Impact of Isomaltulose and Sucrose Based Breakfasts on Postprandial Substrate Oxidation and Glycemic/Insulinemic Changes in Type-2 Diabetes Mellitus Subjects

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Objective: *To investigate the effect of isomaltulose (ISO) and sucrose (SUC) based breakfast on the postprandial substrate oxidation and glycemic/insulinemic changes in type 2 diabetes mellitus subjects (T2DM).*
Material and Method: *This was a randomized, controlled, double blind, and crossover study performed in two to five days. About 10 to 12 hours prior to the test, the subjects were not allowed to consume food or drink other than water. On the experimental day pre- and postprandial plasma glucose, serum insulin, and substrate utilization were measured after the subjects consumed a test breakfast with ISO or SUC, followed by a standard lunch three hours later.*
Results: *The plasma glucose levels in subjects after consuming ISO breakfast tended to be lower than subjects consuming SUC breakfast at 30- and 60-minute, respectively. The second meal effect after standard lunch (240-minute) on insulin levels in subject consuming ISO breakfast tended to be lower than that of subjects consuming SUC breakfast. Substrate oxidation indicated that the incremental area under the fat oxidation of ISO breakfast was 20% higher comparing to SUC breakfast.*
Conclusion: *Therefore, ISO based breakfast tends to provide less postprandial glucose and insulin levels than SUC based breakfast, thereby increasing postprandial fat oxidation.*

Keywords: *Isomaltulose, Glycemic control, Type 2 diabetes, Fat oxidation*

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Breakfast literally refers to breaking the fasting period of the prior night. Breakfast has been referred to as important meal of the day. A regular breakfast meal of high quality provides the energy needed for daily activities, especially controlling blood glucose and reducing the risk of obesity and chronic disease[1]. Postprandial hyperglycemia has been implicated in the development of chronic metabolic diseases like obesity, type 2 diabetes mellitus (T2DM), and cardiovascular disease (CVD)[2]. It also leads to increased secretion of late-phase insulin, thereby promoting the accumulation of fat and reduction in fat oxidation, and in the development of insulin resistance. Thus, it is hypothesized that diabetes could be preventable by inhibiting this postprandial hyperglycemia. Postprandial plasma glucose levels are influenced by both the amount and the type of carbohydrates in food.

According to the Diabetes Control and Complications Trial (DCCT) and Epidemiology of Diabetes Interventions and Complications (EDIC), glycemic control reduces the risk of diabetes complication by about 42 to 76%[3]. The type and amount of carbohydrate consumed affects glycemic response. In general, the high quality meal represents about 45 to 65% carbohydrate of total energy[4]; whereas, the distribution of carbohydrate is over 60% in our daily intake energy in Thailand[5]. The glycemic index (GI) classifies all carbohydrates based on their immediate effects on blood glucose levels. Several studies recently reported that low-GI diets improved both glycemic control and blood lipid profiles in diabetic patients and healthy subjects[6,7]. Thus, the type and amount of carbohydrate in a meal produces a pronounced effect on the regulation of blood glucose. Thailand Health Profile (2005-2007) showed that the consumption of sugar and other foods made from flour and sugar had increased in Thai society by 261.4% during the past two decades from 12.7 kg/person/year in 1983 to 33.2 kg/person/year in 2006[8]. It might be due to the modern busy lifestyle in which people prefer ready-made meals, fast food, and consume large amount of sugar added to food or beverages. Among the sugars, sucrose is one the most common type of

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table sugar consumed (73.2%) in Thailand[1]. Since, isomaltulose is a sucrose isomer made from glucose and fructose linked by α-1,6 instead of α-1,2[9], it is digested slower in the intestine than sucrose, resulting in less availability for absorption. It has also caused reduction of postprandial plasma glucose and insulin levels[9]. Therefore, the present study was conducted to compare the effect of isomaltulose and sucrose based breakfast on the postprandial plasma glucose, serum insulin, and substrate oxidation in middle-aged healthy subjects and T2DM patients.

