

The 4th International Conference on Applied Science and Health (ICASH 2019), 23-24 July 2019, Faculty of Graduate Studies, Mahidol University, Thailand

Storage Stability of High Fiber Snack Bar

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ABSTRACT

Background: Recently, there has been considerable interest in increasing the dietary fiber content in food products because of inadequate dietary fiber consumption when considering the daily recommended intake. To increase dietary fiber intake, dietary fiber fortified foods are recommended. This study aimed to develop a high fiber snack bar (HFSB) using a combination of Jerusalem artichoke powder (JAP) and low-fat desiccated coconut (LFDC) as sources of dietary fiber.

Methods: The changes in physicochemical and microbiological properties, and sensory acceptability were measured during storage at 35 °C and 45 °C for 12 weeks. Therefore, the shelf-life of the products was calculated by Q10 test.

Results: The HFSB had a higher L* value (lightness) than control (C) due to the addition of LFDC. Total dietary fiber of the HFSB was approximately 3.7 times higher than that of the C formula. The L*, a*, and b* values of both C and HFSB were statistically significant different ($p < 0.05$) after storage. The total color different (ΔE) values of the HFSB were higher than those of the C formula due to inulin from JAP, which participated in the Maillard reaction. During storage, the moisture content (MC) and water activity (aw) of the HFSB remained more stable compared to those of the C due to the water-holding capacity of the fiber used. The aw of the C and HFSB during storage were in the range of 0.57 to 0.60 and 0.53 to 0.57, respectively. Those ranges should be stable against microbial growth. Higher storage temperature would increase the TBARS values and decrease the pH ($p < 0.05$) of the C and HFSB due to deterioration. In terms of shelf-life calculation, the C and HFSB snack bar could be kept in metalized polyester at 30 °C for 11 weeks.

Conclusion: The JAP and LFDC exhibited great potential for use as fiber ingredients. Although the JAP and LFDC influenced the physicochemical properties and sensory acceptability, the shelf-life of both C and HFSB was comparable. Therefore, further studies should be conducted to extend the shelf-life of the formulated snack bar.

Keywords: Snack bar, High fiber, Jerusalem artichoke, Low-fat desiccated coconut, Shelf-life

Received: 8 May 2019 **Reviewed:** 14 June 2019 **Revised:** 26 June 2019 **Accepted:** 19 July 2019

DOI: [10.35898/ghmj-33456](https://doi.org/10.35898/ghmj-33456)

Selection and peer-review under responsibility of the scientific committee and the editorial board of The 4th International Conference on Applied Science and Health (ICASH 2019)

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1. Introduction

Many research articles have reported that dietary fiber consumption in children, adolescents, and adults is inadequate when considering the daily recommended intake (Reicks et al., 2014). To increase the consumption of dietary fiber, food products can be fortified using various fiber ingredients. Dietary fiber from conventional foods such as barley bran, oat bran, cereal, fruits, and vegetables, are commonly used as value added fiber ingredients since they provide health benefits (Elleuch et al., 2011). The dietary fiber content in 100 g of Jerusalem artichoke powder (JAP) is approximately 71.10 g,

including fructo-oligosaccharides and inulin (Saengthongpinit and Sajjaanantakul, 2005). Jerusalem artichoke (*Helianthus tuberosus* L.) is a versatile ingredient for food fortification because it has no bitter taste or odor. It has an off-white color and possesses the ability to improve food texture. Accordingly, it could be applied in snack bars with palatable functional ingredients (Praznik et al., 2002). For health benefits, soluble dietary fiber (SDF) promotes blood cholesterol reduction and glucose absorption in the intestinal tract (Timm and Slavin, 2008), whereas insoluble dietary fiber (IDF) promotes water absorption and intestinal regulation by increasing the bulk of feces, thereby accelerating transit time through the gastrointestinal tract (Hillman et al., 1983). Therefore, other ingredients are needed which contain high insoluble dietary fiber to complement soluble dietary fiber. A by-product from coconut milk production, called low-fat desiccated coconut (LFDC), potentially contains 56.80 g of insoluble dietary fiber per 100 g of LFDC (Ng et al., 2010). However, the addition of dietary fiber affects physicochemical properties such as water binding capacity, gelation, structure building, texture, and the color of the food product (Foschia et al., 2013).

