Oils				
Vegetable oils: corn, safflower, soy, etc	1.00	Tbsp		
Olive oil	1.00	Tbsp		
Shortening	1.00	Tbsp		
Lard	1.00	Tbsp		
Margarine	1.00	tsp		
Butter	1.00	tsp		
Mayonnaise	1.00	Tbsp		
Regular salad dressings	1.00	Tbsp		
Low-calorie dressings	1.00	Tbsp		
Sour cream	1.00	Tbsp		
Cream cheese	1.00	Tbsp		
Half & Half, table cream	1.00	Tbsp		

Milk, Yogurt and Cheeses				
Skim milk or low fat milk	1.00	cup		
Whole milk	1.00	cup		
Chocolate milk	1.00	cup		
Yogurt	1.00	cup		
Cheese: cheddar, Colby, American, Monterey Jack, etc.	1.00	oz.		
Other cheeses: Swiss, mozzarella, ricotta, string, etc.	1.00	oz.		
Cottage cheese	0.50	cup		

Vegetables				
Salads: lettuce, celery, green peppers, onions	1.00	cup		
Dark green leafy vegetables, raw or cooked	0.50	cup		
Carrots, raw or cooked	0.50	cup		
Tomatoes, fresh, medium	1.00	item		
Starchy vegetables, cooked: corn, peas, mixed vegetables	0.50	cup		
Other vegetables, cooked: green beans, beets, zucchini	0.50	cup		
Cauliflower, broccoli, brussel sprouts, cabbage	0.50	cup		
Winter squash, cooked: acron, butternut, hubbard	0.50	cup		
White potato, baked, broiled, or mashed	1.00	item		
Sweet potatoes or yams, cooked	0.50	cup		

Beverages				
Cola drinks (1 can = 12 fl. oz)	12.00	fl.oz.		
Diet cola drinks (1 can = 12 fl. oz)	12.00	fl.oz.		

Non-cola drinks: 7-Up, Sprite, Slice, etc. (1 can/12 fl. oz)	12.00	fl.oz.		
Diet non-cola drinks (1 can = 12 fl. oz)	12.00	fl.oz.		
Coffee or tea (1 cup = 8 fl. oz)	8.00	fl.oz.		
Decaffeinated coffee or teas: Sanka, herbal tea, etc.	8.00	fl.oz.		
Hot chocolate or cocoa	1.00	cup		
Beer (1 can = 12 fl. oz)	12.00	fl.oz.		
Wine, dry or table (red, white, or blush)	4.00	fl.oz.		
Liquor: vokda, whiskey, gin, rum, etc.	1.50	fl.oz.		

Protein Foods				
Legumes: lentils, pinto beans, navy beans, cooked	1.00	cup		
Nuts and seeds: peanuts, almonds, sunflower seeds, etc.	0.25	cup		
Peanut butter, nut butters	1.00	Tbsp		
Tofu or other meat substitutes	3.00	oz.		
Beef: rib roast, steak, pot roast, veal, etc.	3.00	oz.		
Beef, ground, cooked	3.00	oz.		
Pork: chops, roast, ham	3.00	oz.		
Lamb: chops, roast	3.00	oz.		
Poultry: chicken, turkey, duck	3.00	oz.		
Fish, canned with oil: tuna, sardines	3.00	oz.		
Tuna, water packed	3.00	oz.		
Fish, fresh or frozen, no breading: trout, halibut, sole, etc.	3.00	oz.		
Shellfish: shrimp, scallops, lobster, clams	3.00	oz.		
Eggs, whole, large	1.00	item		
Egg substitutes or egg whites	0.25	cup		
Lunch meats: bologna, salami, etc.	1.00	item		
Frankfurters or sausage link (4 in x 1 1/8 in)	1.00	item		

Desserts and Sweets				
Cookies: chocolate chip, oatmeal, peanut butter, etc.	2.00	item		
Brownies, 2 in.	1.00	item		
Doughnut or sweet roll	1.00	item		
Cake, 1/12 of 9 in.	1.00	slice		
Granola bars (1 item) or granola (1/2 cup)	1.00	item		
Pie, 1/8 of whole pie	1.00	slice		
Gelatin, flavored	0.50	cup		
Pudding or custard	0.50	cup		
Ice Cream	0.50	cup		
Ice Milk	0.50	cup		
Sherbet	0.50	cup		
Candy bar, chocolate bar (1 bar), M&Ms (1 pkg.)	1.00	item		
Hard candy, gum drops, Lifesavers	1.00	item		