Material and Method

The subjects were enrolled through notification and announcement was made from various communities located nearby Mahidol University, Salaya Campus. The subjects previously diagnosed with T2DM and on concomitant therapy, and stable-oral hypoglycemic drugs for at least two months were placed in T2DM group. Subjects with gastrointestinal diseases, renal diseases, liver diseases, thyroid diseases, concomitant therapy insulin, pregnancy, or lactating females as well as subjects with severe health conditions (e.g., cancer, cardiovascular disease) were excluded. The examination of subjects was terminated if they could not meet the terms of study protocol, having fasting blood glucose level of less than 70 mg/dl or greater than 150 mg/dl before starting each test meals, or hyper- or hypo-glycemic symptoms after running the test meal. The ethical approval was obtained from the Institutional Review Board, Faculty of Medicine, Ramathibodi Hospital, Mahidol University.

The study was performed using randomized double-blind crossover design over two to five days. Subjects were advised to avoid physical exertion prior to the measurements. All the subjects ingested a standard dinner the day before the test, which included fried rice, vegetables (Chinese cabbage) soup, and apple. However, subjects were not allowed to consume food or drink other than water for 10 to 12 hours prior to the test.

On the day of testing, fasting blood glucose by finger-prick method was assessed. Then, the subjects weight, height (first visit only), and body composition was measured. The oxygen consumption (VO_2) and carbon dioxide production (VCO_2) for the calculation of substrate oxidation rate and energy expenditure were determined before and at every interval after the test meal by using indirect calorimetry with a ventilated hood system (Vmax Encore 29 System version 21-1; Viasys Healthcare Inc., SensorMedics, Yorba Linda, CA) calibrated with gases of known concentration and accurate to 2% coefficient of variation (CV) in regular alcohol burn tests. Throughout the measurement of energy expenditure, subjects were instructed to relax and avoid hyperventilation, fidgeting and sleeping. Mean minute-by-minute values of VO_2 and VCO_2 were recorded, and then substrate oxidation was calculated. Carbohydrate and fat oxidations were calculated using VO_2 and VCO_2 (L/minute) values according to the equations of Frayn[10]. Nitrogen (N) excretion was calculated based on the assumption that protein oxidation representing 17% of total energy expenditure[10].

$$N\ (g/min) = 0.17 \times (\text{energy expenditure} / 17 \times 6.25) \quad (1)$$

$$\text{Carbohydrate oxidation } (g/min) = (4.55 \times V_{CO2}) - (3.21 \times V_{O2}) - (2.87 \times N) \quad (2)$$

$$\text{Fat oxidation } (g/min) = (1.67 \times V_{O2}) - (1.67 \times V_{CO2}) - (1.92 \times N) \quad (3)$$

Prior to analysis, subjects were prepared for the collection of venous blood sampling. Subsequently, the subjects were allowed to consume test meal within 15 minutes followed by withdrawal of blood samples at 0-, 30-, 60-, 120-, 180-, 240-, 270-, 300-, 360-, and 420-minute. Nevertheless, the standard lunch was served after withdrawing blood samples at 240-minute. The plasma glucose and insulin level of blood were also examined after the test meal as scheduled (Fig. 1). The plasma and serum samples were separated within 15 minutes using centrifugation at 2,000 g for 10 minutes. Supernatant (plasma) in the gray-top tubes was used for glucose estimation using the automated (enzymatic) method. Insulin was analyzed from serum in the red-top tubes by Chemiluminescence immunoassay (CLIA) (Bangkok Pathology Laboratory).