In the market, there are often time lags between production, transportation, and consumption, which may lead to decreased quality in terms of the desirable attributes of the product such as odor, color, texture, and product safety (Loveday et al., 2009). There are some factors that affect the deterioration of the product, such as ingredients, processing, packaging, and storage condition. The factors that may accelerate product deterioration are chemical reaction and temperature changing. The chemical reactions involve the reaction of rancidity, enzymatic, hydrolytic, as well as light-induced changes. Temperature changing affects fat melting, crystal structure, and emulsion destabilization. These accelerating factors are usually used to monitor the changes in quality of products that occur under typical storage conditions (Hough, 2006). For shelf-life prediction, product properties such as texture, water activity, moisture, pH, color, microbiology, rancidity and sensory attributes, can be used to calculate the shelf-life of products (Altoaimi, 2011). The developed snack bar products were placed in metalized polyester, sealed, and kept in two controlled temperature chambers at 35 °C and 45 °C for 12 weeks following the accelerating shelf-life methods by Mizrahi (2004). During storage, the products were sampled to measure any changes in quality. The objective of this study was to develop a high dietary fiber snack bar using JAP and LFDC in addition to studying the changes occurring in the physicochemical and microbiological properties as well as sensory acceptability of the snack bar products in order to assess their shelf-life.

2. Method

2.1 Materials

Low-fat desiccated coconut (LFDC) was obtained from Theppadungporn Coconut Co., Ltd., Thailand. Jerusalem artichoke powder (JAP) was purchased from Saonfarm, Thailand. The other ingredients for making the snack bar, including corn flakes, oat, butter, eggs, coconut sugar, honey, and salt, were purchased from local supermarkets in Nakhon Pathom, Thailand. All chemical reagents and solvents used in this study were of analytical grade.

2.2 Snack bar preparation

The control (C) formula was adapted from the research of Panyeam (2007). The C formula contained the following ingredients by percentage: corn flakes (27%), oat (22%), butter (10.5%), egg white (8%), egg yolk (4%), coconut sugar (14%), honey (13%), salt (0.5%), and lecithin (0.5%). All ingredients were mixed together and molded into a bar shape (8 x 2.3 x 1.5 cm) then baked in an oven (Axia Built-In ETN8A-MN, Thailand) at 120 °C for 30 min. The amount of JAP and LFDC mixture was added to the snack bar according to the regulations of food labeling, EC No. 1924/2006 of the European Parliament. Food product that contains dietary fiber (DF) > 20% of daily value (DV) per serving or 5 g per serving can be classified as a “high dietary fiber product” (Gilsenan, 2011). The LFDC and JAP with the ratio of 1:1 were added into the C formula to formulate the high dietary fiber snack bar (HFSB). Furthermore,

the developed samples were packaged in a metalized polyester bag (5.5 x 3 x 12 cm) that was heat sealed.

2.3 Proximate analysis of snack bar

The chemical compositions, including carbohydrate, protein, fat, ash, and moisture content of the C and HFSB formula were analyzed according to the procedure of AOAC (2016). Soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) of the products were determined by AOAC (2016) 991.42, 991.43 and (AOAC, 2016) 991.42, respectively. Fructans (inulin + fructo-oligosaccharides) was determined by the protocol of Joye and Hoebregs (2000). Total dietary fiber (TDF) was determined by totaling SDF, IDF and fructans.

2.4 Shelf-life study

The shelf-life of both C and HFSB formulas was studied using the Q10 test. The products were stored at 35 °C and 45 °C for 12 weeks. The samples were checked every 2 weeks to measure their physico-chemical properties including color, pH, water activity (aw), and moisture content (MC), and every 4 weeks for measuring Thio-barbituric acid reactive substances (TBARS), microbiological properties, and sensory acceptability using 30 panelists. Then, the shelf-life was calculated using the following formula by considering total color difference (ΔE), overall acceptability, and difference from control (DFC).

$$Q_{10} = \frac{\theta_s(T)}{\theta_s(T + 10)} \quad Q_1 = Q_{10}^{0.1} \quad Q^{\Delta T} = \frac{\theta_s(T)}{\theta_s(T + \Delta T)} \quad (1)$$

when,

- $\theta_s(T)$ = shelf-life at temperature T °C (week)
- $\theta_s(T + 10)$ = shelf-life at temperature T+10 °C (week)
- Q_1 = rate of loss quality at temperature T °C (week)
- Q_{10} = rate of loss quality at temperature T+10 °C (week)
- ΔT = different between measured (T) and predicted temperature

2.5 Physicochemical determination of snack bar

2.5.1 Water activity

Water activity (a_w) of the JAP and LFDC was measured using an aw meter at room temperature (25 °C) (AQUA Lab model 3TE Series 3B v 3.0, Decagon Devices Inc., Washington, USA).