Miscellaneous Foods				
Fast food - pizza	1.00	slice		
Fast food - hamburger or cheeseburger	1.00	item		
Fast food - burrito or taco	1.00	item		
Bacon	2.00	slice		
Popcorn, popped	2.00	cup		
Potato chips, corn chips, tortilla chips	1.00	oz.		
Catsup or chili sauce	1.00	Tbsp		
Tomato based sauce (spaghetti sauce)	0.50	cup		
Pickles or pickle relish (1 Tbsp)	1.00	Tbsp		
Olives	5.00	item		
Sauces: soy sauce, steak sauce, barbeque sauce	1.00	Tbsp		
Brown gravy, giblet gravy, or white sauce	0.25	cup		
Soups, vegetable or noodle type	1.00	cup		
Soups, cream	1.00	cup		
Chewing gum	1.00	item		
Sugar, honey, jam, jelly, syrups	1.00	Tbsp		

Can you think of any other food or drink that you had in the past week that was not on this form? If so, what was it? What was the amount? How many times did you have this in the past week?

Food ____

Amount ________________________ How often? ________ per day, ________ per week

Food ____

Amount ________________________ How often? ________ per day, ________ per week

Food ____

Amount ________________________ How often? ________ per day, ________ per week

Food ____

Amount ________________________ How often? ________ per day, ________ per week

How many times do you consume **white rice**?

(1) <1 serving/month (2) 1-3 servings/month
(3) 1 serving/week (4) 2-4 servings/week (5) ≥5 servings/week
(6) ________ per week

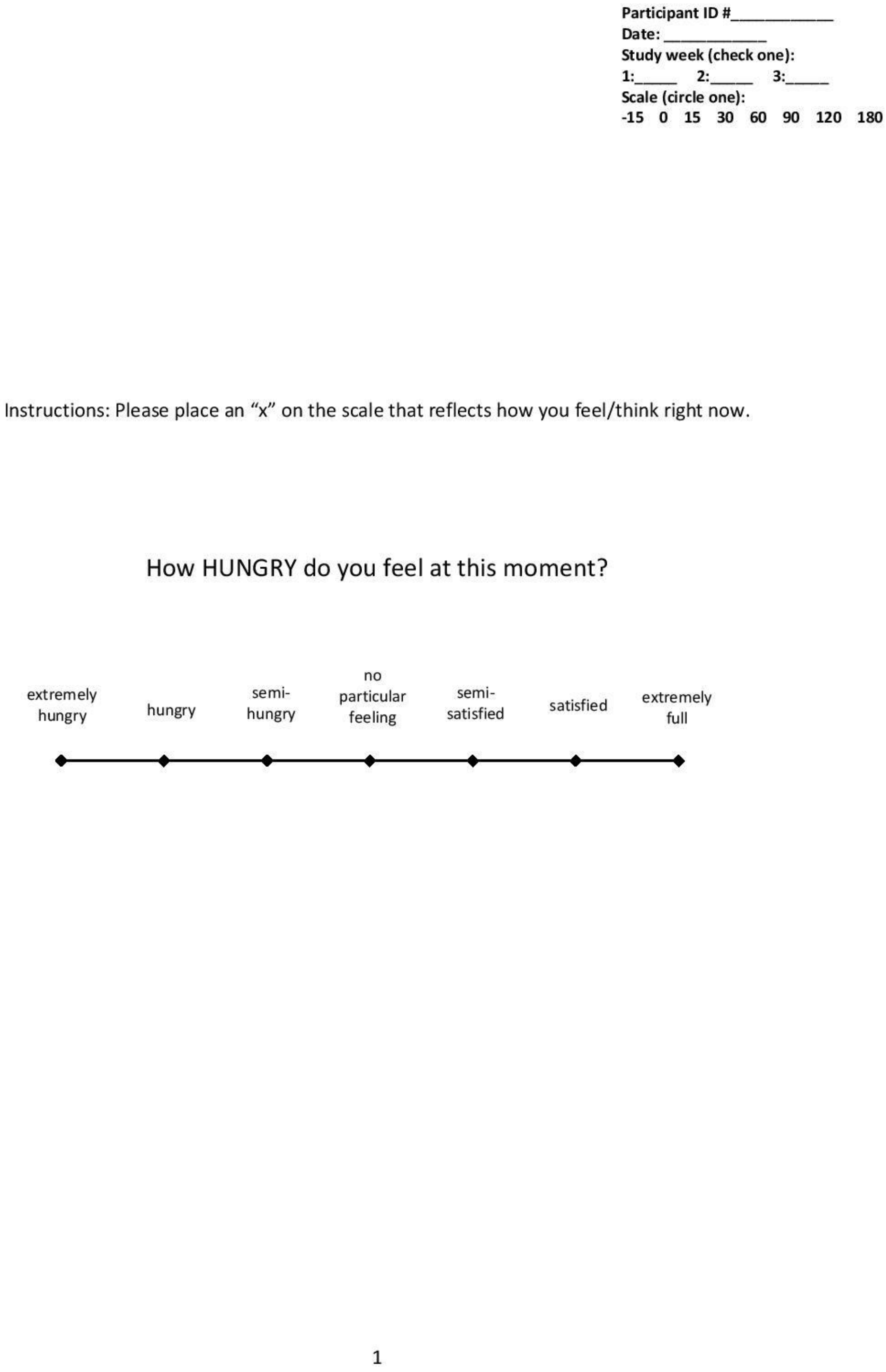
How many times do you consume **brown rice**?