Table 1. Composition of meals during the study

Component	Energy (kcal)	Composition of meal (%)		
		Carbohydrate	Protein	Fat
Dinner (the day before testing), included; fried rice, cucumber, vegetables (Chinese cabbage) soup, and apple	590	50.8	18.2	31.0
Breakfast* (the test day), included; cooked rice, fried boiled egg with tamarind sauce, Chinese cabbage plus minced pork soup, hot cocoa drink	559	55.6	17.1	27.3
Lunch (the test day), included; commercial frozen menu namely rice with chicken teriyaki	510	67.0	15.0	18.0

* The test formula prepared by partially replacing sucrose in control formula with 51% isomaltulose

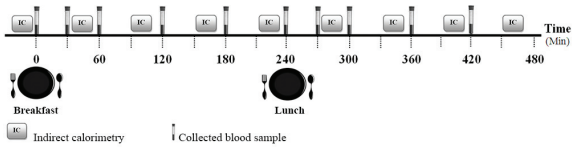

Fig. 1 Timeline of experimental.

Data analysis

Statistical analysis was performed by using SPSS for Windows, Version 18 (SPSS Inc., 2004 Chicago, USA). The results were reported as mean ± SD. A distribution of the data was analyzed according to the Shapiro-Wilk test. The effect of different sugars added in breakfast on plasma glucose, serum insulin and substrate utilization for all subjects were analyzed by repeated measure analysis (time x treatment). The incremental area under the curve (IAUC) for plasma glucose and insulin were calculated geometrically using the trapezoid rule and ignoring the area beneath the baseline using GRAPHPAD PRISM 4 for Windows version 4.03 (GraphPad Software Inc., San Diego, California, USA). The responses of ISO and SUC based breakfasts were analyzed by using linear mixed models analysis of variance and corrected for autocorrelation of errors over time. The effect of the test breakfast on dependent variables in which the subject number was modeled as a random variable, and the test breakfast, period, and period x diet interaction were included as fixed variables. The difference was considered statistically significant if p-value <0.05. The sample size for 2-treatment crossover study was calculated by using formula for testing difference of dependent mean, paired t-test with 2-sided test hypothesis, based on 95% CI and 0.80 power to detect a difference of 93.1 mmol $min^{-1}L^{-1}$ in the AUC for plasma glucose between treatment conditions, a pooled standard deviation of 98.60 mmol $min^{-1}L^{-1}$, was derived from the study of Arai et al study[11]. A sample size for group was nine subjects. Adding 20% drop out, 11 subjects were needed.

Results

General characteristics of subjects

The subjects with T2DM were 11 female middle-aged patients previously diagnosed as T2DM and had been treated with a stable dose of hypoglycemic drugs for at least two months prior to the test. Their ages and body mass index (BMI) varied between 47 and 51 years (49.64±5.71 years) and 27.2 and 28.4 kg/m^2 (27.81±2.04 kg/m^2), respectively. No carryover effect was observed for any variable. The general characteristics of the T2DM subjects at baseline were illustrated in Table 2.

Table 2. The general characteristics of T2DM subjects (mean ± SD) at baseline

Characteristics	T2DM group (n = 11)
Age (year)	49.64±5.71
Weight (kg)	64.30±7.61
BMI (kg/m^2)	27.81±2.04
SMM (kg)	22.33±4.41
BFM (kg)	29.28±8.01
FFM (kg)	35.02±6.17
HOMA-IR	2.88±3.14
REE (kcal)	1,266±162

T2DM = type 2 diabetes mellitus; BMI = body mass index; SMM = skeletal muscle mass; BFM = body fat mass; FFM = fat free mass; HOMA-IR = homeostasis model assessment of insulin resistance; REE = resting energy expenditure

Effect of ISO and SUC based breakfasts on postprandial plasma glucose and response after standard lunch

The effect of ISO and SUC based breakfasts on postprandial plasma glucose levels in T2DM subjects were shown in Fig. 2A. The plasma glucose levels in subjects that consumed SUC breakfast were higher as compared to subjects that consumed ISO breakfast. The plasma glucose levels were tended to be lower in subjects that consumed ISO breakfast at 30^{th} and 60^{th} minute (1 hour). The peak plasma glucose appeared at the 60^{th} minute in subjects that consumed SUC (106.18±26.24 mg/dl) and ISO (87.18±30.78 mg/dl) based breakfast. After standard lunch (at the 240^{th} minute), the postprandial plasma glucose levels were similar until the 300^{th} minute, in both subjects that consumed SUC and ISO breakfast. Thereafter, the plasma glucose level in subjects that consumed ISO breakfast tended to be lower until the 420^{th} minute as compared to SUC consumed counterparts.