2.5.2 Moisture content

Moisture content (MC) of the JAP and LFDC was determined by following the protocol of AOAC (2016).

2.5.3 pH

pH of JAP and LFDC was determined by following the protocol of AOAC (2016). The sample was ground using a blender (VKitch 565, China). Subsequently, 5 g of sample was mixed with 45 ml of double distilled water in a 50-ml centrifuge tube, which was allowed to stand for 10 min before being centrifuged (Hermle labortechnik GmbH, Germany) at 6,000 rpm for 5 min. After that, the sample was filtered using filter paper (Whatman no 1, \varnothing 110 mm). The pH of the filtrate was directly measured at room temperature (25 °C) using a pH meter (Waterproof pen meter, ST10 Ohaus, China).

2.5.4 Color

The color of JAP and LFDC was measured using a Hunter Lab Digital Colorimeter (ColorFlex EZ, Hunter Associates Laboratory, Inc., Reston, Virginia) in CIE-color system (L^* , a^* , b^*). The color parameters: L^* represents lightness from black to white (0 to 100); a^* ; from green (-) to red (+); and b^* ; from blue (-) to yellow (+). The total color difference, Delta E (ΔE^*), was calculated with the following formula:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

2.6 Thio-barbituric acid reactive substances (TBARS)

The level of rancidity in the snack bar was determined by measuring thio-barbituric acid reactive substances (TBARS), according to the method of [Sinnhuber and TC \(1977\)](#). The ground sample (200 mg) was weighed and transferred to a 50 ml-centrifuge tube. The blank sample was prepared using the same step without sample addition. Then, three drops of tertiary butyl hydroxyl quinine (TBHQ) and 3 ml of TBA were added into the tubes, with and without sample. Then, they were vortexed for 30 s. Seventeen ml of TCA-HCl reagent was added into the sample tubes before heating them in a water-bath (Stirring water bath-SWB-10L-1, Saratoga, CA, USA) at 95 °C for 30 min. The sample tubes were then placed in an ice-bath for 5 min to stop the reaction. After that, 5 ml of chloroform was added and vortexed for 30 s before centrifugation (Hermle labortechnik GmbH, Germany) at 6,000 rpm for 10 min. The absorbance of the supernatant was measured at 532 nm using a UV-Vis spectrophotometer (UV-1601 SHIMAZU, Japan). The TBARS value is expressed as mg of malondialdehyde (mg MDA) / kg sample, as calculated by the equation below:

$$\text{TBARS value (mg MDA/kg sample)} = \frac{\text{Abs sample} - \text{Abs blank}}{\text{Weight of sample}} \times 46 \quad (3)$$

2.7 Microbiological analysis

Microbial properties was carried out according to BAM method chapters 3, 8, and 4 for total plate count (TPC), yeast and mold and E. Coli, respectively ([Food and Drug Administration Division of Microbiology and Association of Official Analytical Chemists, 1998](#)).

2.8 Sensory test

The sensory test was conducted using a 9-point hedonic scale and difference from control (DFC) method. This hedonic scale describes the appearance and overall liking. The lowest score is described as “extremely dislike” with 1 scoring point, while the highest score is described as “extremely like” with 9 scoring points. The DFC is described as “no difference” with 0 scoring points to “extremely different” with 6 scoring points. This method was used to determine the differences between the HFSB and C samples.

2.9 Statistical analysis

The results are reported as mean and standard deviation. All experiments conducted in this study, except dietary fiber and proximate analysis, were performed in triplicate. The dietary fiber and proximate analyses were performed in duplicate. Data of the physicochemical properties of C and HFSB snack bar were analyzed by independent T-test. One-way analysis of variance (ANOVA) and Duncan's multiple range test were used to establish the significance of differences ($p < 0.05$) among the mean values of physicochemical properties and sensory evaluation of the C and HFSB formulas during storage. Statistical analyses were performed using SPSS program version 19.0 for Windows (SPSS Inc, Chicago, IL, USA).

