การพัฒนาผลิตภัณฑ์ธัญพืชอัดแท่งจากข้าวไรซ์เบอรี่อบกรอบเสริมฟรักโทโอลิโกแซ็กคาไรด์

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บทคัดย่อ

ธัญพืชอัดแท่งเป็นผลิตภัณฑ์ที่ได้รับความนิยมเนื่องจากมีความหลากหลาย พกพาสะดวก และรับประทานง่าย แต่อาจมีปริมาณน้ำตาลสูง ในขณะที่ฟรักโทโอลิโกแซ็กคาไรด์ (Fructo-oligosaccharide; FOS) เป็นใยอาหารที่ละลายน้ำ มีคุณสมบัติเป็นพรีไบโอติก และสามารถใช้เป็นสารให้ความหวานได้ FOS จึงเป็นสารที่น่าสนใจสำหรับนำมาใช้ในธัญพืชอัดแท่งเพื่อลดการใช้น้ำตาล และทำให้ผลิตภัณฑ์มีประโยชน์ต่อสุขภาพมากขึ้น งานวิจัยนี้มีวัตถุประสงค์เพื่อพัฒนาผลิตภัณฑ์ธัญพืชอัดแท่งจากข้าวไรซ์เบอร์รี่โดยใช้ FOS เป็นสารทดแทนน้ำตาล จากการศึกษาผลของระดับการแทนที่น้ำตาลด้วย FOS (20 – 80 %) ต่อคุณภาพทางกายภาพ และสารอาหารของธัญพืชอัดแท่ง พบว่า การเพิ่มระดับการแทนที่ FOS จาก 20 % เป็น 80 % ส่งผลให้ค่าความแข็ง ปริมาณคาร์โบไฮเดรต ปริมาณน้ำตาลทั้งหมด ปริมาณน้ำตาลรีดิวซ์ และปริมาณซูโครสของผลิตภัณฑ์ลดลงอย่างมีนัยสำคัญทางสถิติ ($p \leq 0.05$) ในขณะที่ปริมาณใยอาหารทั้งหมด ใยอาหารที่ละลายน้ำ และใยอาหารที่ไม่ละลายน้ำของผลิตภัณฑ์เพิ่มขึ้นอย่างมีนัยสำคัญทางสถิติ ($p \leq 0.05$) โดยสูตรที่เหมาะสมของผลิตภัณฑ์ธัญพืชอัดแท่ง คือ สูตรที่มีการใช้ FOS ทดแทนน้ำตาล 80 %

คำสำคัญ: ธัญพืชอัดแท่ง ฟรักโทโอลิโกแซ็กคาไรด์ ข้าวไรซ์เบอร์รี่ ใยอาหาร ซูโครส

Development of Cereal Bar from Riceberry Rice containing Fructo-oligosaccharide

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Abstract

Cereal bars were popular because of their versatile, portable and convenience. However, they were discouraged for the high content of sugar. Fructo-oligosaccharide (FOS) was a prebiotic soluble dietary fiber and an alternative sweetener, so it was an interesting additive for cereal bars. Then, this study aimed to develop healthier cereal bars from Riceberry rice, by replacing sugar with FOS. The effect of FOS substitution (20 – 80 %) on physical quality and nutritional values of cereal bars was investigated. By increasing the level of FOS substitution from 20 % to 80 %, the hardness, carbohydrate, total sugar, reducing sugar, and sucrose contents in the cereal bars were significantly decreased ($p \leq 0.05$). In contrast, the total dietary fiber, soluble dietary fiber and insoluble dietary fiber were significantly increased ($p \leq 0.05$). Additionally, replacing 80 % of sugar with FOS was recommended as the optimal cereal bar formulation.

Keywords: Cereal bar, Fructo-oligosaccharide, Riceberry rice, Dietary fiber, Sucrose

1. Introduction

Cereal bars, granola bars, or muesli bars are a simple and convenient ready–to–eat food [1, 2]. The global cereal bars market is estimated to grow a compound annual growth rate (CAGR) of 8.5 % between 2021 and 2026 [3]. Cereal bars are bar-shaped food products that serve as versatile and portable sources of carbohydrates, proteins, fats, and dietary fibers [2, 4]. They typically consist of cereals, dried fruits or berries, crispy rice, and a sugar–based binding syrup [4]. In case sugar provides the desired flavor and texture in cereal bars and holds the shape of cereal bars. This leads to cereal bars being discouraging because of their high sugar content [5]. Moreover, an increase in health consciousness of the consumer and awareness of negative effects of sugar has occurred [6]. Thus, this is an interesting for development the cereal bar with reduced sugar and healthier ingredients as alternative cereal bar choices.