(1) <1 serving/month (2) 1-4 servings/month (3) ≥2 servings/week
(4) ________ per week

Thank you for your participation and your time!

Appendix B:

Visual Analog Scale



Participant ID #____________
Date: ____________
Study week (check one):
1:_____ 2:_____ 3:_____
Scale (circle one):
-15 0 15 30 60 90 120 180

Instructions: Please place an “x” on the scale that reflects how you feel/think right now.

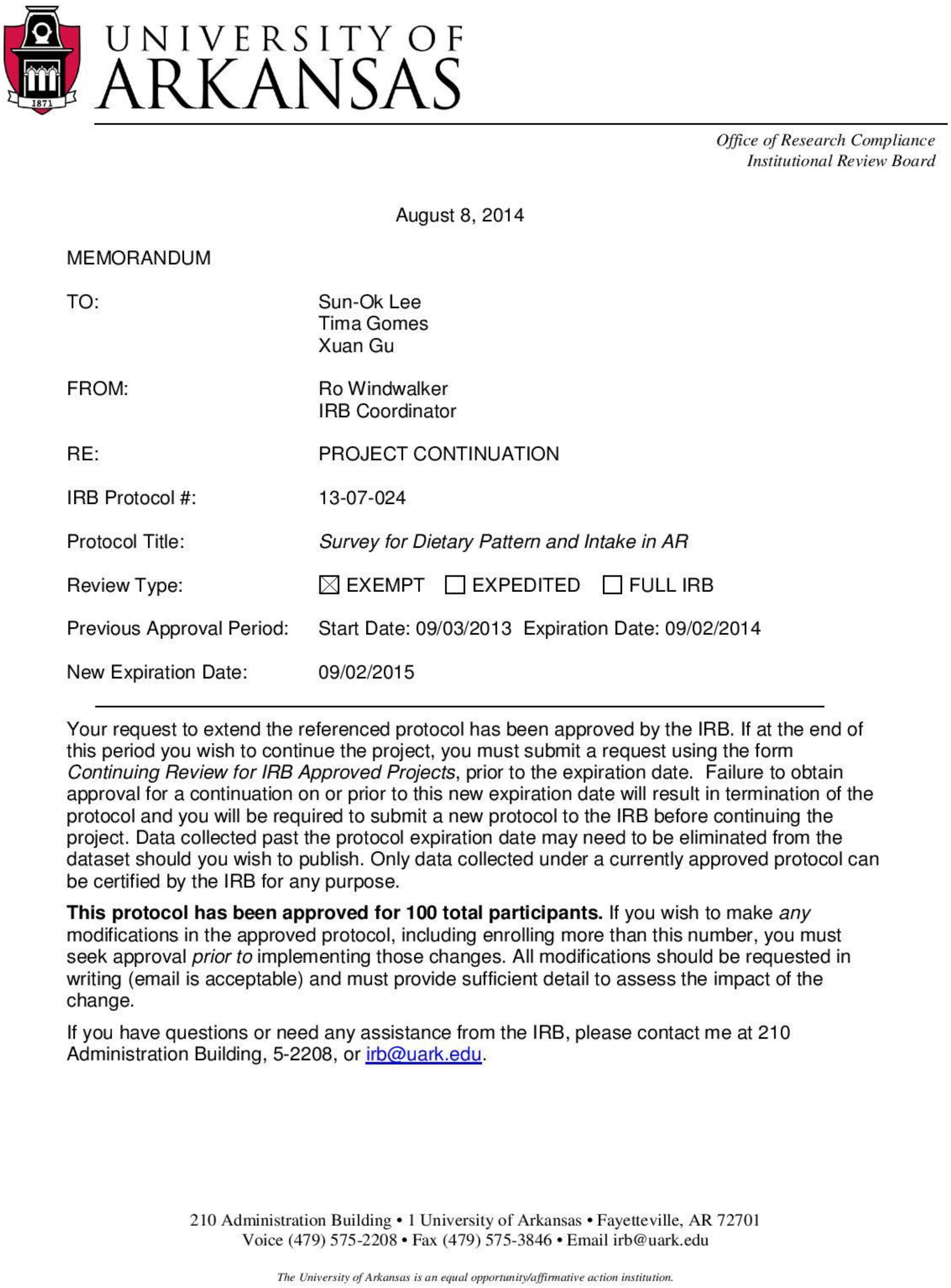
How HUNGRY do you feel at this moment?