The incremental area under the plasma glucose curve was about 11.98% lower in subjects that consumed ISO breakfast compared to SUC breakfast consumed subjects. Similarly, lower incremental area under the plasma glucose curve was also observed in subjects consumed ISO breakfast after standard lunch shown in Fig. 2B.

Effect of ISO and SUC based breakfasts on postprandial serum insulin and response after standard lunch

The postprandial serum insulin levels in subjects after consuming SUC and ISO based

breakfasts were higher at 120th minute. From Fig. 3A, the postprandial serum insulin level using ISO breakfast tended to be lower throughout the pre- and post-lunch session as compared to subjects who consumed SUC breakfast. The serum insulin level after ISO test meal at 30th minute (12.18±6.72 µIU/ml) was found about 11% lower than that of the SUC consuming subjects (13.55±7.45 µIU/ml).

In general, the incremental area under the insulin curve was lowered after using ISO breakfast. However, the difference was not big enough to influence the entire study. Even though the incremental area under the insulin curve after ISO breakfast was lower than that of the SUC breakfast, it did not cause a significant difference as well.

Effect of ISO and SUC based breakfasts on postprandial nutrient substrate oxidation

After standard lunch, fat oxidation in ISO breakfast based group tended to be higher as compared to SUC breakfast based group. The overall percent difference after standard lunch was found in the range of 7 to 23%. The results indicated that higher fat was utilized by the body after standard breakfast based on the greater percent difference of fat oxidation (32 to 40%). However, no significant difference in fat oxidation was noted between the ISO and SUC based breakfast after standard lunch at 270 to 450 minutes. In addition, the total area under the fat oxidation curve (TAUC) after ISO based group was higher than that the SUC based group by about 20% (Table 3).

The effect of ISO and SUC based breakfasts on postprandial nutrient substrate oxidation was shown in Fig. 4. The contribution of carbohydrate and fat oxidation to total energy expenditure was calculated by assuming the constant protein oxidation. The energy distribution from fat during the 1st hour after breakfast increased from 4.75±4.28% to 8.50±6.78% after consuming SUC and ISO based breakfast, respectively.

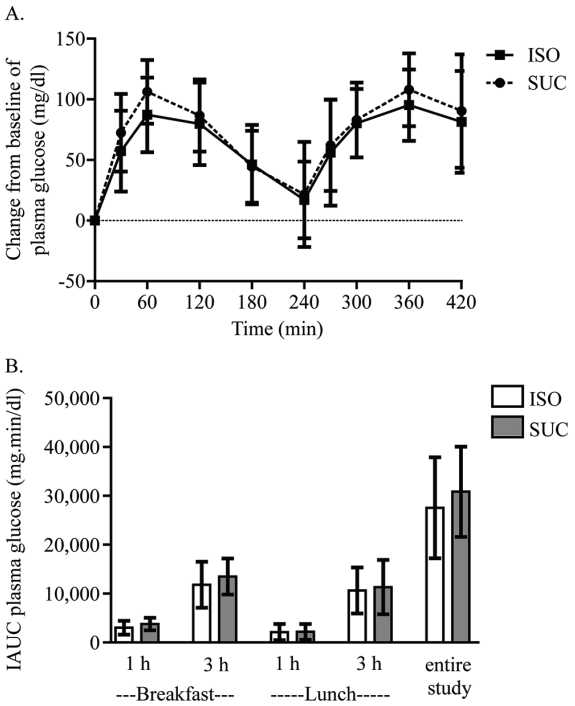

Fig. 2 A. Change in plasma glucose after intake breakfast from baseline, followed by a standard lunch. B. Incremental area under the plasma glucose curve after ISO and SUC breakfast, followed by a standard lunch (breakfast: 1- and 3-hour, lunch: 1- and 3-hour, and entire study: 7-hour. Values were mean ± SD.