Riceberry rice (deep purple grain; *Oryza sativa*) belongs to the Poaceae family. It is a special cultivar of rice developed in Thailand. It is developed through crossbreeding between Chao Hom Nin rice variety containing antioxidant properties and Khao Dawk Mali 105 known as fragrant Thai Jasmine rice [7, 8]. It is rich in nutrients and antioxidants, including iron, vitamin B1 , tannins, omega–3 , vitamin E complex (tocopherols and tocotrienols) anthocyanins (cyanidin–3 – O–glucoside and peonidin–3 – O–glucoside), polyphenols, β–carotene, gamma–oryzanol, and folic acid [9]. It possesses several health benefits, including antioxidant, anti-inflammatory. Additionally, it has potential to reduce the risk of cancer, diabetes, cardiovascular diseases, and other chronic conditions [10].

Fructo–oligosaccharide (FOS), a well–known prebiotic, is a soluble dietary fiber with D–fructose units linked by β–(2,1) bonds. The number of fructose units ranges from 2 to 60 and often terminates with a glucose unit [11, 12]. It is naturally found in various plants, including chicory, onion, garlic, artichoke, asparagus, dragon fruit, banana, wheat, rye, and others. It is beneficial for human health by reducing cholesterol levels, enhancing immunity, and improving gut health [13, 14]. Moreover, it is a sugar substitute possessing 30 – 50% of sweetness of sucrose. It is low in energy containing approximately 1 – 1.5 kilocalories per gram [15]. It reduces the glucose peak in blood after eating. Thus, these FOS properties provide a greater choice to healthy people looking for an alternative sweetener and those suffering from diabetes [13, 16].

As above mention, both Riceberry rice and FOS are interesting ingredients used in formulating a healthier cereal bar because of their several nutrition and potential health benefits. In case Riceberry rice is rich in antioxidant properties. FOS is not only an alternative sweetener, but also a prebiotic dietary fiber. Hence, this research aims to develop cereal bar from Riceberry rice with FOS. The objective of this research is to investigate the physical properties and nutritional composition of the cereal bar from Riceberry rice with varying levels of FOS. From this study, the healthier cereal bar with reduced sugar and fortified dietary fiber will benefit the health-conscious consumers and food industries.

2. Material and Methods

2.1 Materials

Riceberry rice (Nadi, Thailand), fructo–oligosaccharide (Bangkok chemical, Thailand), cashew nuts, sliced almonds (Sun grains, Thailand), dried cranberries (Aro, Thailand), glucose syrup (Chang ha dao, Thailand), cornflakes (Nestlé, Thailand), peanuts (Rai thip, Thailand), white sesame seeds (Rai thip, Thailand), dried bananas (Mae arak, Thailand), salt (Prung thip, Thailand), honey (Doi kham, Thailand), brown sugar (Mitr phol, Thailand), unsalted butter (Allowrie, Thailand), vanilla flavor (Winner, Thailand), and lemon powder (Knorr, Thailand), raisins (Aro, Thailand), were used as ingredients.

2.2 Preparation of cereal bars

Firstly, the syrup mixture (33.32 g per 100 g of sample) was prepared using 13.00 g of honey, 7.24 g of butter, 5.79 g of glucose syrup, 0.50 g of lemon powder, 0.05 g of vanilla flavor, 0.50 g of salt, 1.34 – 6.24 g of brown sugar and/or 0 – 4.90 g of FOS per 100 g of sample. In case brown sugar was partially replaced with FOS at levels of 0%, 20%, 40%, 60%, and 80% according to Handa *et al.* with some modification [15]. For cereal bars preparation (100 g), all dry ingredients (including 42.73 g of crispy deep-fried Riceberry rice, 6.10 g of cornflakes, 3.00 g of cashew nuts, 1.76 g of sliced almonds, 3.25 g of peanuts, 3.33 g of dried cranberries, 3.30 g of dried bananas, 1.76 g of raisins, and 1.45 g of white sesame seeds) were combined with the boiled syrup mixture (100 ± 5 °C) in a mixing bowl. The combined mixture was placed into a mold (12 × 16 × 1 inch) and baked at 150 °C for 5 min. After baking, it was allowed to cool for 3 h. The cooled product was cut into 6 × 2 cm bars and packed in a plastics bag for further analysis following the procedure of Padmashree *et al.* [17] and Lainumngen *et al.* [18] with some modification.