extremely hungry
hungry
semi-hungry
no particular feeling
semi-satisfied
satisfied
extremely full

1

Appendix C:

(I) IRB Approval Form #13-07-024



UNIVERSITY OF
ARKANSAS

Office of Research Compliance
Institutional Review Board

August 8, 2014

MEMORANDUM

TO:	Sun-Ok Lee Tima Gomes Xuan Gu
FROM:	Ro Windwalker IRB Coordinator
RE:	PROJECT CONTINUATION
IRB Protocol #:	13-07-024
Protocol Title:	*Survey for Dietary Pattern and Intake in AR*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Previous Approval Period:	Start Date: 09/03/2013 Expiration Date: 09/02/2014
New Expiration Date:	09/02/2015

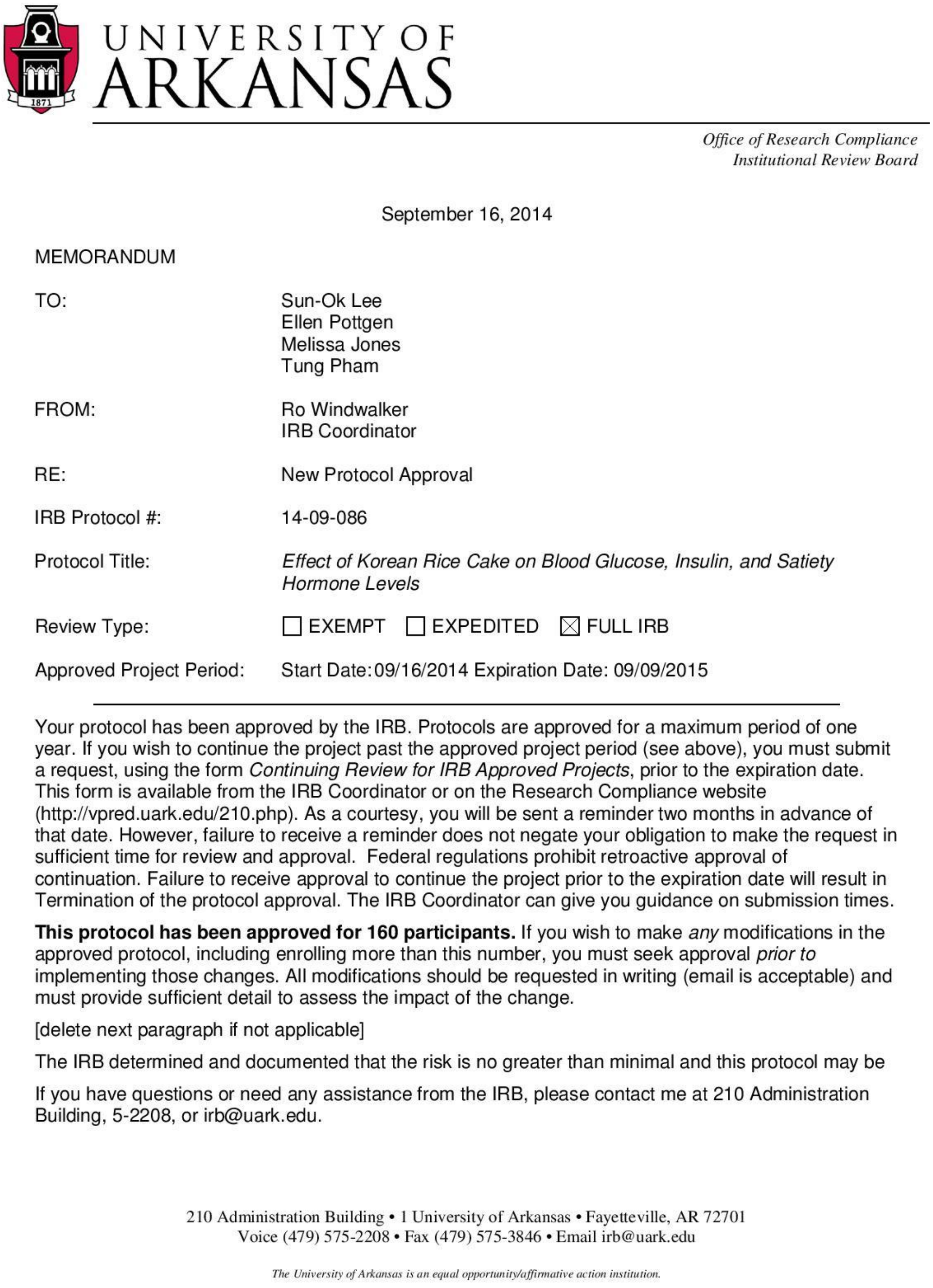
Your request to extend the referenced protocol has been approved by the IRB. If at the end of this period you wish to continue the project, you must submit a request using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. Failure to obtain approval for a continuation on or prior to this new expiration date will result in termination of the protocol and you will be required to submit a new protocol to the IRB before continuing the project. Data collected past the protocol expiration date may need to be eliminated from the dataset should you wish to publish. Only data collected under a currently approved protocol can be certified by the IRB for any purpose.

This protocol has been approved for 100 total participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 210 Administration Building, 5-2208, or irb@uark.edu.

210 Administration Building • 1 University of Arkansas • Fayetteville, AR 72701
Voice (479) 575-2208 • Fax (479) 575-3846 • Email irb@uark.edu

(II) IRB Approval Form #14-09-086



UNIVERSITY OF
ARKANSAS

Office of Research Compliance
Institutional Review Board

September 16, 2014