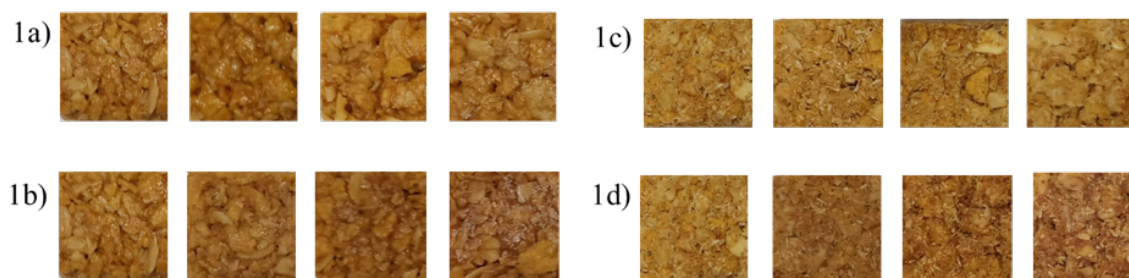


Figure 1. Appearance of control (C) snack bar during storage at 35 °C (1a) and at 45 °C (1b) every 4 weeks; appearance of high dietary fiber (HFSB) at 35 °C (1c) and HFSB at 45 °C (1d) every 4 weeks.

3. Results

3.1 Physicochemical properties of freshly prepared control (C) and high dietary fiber snack bar (HFSB)

Color values, water activity (a_w), moisture content (MC), and pH of the C and HFSB are shown in Table 1. The HFSB had higher L^* value (lightness) than the C formula. The b^* value (yellowness) of the C was higher than that of the HFSB, which means the C was more yellow than the HFSB. There were statistically significant differences ($p < 0.05$) in pH and MC between the C and HFSB. The pH the HFSB was 6.21, which was lower than that of the C (6.31). Otherwise, MC of HFSB was 7.87%, which was higher than that of C (6.53). Photographs showing the appearance of freshly prepared C and HFSB are presented in Figure 1.

Table 1. Color values (L^* , a^* , b^*), a_w , MC, and pH of control (C) and high dietary fiber (HFSB) snack bar

Physical property	C ¹	HFSB ¹
Color		
L^*	35.07±0.53	37.49±0.92*
a^*	5.94±0.29*	4.75±0.31
b^*	15.61±0.31	14.74±0.53
a_w	0.58±0.07	0.57±0.05
MC (%)	6.53±0.45	7.87±0.26*
pH	6.31±0.02*	6.21±0.02

¹Results are reported as mean±SD of triplicate analysis.

*Means significantly different ($p < 0.05$) in the same row.

Table 2 shows that C snack bar contained 1.81 g of dietary fiber per serving (44 g). This means the product was not able to be classified as a high dietary fiber product. However, the HFSB could claim to be a high dietary fiber product because it contained 6.78 g of dietary fiber per serving (>20% daily value per serving).

3.2 Physicochemical properties of control and high dietary fiber snack bar during storage

Color is one of the most important attributes related to quality, affecting consumer acceptability because it is the first thing that is clearly detected by consumers. However, a colorimeter instrument was used in this study in parallel with sensory test by humans to get accurate and quantitative results. Higher storage temperature (45 °C) would accelerate the decrease in L^* value and increase a^* value, thereby decreasing lightness and increasing the redness of the products. It is clear that the L^* , a^* , and b^* values were significantly different ($p < 0.05$) after storage (Figure 2). Total color difference

Table 2. Proximate values and dietary fiber content of control (C) and high dietary fiber (HFSB) snack bar (44g)

Nutrients	C ¹	HFSB ¹
Energy (kcal)	191.86	198.31
MC (g)	4.27	4.03
Protein (g)	3.16	3.01
Total fat (g)	5.83	6.95
Carbohydrate (g)	31.69	30.94
Ash (g)	0.92	0.84
TDF (g)	1.81	4.38
SDF (g)	0.72	1.00
IDF (g)	1.09	3.38
Inulin (g)	ND	2.40
Sum of inulin + TDF (g)	1.81	6.78

¹ Results are duplicate analysis.