2.3 Determination of physical properties

The water activity (a_w) of cereal bars was measured in triplicate at 25 °C using an electric water activity meter (Novasina, MS1, Switzerland) following the procedure of Chompoo *et al.* with some modification [19].

The color of cereal bar was analyzed in triplicate using a spectrophotometer (UltraScan PRO, HunterLab, VA, USA) with the CIE L*a*b* system. The color parameters were L*—describing the lightness, a*—describing greenness (−) to redness (+), and b*—describing blueness (−) and yellowness (+) following the procedure of Lainumngen *et al.* with some modification [18].

The hardness, cohesiveness, and chewiness were analyzed in quadruplicate using a texture analyzer (TA–XT Plus, Stable Micro Systems, UK) with a SMSP/50 cylindrical probe, pressing the sample at a speed of 15 mm/min according to Kamolwan *et al.* with modification [20].

2.4 Determination of nutritional composition

The moisture, protein, fat and ash content of all samples were analyzed in triplicate according AOAC method [21]. Total carbohydrate content was calculated by subtracting the total moisture, protein, fat, and ash content from 100%. Soluble and insoluble dietary fibers of all samples were analyzed in duplicate according AOAC method [21].

2.5 Determination of total sugar, reducing sugar and sucrose

The sugar content of all samples was analyzed in triplicate using the Lane and Eynon titration method, following the procedure of AOAC [21]. The total sugar, reducing sugar and sucrose content were calculated and expressed in percentage (w/w).

2.6 Statistical analysis

The experiment was designed using a completely randomized design (CRD) to determine variation of cereal bars characteristics due to variation of FOS contents (0%, 20%, 40%, 60%, and 80%). The difference among the means of all five treatments was analyzed. Duncan's multiple range test was used to identify a significant difference ($p \leq 0.05$) by SPSS statistics version 28.0.

3. Results and Discussion

3.1 Physical properties of cereal bars

In Table 1, the a_w, L*, a* and b* values of cereal bars were significantly increased ($p \leq 0.05$) when FOS (20 – 80 %) was increased into the cereal bar formulation. The increase in a_w values (0.17±0.00 – 0.20±0.01) were due to FOS was highly hygroscopic and possessed a greater water retention capacity than sucrose. In case freeze-dried FOS would absorb and retain moisture from the environment during storage, leading to increased water activity of the final product [22]. For the color of cereal bars, this finding consistent with Linggo *et al*. [23] determined the effects of substituting sugar with FOS (0 – 75 %) on marshmallow quality. The result showed that increasing the FOS contents increased L* values which in the range of 86.43 ± 0.79 to 89.50 ± 0.25. Additionally, when FOS (20 – 80 %) was increased into the cereal bar formulation, the hardness, chewiness, and cohesiveness values of cereal bars were significantly decreased ($p \leq 0.05$) (Table 1). This was because of the water–holding capacity and moisture absorption property of FOS. This reduced the aggregation of ingredients in the cereal bar, leading to a less compact structure [24]. This coincided with Handa *et al.* [15] reported that increasing FOS content (40 – 80 %) in cookies significantly reduced their hardness ($p \leq 0.05$). The hardness of cookies with the addition of FOS (6,538 ± 128 – 7,109 ± 75 g) was lower than that of cookies without FOS (7,139 ± 166 g). Peñaranda and Garrido [25] reported that incorporating 2 – 6 g of FOS content as a substitute for methylcellulose in plant–based burgers significantly reduced their cohesiveness and chewiness ($p \leq 0.05$). The cohesiveness (0.34 – 0.35) and chewiness (2.00 – 2.30 mJ) of plant-based burgers with the addition of FOS was lower than those of plant-based burgers without FOS (cohesiveness = 0.38; chewiness = 2.74 mJ).

Table 1 Physical properties of cereal bars with different FOS substitution levels