MEMORANDUM

TO:	Sun-Ok Lee Ellen Pottgen Melissa Jones Tung Pham
FROM:	Ro Windwalker IRB Coordinator
RE:	New Protocol Approval
IRB Protocol #:	14-09-086
Protocol Title:	*Effect of Korean Rice Cake on Blood Glucose, Insulin, and Satiety Hormone Levels*
Review Type:	☐ EXEMPT ☐ EXPEDITED ☒ FULL IRB
Approved Project Period:	Start Date: 09/16/2014 Expiration Date: 09/09/2015

Your protocol has been approved by the IRB. Protocols are approved for a maximum period of one year. If you wish to continue the project past the approved project period (see above), you must submit a request, using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. This form is available from the IRB Coordinator or on the Research Compliance website (http://vpred.uark.edu/210.php). As a courtesy, you will be sent a reminder two months in advance of that date. However, failure to receive a reminder does not negate your obligation to make the request in sufficient time for review and approval. Federal regulations prohibit retroactive approval of continuation. Failure to receive approval to continue the project prior to the expiration date will result in Termination of the protocol approval. The IRB Coordinator can give you guidance on submission times.

This protocol has been approved for 160 participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

[delete next paragraph if not applicable]

The IRB determined and documented that the risk is no greater than minimal and this protocol may be

If you have questions or need any assistance from the IRB, please contact me at 210 Administration Building, 5-2208, or irb@uark.edu.

210 Administration Building • 1 University of Arkansas • Fayetteville, AR 72701
Voice (479) 575-2208 • Fax (479) 575-3846 • Email irb@uark.edu