Samples were calculated in dry basis; ND: Not determined.

(E) values of the C and HFSB kept at 35 oC were below 3.7 throughout storage time. On the other hand, the E values of the C and HFSB kept at 45 oC were higher than 3.7 at week 6 and week 4 of storage, respectively (Table 3).

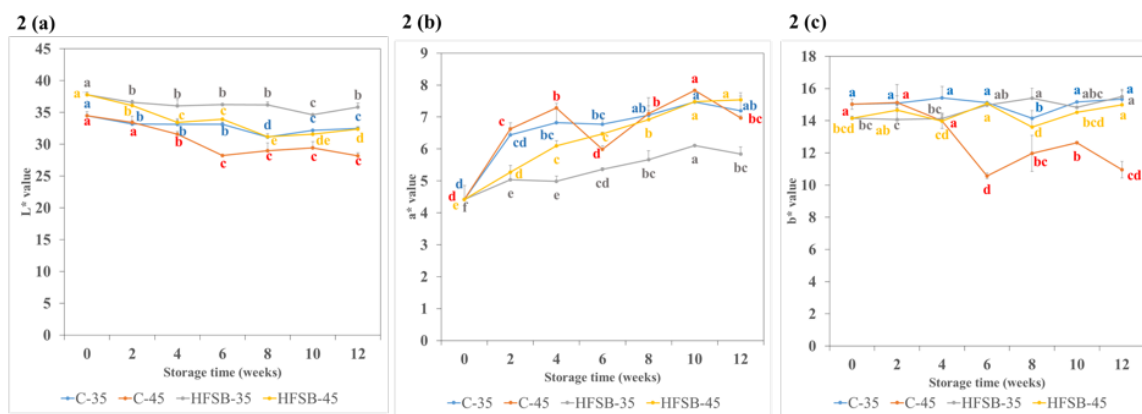


Figure 2. L* (2a), a* (2b), and b* (2c) of control (C) and high dietary fiber (HFSB) snack bar during storage at 35°C and 45 °C for 12 weeks. Different superscripts (a-f) mean significantly different ($p < 0.05$) in the same line.

The pH, aw, and MC values of the C and HFSB snack bar throughout storage period are presented in Figure 3. The pH of the C and HFSB slightly decreased ($p < 0.05$) throughout the storage time. However, the pH values of the snack bar formulas kept at 45 oC rapidly decreased compared to those of the formulas kept at 35 oC. The initial aw of the C and HFSB were 0.57 and 0.56, respectively. During storage, aw of the C and HFSB were in the ranges of 0.52-0.63 and 0.48-0.57, respectively. The initial MC of the C and HFSB were 5.73% and 7.76%, respectively. The MC of the C snack bar ($p < 0.05$) increased significantly after storage, otherwise the MC of the HFSB remained more constant.

Table 3. Total color difference (ΔE) of control (C) and high dietary fiber (HFSB) snack bar during storage at 35 °C and 45 °C for 12 weeks

Storage time (week)	C		HFSB	
	35 °C	45 °C	35 °C	45 °C
2	1.48±0.53 ^d	1.72±0.29 ^d	1.53±0.22 ^c	2.02±0.78 ^c
4	1.85±0.40 ^{cd}	3.37±0.53 ^c	1.87±0.97 ^{bc}	4.68±0.64 ^b
6	1.59±0.39 ^d	7.69±0.18 ^b	2.00±0.01 ^{bc}	4.45±0.17 ^b
8	3.23±0.99 ^a	6.45±1.53 ^{ab}	2.40±0.73 ^{bc}	6.85±0.13 ^a
10	2.75±0.39 ^b	5.94±0.06 ^a	3.63±0.08 ^a	6.93±0.07 ^a
12	2.43±0.47 ^{bc}	7.57±0.62 ^a	2.84±0.29 ^{ab}	6.73±0.11 ^a

Results are reported as mean±SD of triplicate analysis.

Different superscript (a-d) mean significantly different in the same column (p<0.05).