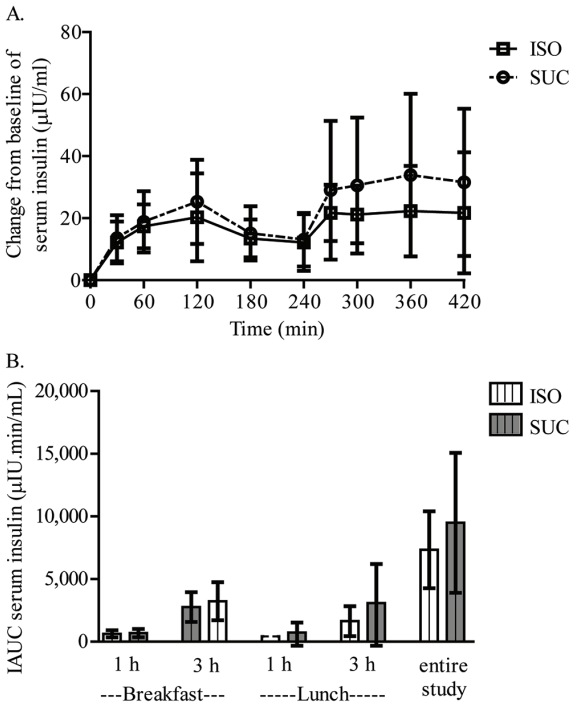

Fig. 3 A. Change in serum insulin after intake breakfast from baseline, followed by a standard lunch. B. Incremental area under the serum insulin curve after ISO and SUC breakfast, followed by a standard lunch (breakfast: 1- and 3-hour, lunch: 1- and 3-hour, and entire study: 7-hour. Values were mean ± SD.

Table 3. Fat oxidation (μmol/kg FFM/minute)† (mean ± SD) after ISO or SUC breakfast, followed by a standard lunch

Time (minute)	ISO	SUC	%††
0 (baseline)	1.55±0.68	1.52±0.65	2
30 (after breakfast)	1.01±0.47	0.69±0.57	32
90	0.58±0.43	0.35±0.32	40
150	1.24±0.44	0.83±0.51	33
210	1.56±0.75	1.45±0.57	7
240-255 (standard lunch)	-	-	-
270 (after standard lunch)	1.10±0.50	0.94±0.58	15
330	0.64±0.27	0.49±0.29	23
390	1.27±0.61	1.00±0.40	22
450	1.47±0.72	1.34±0.59	9
TAUC†††	497±184	397±184	20

ISO = isomaltulose; SUC = sucrose
† Values were mean ± SD
†† (Value of mean's breakfast with ISO - Value of mean's breakfast with SUC) x100/Value of mean's breakfast with ISO
††† Total area under (0-420 minutes) the curve calculated by using Graph Prism Version 4.03

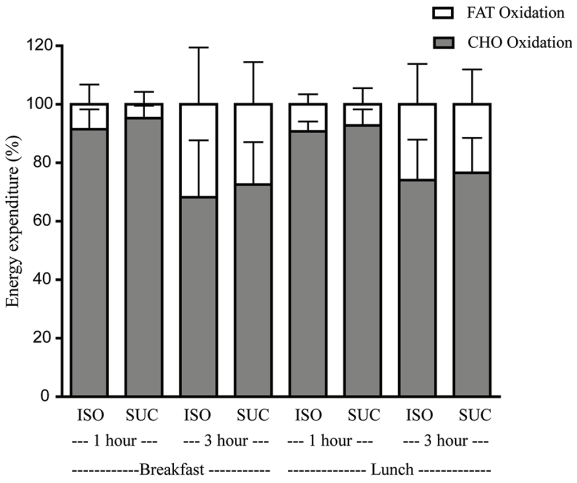

Fig. 4 Percentage of energy expenditure from substrate during the first and third hour after breakfast and lunch in the isomaltulose (ISO) or sucrose (SUC) breakfast, followed by a standard lunch. Values were mean ± SD.