Physical properties	FOS 0%	FOS 20%	FOS 40%	FOS 60%	FOS 80%
a_w	$0.19{\pm}0.00^{ab}$	$0.17{\pm}0.00^{c}$	$0.18{\pm}0.00^{bc}$	$0.19{\pm}0.02^{ab}$	$0.20{\pm}0.01^{a}$
L*	$42.98{\pm}1.63^{a}$	$40.41{\pm}0.40^{c}$	$41.82{\pm}0.06^{b}$	$44.08{\pm}0.34^{a}$	$43.83{\pm}0.10^{a}$
a*	$2.61{\pm}0.51^{a}$	$1.72{\pm}0.40^{b}$	$1.80{\pm}0.31^{b}$	$1.90{\pm}0.72^{ab}$	$2.12{\pm}0.22^{ab}$
b*	$7.37{\pm}1.70^{a}$	$3.75{\pm}0.41^{c}$	$4.72{\pm}0.35^{bc}$	$5.37{\pm}1.96^{bc}$	$5.83{\pm}0.40^{ab}$
Hardness (N)	$328.77{\pm}10.83^{a}$	$306.17{\pm}9.16^{a}$	$265.90{\pm}10.14^{b}$	$216.53{\pm}6.22^{b}$	$194.28{\pm}2.64^{c}$
Cohesiveness (–)	$0.17{\pm}0.02^{a}$	$0.18{\pm}0.01^{a}$	$0.14{\pm}0.02^{b}$	$0.12{\pm}0.00^{c}$	$0.11{\pm}0.01^{c}$
Chewiness (N)	$15.51{\pm}0.39^{a}$	$14.37{\pm}0.10^{a}$	$11.47{\pm}1.01^{b}$	$9.33{\pm}0.70^{c}$	$7.45{\pm}2.25^{c}$

Note: values denoted by different superscripts within the row are significant different ($p \leq 0.05$).

3.2 Nutritional composition of cereal bars

Increasing the FOS content (20 – 80 %) in the cereal bar formulation did not significantly affect their moisture, protein, ash, and fat contents ($p > 0.05$) (Table 2). However, the moisture content of cereal bars increased because of the high moisture retention capacity of FOS [26]. Additionally, the carbohydrate content of cereal bars with addition of FOS decreased from 57.93±0.31 % to 52.90±1.84 % (Table 2) because the carbohydrate content of FOS (1 – 1.5 %) was normally lower than that of sugar (4.5%). These aligned with Handa *et al.* [15] reported that the moisture content of cookies increased from 2.4 g/100 g to 2.6 g/100 g, when the FOS content was increased from 40 % to 80 % in the cookies. However, increasing FOS content in cookies decreased their carbohydrate content (54.0 – 61.4 g/100 g) comparing to that of the cookies without FOS (69.0 g/100 g). In case total dietary fiber, soluble dietary fiber and insoluble dietary fiber of cereal bars with addition of FOS (20 – 80 %) was significantly increased ($p \leq 0.05$) (Table 2) because FOS was a complex carbohydrate that could not be hydrolyzed by human digestive enzymes. It was classified as a soluble dietary fiber. It was highly water–soluble and helped to improve the dietary fiber content in food products [26, 27]. This aligned with Handa *et al.* [15] reported that increasing FOS content (40 – 80%)

in cookies significantly increased the total dietary fiber content of cookies ($p \leq 0.05$). The total fiber content of cookies with addition of FOS (8.7 – 15.9 g/100 g) was higher than that of cookies without FOS (1.3 g/100 g). Additionally, the insoluble dietary fiber content of cereal bars (5.10±0.01 – 5.15±0.01 g/100 g) was slightly higher than that of soluble dietary fiber content (1.21±0.01 – 4.69±0.01 g/100 g) (Table 2). This was because the formulation of cereal bars consisted of cereals and grains (such as Riceberry rice, cashew nuts, white sesame seeds and others) which were rich sources of insoluble dietary fiber [28]. Interestingly, the cereal bar with 80 % FOS provided high fiber, as evaluated based on the recommended dietary allowances for Thai (Thai RDI). It complied with the definition of “Good Source of Dietary Fiber” according to the Notification of the Ministry of Public Health No. 445, B.E. 2566 (2023).

Table 2 Nutritional composition of cereal bars with different FOS substitution levels

Nutritional composition	FOS 0%	FOS 20%	FOS 40%	FOS 60%	FOS 80%
Moisture (%)	3.86±0.27^{a}	3.80±0.08^{a}	4.45±0.36^{a}	4.04±0.59^{a}	4.46±0.51^{a}
Protein (%)	20.13±0.68^{a}	20.02±1.12^{a}	20.20±0.10^{a}	20.32±0.57^{a}	20.42±2.36^{a}
Ash (%)	1.56±0.15^{a}	1.54±0.15^{a}	1.61±0.05^{a}	1.34±0.41^{a}	1.26±0.24^{a}
Fat (%)	10.58±0.44^{a}	10.40±1.22^{a}	11.21±1.96^{a}	11.20±0.57^{a}	11.12±0.51^{a}
Carbohydrate (%)	57.71±1.00^{a}	57.93±0.31^{a}	54.04±1.97^{b}	54.40±1.86^{b}	52.90±1.84^{b}
Total dietary fiber (g/100 g)	5.83±0.01^{e}	6.31±0.01^{d}	7.49±0.09^{c}	8.70±0.01^{b}	9.84±0.01^{a}
Soluble dietary fiber (g/100 g)	0.77±0.01^{e}	1.21±0.01^{d}	2.37±0.01^{c}	3.56±0.01^{b}	4.69±0.01^{a}
Insoluble dietary fiber (g/100 g)	5.06±0.01^{d}	5.10±0.01^{c}	5.12±0.01^{b}	5.14±0.01^{ab}	5.15±0.01^{a}