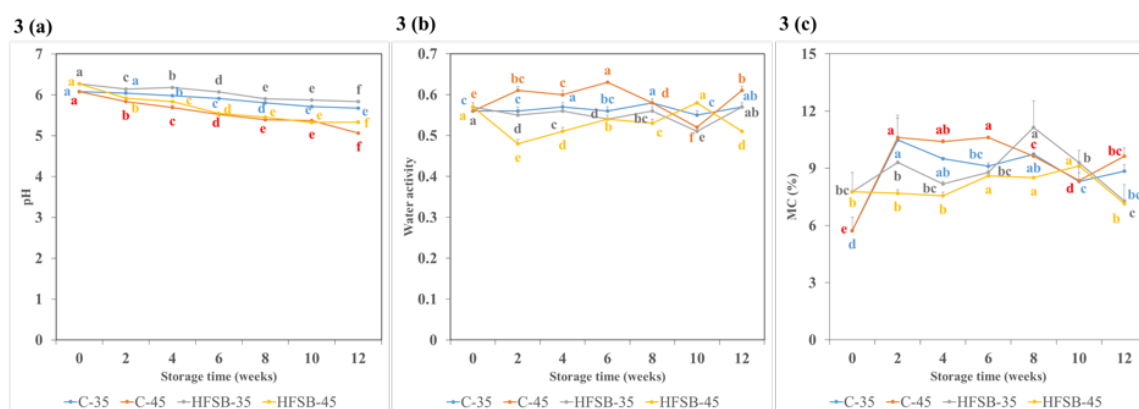
**Figure 3.** pH (3a), water activity (3b), and moisture content (3c) of control (C) and high dietary fiber (HFSB) snack bar at 35°C and 45 °C for 12 weeks. Different superscripts (a-f) mean significantly different (p<0.05) in the same line.

Table 4. Thio-barbituric acid reactive substances (TBARS) of control (C) and high dietary fiber (HFSB) snack bar during storage at 35 °C and 45 °C for 12 weeks

Storage time (weeks)	C (mg MDA/kg sample)		HFSB (mg MDA/kg sample)	
	35 °C	45 °C	35 °C	45 °C
0	0.019±0.001 ^a	0.019±0.001 ^b	0.022±0.001 ^b	0.023±0.001 ^b
4	0.019±0.001 ^a	0.021±0.001 ^a	0.024±0.002 ^a	0.026±0.001 ^a
8	0.019±0.001 ^a	0.023±0.002 ^a	0.023±0.001 ^a	0.026±0.002 ^a
12	0.020±0.001 ^a	0.022±0.002 ^{a,*}	0.023±0.001 ^a	0.026±0.004 ^{a,*}

Results are reported as mean±SD of triplicate analysis.

Different superscript (a-d) mean significantly different in the same column (p<0.05).

* Means significant differences (p<0.05) in the same row.

3.3 Thio-barbituric acid reactive substances (TBARS) of control (C) and high dietary fiber snack bar (HFSB) during storage

Thio-barbituric acid reactive substance (TBARS) values of the C and HFSB after each week of storage are presented in Table 4. The TBARS values of the HFSB were higher than the C formula. Furthermore, there was no statistically significant difference (p>0.05) in the TBARS values of the C stored at 35 oC throughout the storage time. However, the TBARS values of the C and HFSB kept at 45 oC increased gradually after storage from 0.019 to 0.022 and 0.023 to 0.026 mg MDA/kg, respectively. The TBARS values of the C and HFSB snack bars kept at 45 oC were significantly increased (p<0.05) at week 4, after which the values became constant until the end of storage.

3.4 Microbiological test

The microbiological results showed that yeast and mold and total plate count (TPC) were detected less than 10 CFU/g, while MPN E. Coli was detected less than 2 in both C and HFSB during storage.

3.5 Sensory evaluation

The sensory scores of the C and HFSB kept at 35 oC are shown in Table 5. The overall acceptability scores of the C and HFSB at week 12 were below 6 (neither like nor dislike). The DFC scores of the C formula were higher than 3 at week 4 and week 12. Otherwise, the DFC scores of the HFSB were below 3 throughout the storage period. The sensory scores of the C and HFSB snack bar kept at 45 oC are presented in Table 6. The DFC scores of the C and HFSB were higher than 3 at week 4. Interestingly, the DFC scores of the C and HFSB were below 6 (neither like nor dislike) at week 8. Thus, sensory evaluation of the developed snack bar at week 12 was not performed.