Discussion

The present randomized double-blind crossover study was designed to compare the glycemic and insulinemic responses, and substrate oxidation after the ingestion of SUC and ISO based breakfast by female middle-aged T2DM subjects.

The ISO based breakfast could attenuate the postprandial glycemic and insulinemic response in comparison with SUC breakfast. The lower peaks of plasma glucose and insulin concentrations were evident after the ingestion of ISO based breakfast (Fig. 2, 3). In addition, glucose and insulin peaks in T2DM patients (60- and 120-minute) after consuming ISO based breakfast were tended to be lower than that of SUC breakfast. Moreover, the incremental area under the plasma glucose curve after consuming ISO breakfast in the 1st and 4th hour tended to be lower than that of SUC breakfast. The results were consistent with the study of Arai et al (2007)[11], which showed peak plasma glucose and insulin levels decreased after 30 minutes with the ingestion of isomaltulose-containing liquid meal as compared to control formula in healthy men. It was noted that the ISO is a sucrose isomer found in honey, metabolized by isomaltase, and less rapidly, although completely, and subsequently cleaved in the intestine than sucrose[9]. ISO was used as the main slowly digestible carbohydrate source. The slower digestion and absorption of ISO is more likely responsible for the attenuated postprandial rise in blood glucose and insulin concentrations. In vitro studies using human small intestinal mucosa homogenates demonstrated that human intestinal enzymes hydrolyze ISO at a much slower rate when compared with sugars such as maltose or sucrose[9]. The effect of ISO had also been studied previously in various individuals, healthy[11], T2DM[12], critically ill patients[13], and esophageal cancer complicated by diabetes mellitus[14]. The effect of ISO consumption at breakfast did not limit to breakfast only but rather extended to lunch. The ISO based breakfast might attenuate insulin levels and incremental area after lunch as evidenced by serum insulin curve (Fig. 3B).

The present study provided evidence that attenuated rise in glycemic and insulinaemic responses as ISO shifted postprandial substrate utilization towards greater fat use (Fig. 4). It was noted that intake of ISO in combination with a mixed meal resulted in 20% increased postprandial fat oxidation. The hypothesis was that SUC based breakfast increases serum insulin and glucose levels, thereby promoting carbohydrate oxidation and suppressing fat oxidation[11], while ISO based breakfast reduces plasma glucose and serum insulin resulting reduces insulin-mediated suppression of lipolysis[15] and reduces inhibition of postprandial fat oxidation[16]. The findings of presented data are consistent with other reported papers, which highlighted the stimulating effect of ISO ingestion on

fat oxidation. Arai et al (2007)[11] and Van Can et al (2009)[16] found that ISO meal provided greater postprandial fat consumption accompanied with higher circulating plasma non-esterified fatty acid concentration. Arai et al (2007) showed that postprandial fat oxidation rates following the ingestion of ISO meal group were 50% higher when compared with the control formula group[11]. More recent study by Van Can et al (2009) also found that postprandial fat oxidation rate was higher (14%) in ISO compared with SUC[16].

The findings of present study also showed that ISO tended to stimulate postprandial fat oxidation in comparison with SUC. The observation implied that substitution of SUC with ISO might support body-weight control in obesity. A shift towards a greater postprandial fat consumption may attenuate fat accumulation in non-adipose tissues leading to reduced insulin resistance[17]. Sato et al (2007) observed significant reductions in visceral fat mass, adipocyte cell size, hyperglycaemia, and hyperlipidaemia after eight weeks of ISO feeding as compared to SUC feeding in Zucker fatty (fa/fa) rats[18]. Subsequently, the study conducted by Oizumi et al (2007) found that ISO based formula reduced body fat and visceral fat accumulation in obese subjects[19].

Diabetic subjects included in the present study were screened by history and fasting blood glucose by finger-prick. The degree of carbohydrate metabolism disturbance by oral glucose tolerance test was not assessed. Therefore, there might be more difference in severity of disease in diabetic subjects included in the study, which may affect more variation in glycemic and insulinemic responses comparing to healthy volunteer. Increased number of sample size would be needed to obtain better results.