Note: values denoted by different superscripts within the row are significant different ($p \leq 0.05$).

3.3 Total sugar, reducing sugar and sucrose of cereal bars

Increasing the FOS content (20 – 80 %) in the cereal bar formulation significantly decreased the total sugar, reducing sugar, and sucrose contents ($p \leq 0.05$) (Table 3). This might be because FOS, which was an oligosaccharide, was not hydrolyzed by human digestive enzymes. It provided 30 – 50 % sweetness compared to sucrose. As the result, replacing sugar with FOS in cereal bars led to a proportional reduction in sucrose. Furthermore, FOS was not considered a reducing sugar because it did not contain aldehyde or ketone groups that could participate in redox reactions [29, 30]. Therefore, using FOS in the cereal bar reduced the total sugar, reducing sugar, and sucrose contents comparing to the cereal bar without addition of FOS. In case the reducing sugar content of cereal bars (1.35±0.01 – 2.62±0.02 %) was higher than the sucrose content (0.61±0.02 – 1.21±0.03 %) (Table 3). This was because sucrose, a non–reducing sugar, was hydrolyzed into glucose and fructose during heating. Both glucose and fructose were normally reducing sugars. This aligned with Nakhon *et al.* [31] reported the effect of replacing sugar with sweeteners in the ratio of sorbitol and FOS in sweet egg yolk drop, which was one of the traditional Thai desserts. The results showed that the reducing sugar and sucrose contents of the product were significantly reduced ($p \leq 0.05$), when the sugar replacement was increased (25 – 100 %). The reducing sugar content (0.45 – 0.68 as invert sugar g/100 g) and sucrose content (0.88 – 33.30 g/100 g) of products with addition of sorbitol and FOS in a 50:50 ratio were lower than those of the product without addition of sweeteners (reducing sugar content = 0.68 ± 0.03 as invert sugar g/100 g; sucrose content = 43.10 ± 0.56 g/100 g). Additionally, the 80 % FOS cereal bar was recommended because replacing 80 % of sugar with FOS could reduce the sugar content of the cereal bar. It complied with the definition of “Reduced Sugar” according to the Notification of the Ministry of Public Health No. 445, B.E. 2566 (2023).

Table 3 Total sugar, reducing sugar and sucrose of cereal bars with different FOS substitution levels

Sample	Total sugar (%)	Reducing sugar (%)	Sucrose (%)
FOS 0%	4.89±0.02^{a}	3.39±0.09^{a}	1.50±0.09^{a}
FOS 20%	3.83±0.01^{ab}	2.62±0.02^{ab}	1.21±0.03^{a}
FOS 40%	2.87±0.01^{b}	2.03±0.02^{b}	0.84±0.01^{ab}
FOS 60%	2.34±0.01^{b}	1.66±0.02^{bc}	0.68±0.02^{c}
FOS 80%	1.96±0.01^{c}	1.35±0.01^{c}	0.61±0.02^{c}

Note: values denoted by different superscripts within the column are significant different ($p \leq 0.05$).


FOS 0%


FOS 20%


FOS 40%


FOS 60%


FOS 80%

Figure 1 Photograph of cereal bars with variations of FOS content (0 – 80 %).

4. Conclusions

This study provided guidance for recipe development and evaluated the characteristics of cereal bars from Riceberry rice with sugar substituted by FOS. It concluded that FOS could be used as a partial sugar replacer. Moreover, its inclusion significantly influenced several characteristics of the cereal bars. An increase in FOS (20 – 80 %) in cereal bars significantly decreased the hardness, total carbohydrate, total sugar, reducing sugar, and sucrose contents ($p \leq 0.05$). In contrast, their total dietary fiber, soluble dietary fiber, and insoluble dietary fiber contents were significantly increased ($p \leq 0.05$). Hence, the substitution of sugar with FOS in cereal bars could reduce sugar content and enhance prebiotic properties, thereby improving health benefits for consumers.

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6. References

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