3.6 Cut-off point parameter

To determine the shelf-life of the snack bar, the selection of cut-off points which are associated with maximum deterioration should be considered. The lowest scores for the cut-off point were selected to calculate the shelf-life due to the quality and stability of the products that should be considered. The cut-off point for calculating the shelf-life of the C and HFSB snack bars at 35 oC and 45 oC were at 8 weeks and 4 weeks of storage, respectively (Table 6).

Table 5. Sensory evaluation of control (C) and high dietary fiber (HFSB) snack bar during storage at 35 °C for 12 weeks

Storage time (weeks)	Appearance		Overall acceptability		DFC	
	C	HFSB	C	HFSB	C	HFSB
0	7.20±1.06 ^a	6.40±1.45 ^a	7.07±1.11 ^a	6.83±1.14 ^a		
4	6.73±0.86 ^a	6.27±1.52 ^a	6.30±0.95 ^b	6.27±1.38 ^{ab}	3.10±1.51 ^a	2.70±1.11 ^a
8	7.03±1.03 ^a	6.80±1.21 ^a	6.00±1.43 ^b	6.70±0.79 ^a	2.77±1.25 ^a	2.30±1.09 ^a
12	6.60±1.35 ^a	6.06±1.76 ^a	5.90±1.34 ^b	5.93±1.70 ^b	3.20±1.30 ^a	2.70±1.34 ^a

Nine-point hedonic scale (9= extremely like, 5= neither like nor dislike, 1= extremely dislike)

DFC (difference from control): 0 = no difference, 6 = very large difference

Results are reported as mean±SD, n=30

Different superscript (a-b) mean significantly different (p<0.05) in the same column.

Table 6. Cut-off point parameter of control (C) and high dietary fiber (HFSB) snack bar during storage at 35 °C and 45 °C.

Sample	Parameter (weeks)			Cut-off point (weeks)
	ΔE	Overall acceptability	DFC	
C-35	12	8	8	8
C-45	6	4	4	4
HFSB-35	12	8	12	8
HFSB-45	4	4	4	4

4. Discussion

4.1 Physicochemical properties of freshly prepared control (C) and high dietary fiber snack bar (HFSB)

The L^* value of HFSB was higher than C, expressed to be lighter, due to the addition of low-fat desiccated coconut (LFDC). There were statistically significant differences ($p < 0.05$) in pH and MC between the C and HFSB. The pH of the HFSB was lower than that of the C. Ozturk and Serdaroglu (2018) reported that the addition of JAP in food products would decrease pH due to the natural characteristics of the ingredient. However, the MC of the HFSB was higher than that of the C due to the moisture content from JAP. In the proximate analysis, the C snack bar contained 1.81 g of dietary fiber per serving (44 g), meaning the product was not able to be classified as a high dietary fiber product. However, the HFSB could claim to be a high dietary fiber product because it contained 6.78 g of dietary fiber per serving ($>20\%$ daily value per serving) (Gilsenan, 2011). It is clearly seen that the JAP and LFDC successfully helped to increase the dietary fiber content in the HFSB. Soluble dietary fiber (SDF) including inulin mostly came from the JAP, whereas insoluble dietary fiber (IDF) mostly came from LFDC.

4.2 Physicochemical properties of control and high dietary fiber snack bar during storage

Total color difference (E) values of the C and HFSB kept at 35 °C were below 3.7 throughout the storage time. On the other hand, the E values of the C and HFSB kept at 45 °C were higher than 3.7 at 6 and 4 weeks of storage, respectively. Eliades et al. (2004) suggested that the acceptance limit of E value is 3.7, which is clinically visible by human eyes beyond this value. The color alteration of the HFSB was faster than that of the C because the inulin content from JAP participated in the Maillard browning reaction, thereby reducing the lightness of the products (Broyart et al., 1998). The higher storage temperature (45 °C) would accelerate the decrease in L^* value and increase a^* value, thereby decreasing lightness and increasing the redness of the products. High storage temperature affected the properties and quality of the products. Sun-Waterhouse et al. (2010) also observed that prolonged exposure to high temperature would have serious effects on the color of the product. Maillard reaction plays an important role in the change in color, which is favored by high temperature and alkaline pH (Loveday et al., 2009). The other factor is an excess of reducing sugar present in the product. Pallavi and Chetana observed that a snack bar with artificial sweeteners would be more stable than a snack bar with sugar as the equilibrium relative humidity was closer to normal ambient conditions, especially reducing sugar. Reducing sugars such as all monosaccharides and some disaccharides, which were also used as ingredients in this experiment, increased the Maillard reaction (Yilmaz and Toledo, 2005) as well as caramelization (Ameur et al., 2008). Maillard reaction produces several intermediate compounds such as hydroxymethylfurfural (HMF), methyl ketones, formic acid, and galactosyl- β -pyranone from advanced Maillard (Cattaneo et al., 2008) in addition to brown-colored melanoidins (Deeth, 2010). Melanoidin is produced from the final stage of the Maillard reaction, which establishes brown and dark pigmentation color (Perez-Locas and Yaylayan, 2010).