In the present study, all subjects received the same standardized meal in the evening prior to each test day. Despite such rigorous dietary standardization, it was evident that postprandial glucose and insulin responses can vary substantially on a day-to-day basis. The fact that the test diet were tested only once in each subject might represent limitation of the presented work. Furthermore, it should be noted that the clinical relevance of these findings when applied in more long-term conditions remain to be established. Clearly, more research is required to study the impact of the slowly digestible carbohydrate on long-term glycemic control.

Conclusion

The purpose of the present study was to investigate the effect of ISO and SUC based breakfast on postprandial plasma glucose, insulin, substrate oxidation, and the second-meal effect in type 2 diabetic subjects.

The results of the present study demonstrated the benefits of a slowly digestible disaccharide, ISO, on glycemic control on type 2 diabetic subjects. Based on the results, higher fat oxidation percentage indicating great use of fat substrate was noted in case of ISO breakfast consumed subjects. Therefore, substituting ISO for SUC in mixed meal diet attenuated the postprandial glycemic and insulinaemic responses and increased postprandial fat oxidation.

In conclusion, the present study suggested that type 2 diabetic patients could be benefited by the ingestion of ISO based diets due to its slow digestion and absorption, thereby could help to utilize the fat substrate.

What is already known on this topic?

Postprandial hyperglycemia has been implicated in the development of chronic metabolic diseases like obesity, T2DM and cardiovascular disease. It also leads to increased secretion of late-phase insulin, thereby promoting the accumulation of fat and reduction in fat oxidation, and in the development of insulin resistance. Thus, it is hypothesized that diabetes could be preventable by inhibiting this postprandial hyperglycemia. Postprandial plasma glucose levels are influenced by both the amount and the type of carbohydrates in food.

A low-GI breakfast might improve glucose tolerance after lunch; this improvement has been referred to as the second-meal effect. In addition, low-GI foods produced higher production rates of fat oxidation than high-GI foods of isoenergetic diets, and enhanced energy requirement.

Generally, diabetic patients who love sweet are advised to use artificial sweeteners or sugar substitutes as another way to control blood glucose levels. However, sweeteners could not replace all the sugar content in recipe. Some sweeteners lose sweetness when heated at high temperatures for long periods. It also may not work well in some recipes that rely upon sugar for structure. Some sweeteners such as sorbitol or mannitol may have laxative effect especially in high intake. Thus, it is necessary to choose sugar substitutes or sweeteners to optimal individual preference, nutrition, and health.

What this study adds?

It is the first study to use alternative sugar, isomaltulose, and substitute to sucrose in Thai food to

study postprandial and substrate utilization in type 2 diabetic patients. In this study, we investigated the effect of isomaltulose-based breakfast on postprandial plasma glucose, insulin, substrate oxidation, and the second-meal effect in type 2 diabetic subjects. Isomaltulose was used as a replacement for sucrose, which is conventionally used in Thai food. Isomaltulose is known to control plasma glucose better than sucrose and was investigated thoroughly in the present study. Sugars, especially sucrose increase plasma glucose easily. Isomaltulose has similar functional properties that of sucrose. Since, isomaltulose is a sucrose isomer made from glucose and fructose linked by α-1,6 instead of α-1,2. It is digested slower in the intestine than sucrose resulting in less availability for absorption. It has also caused reduction of postprandial plasma glucose and insulin levels. We concluded from the present study that type 2 diabetic patients might be beneficial from ingestion of isomaltulose as a substitute for sucrose in their diet. In addition, we noted that lower postprandial plasma glucose and insulin concentrations shifted postprandial substrate towards greater fat use and affected the second meal prominently in type 2 diabetic subjects. Results obtained from this study provide an evidence-based practice for dietitian or other health practitioners to apply for controlling blood glucose in diabetic patients.

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Potential conflicts of interest

None.

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ผลของการรับประทานชุดอาหารเช้าที่มีชนิดน้ำตาลที่แตกต่างกันระหว่างน้ำตาลไอโซมอลตูโลส กับน้ำตาลซูโครสต่อการนำสารอาหารไปใช้และการเปลี่ยนแปลงของระดับน้ำตาลและอินซูลินในเลือด ศึกษาในผู้ป่วยเบาหวานชนิดที่ 2

พิมพ์นภาณัท ศรีดอนไผ่, สุรัตน์ โคมินทร์, วันทนีย์ เกรียงสินยศ

วัตถุประสงค์: *เพื่อศึกษาผลของการใช้สารอาหาร การเปลี่ยนแปลงระดับน้ำตาลและอินซูลินในเลือดในผู้ป่วยเบาหวานชนิดที่ 2 (T2DM) หลังรับประทานชุดอาหารเช้าที่ประกอบด้วยน้ำตาลที่แตกต่างกัน ระหว่างน้ำตาลไอโซมอลตูโลส (ISO) และน้ำตาลทรายหรือน้ำตาลซูโครส (SUC)*

วัสดุและวิธีการ: *เป็นการศึกษาเชิงทดลองไขว้กลุ่มแบบสุ่มที่มีการปกปิดชนิดอาหารที่ได้รับของผู้เข้าร่วมการทดสอบและผู้ประเมินผลลัพธ์ โดยมีระยะห่างระหว่างการศึกษาประมาณ 2-5 วัน ในวันก่อนการทดสอบผู้เข้าร่วมการทดสอบจะงดการรับประทานอาหารหรือเครื่องดื่ม ยกเว้น น้ำเปล่า ประมาณ 10-12 ชั่วโมง ก่อนการทดสอบ ในวันทดสอบผู้นิพนธ์วัดการเปลี่ยนแปลงระดับน้ำตาลและอินซูลินในเลือด การใช้สารอาหารก่อนและหลังการรับประทานอาหารเช้าที่ประกอบด้วยชนิดน้ำตาลที่แตกต่างกัน ได้แก่ ISO และ SUC และติดตามการเปลี่ยนแปลงหลังจากการรับประทานอาหารกลางวันมาตรฐานที่มีปริมาณเท่ากัน ต่อไปอีก 3 ชั่วโมง*

ผลการศึกษา: *ผู้ป่วยเบาหวานชนิดที่ 2 มีแนวโน้มค่าระดับน้ำตาลในเลือดหลังรับประทานอาหารเช้าที่ประกอบด้วยน้ำตาล ISO ที่ต่ำกว่าหลังรับประทานชุดอาหารเช้าที่ประกอบด้วยน้ำตาล SUC ที่ 30 และ 60 นาที เมื่อติดตามอิทธิพลต่อมื้ออาหารถัดไปพบว่าการเพิ่มขึ้นของระดับอินซูลินหลังรับประทานอาหารกลางวันมาตรฐาน (นาทีที่ 240) ของอาหารเช้าที่ประกอบด้วยน้ำตาล ISO มีแนวโน้มค่าการเพิ่มขึ้นต่ำกว่าน้ำตาล SUC การนำสารอาหารไปใช้ โดยติดตามการเพิ่มขึ้นของการเผาผลาญไขมัน พบว่า พื้นที่ใต้กราฟของการเผาผลาญสารอาหารไขมันในอาหารเช้าที่ประกอบด้วยน้ำตาล ISO มีค่าสูงกว่า SUC ร้อยละ 20*

สรุป: *การรับประทานอาหารเช้าที่ประกอบไปด้วยน้ำตาล ISO มีแนวโน้มทำให้ระดับน้ำตาลในเลือดและอินซูลินหลังรับประทานอาหารเช้าเพิ่มขึ้นน้อยกว่า และทำให้เกิดการเผาผลาญสารอาหารไขมันเพิ่มขึ้น เมื่อเปรียบเทียบกับการรับประทานอาหารเช้าที่ประกอบด้วยน้ำตาล SUC*