The HFSB could retain MC due to the high water-holding capacity (WHC) of the fiber used (Grigelmo-Miguel et al., 1999). In commercial products, MC of cereal bar was in a range between 8.00% and 10.06% (Padmashree et al., 2012). Theoretically, MC is the total amount of water present; the shifting of MC in a product will affect its texture (Kong and Singh, 2011). Otherwise, a_w is a key parameter used for determining the rate of many chemical reactions and also the microbial growth in food products (Bchir et al., 2018). Throughout the storage period, the a_w of the C and HFSB was in the ranges of 0.52-0.63 and 0.48-0.57, respectively. Aigster et al. (2011) observed the initial a_w of granola and cereal bar was 0.69, which gradually increased to 0.77 during the storage time. However, the snack bars were packed with good oxygen, light, and moisture barrier properties. Thus, the alteration in a_w could be associated with starch retrogradation, which removes water instead of the migration of moisture through the packaging (Silva et al., 2013). In fact, yeast and mold start to grow at a_w in the

range between 0.70 and 0.80 (Rawat and Darappa, 2015). The snack bar can normally be classified as a low moisture food product (LMF) due to the *aw* value being below 0.70. The low *aw* of the snack bar product would help to extend its shelf life (Farakos et al., 2013). The pH values of the C and HFSB were slightly decreased ($p < 0.05$) throughout the storage time. The pH values of snack bar formulas kept at 45 °C rapidly decreased more than those of products stored at 35 °C. The higher temperature could accelerate the deterioration of food products (Elmlund, 2014). In food products, formic acid generated by the Maillard reaction contributes to the decrease in pH during heat treatment (da Silva et al., 2014; Deeth, 2010). Moreover, it should be noted that the decrease in pH may be a sign of microbial growth and chemical reaction.

4.3 Thio-barbituric acid reactive substances (TBARS) of control and high dietary fiber snack bar during storage

The TBARS values of the C and HFSB snack bars kept at 35 and 45 °C for 12 weeks are shown in Table 4. The TBARS values of the HFSB were higher than those of the C throughout storage time because of the addition of JAP and LFDC in the formulation. There was no statistically significant difference ($p > 0.05$) in TBARS values of the C at 35 °C during the storage time. However, the TBARS values of the C and HFSB increased significantly ($p < 0.05$) at 4 weeks of storage, after which the values became constant until the end of storage. Trinidad et al. (2006) observed that proximate analysis of LFDC per 100 g of sample is as follows: 3.6% moisture, 3.1% ash, 10.9% fat, 12.1% protein, and 70.3% carbohydrates. Otherwise, the proximate analysis of JAP per 100 g sample is as follows: 3.39% moisture, 3.66% ash, 0.91% fat, 8.91% protein, and 83.13.3% carbohydrates (Bui et al., 2016). It is clear that the fat content of the HFSB was higher than that of the C, at 6.95 and 5.83, respectively (see Table 2). Thus, fat from the LFDC and JAP contributed to increase the TBARS value because of lipid oxidation. Lipid oxidation is one of the big problems in food products, where oxidative rancidity causes shelf life quality deterioration, including nutritional loss and toxic compound formation. Lipid oxidation produces aldehyde compounds. Thus, it can be detected as malondialdehyde (MDA) as it is associated with off-flavors and aromas, which are usually found in meat products (Ghani et al., 2017). Table 4 shows that snack bar formulas kept at 45 °C had higher TBARS values than those kept at 35 °C. This was probably due to lipid oxidation, which was expedited by several factors such as the presence of lipoxidase, peroxide, light, MC, and high temperature (Chow, 1980). However, the TBARS values of the C and HFSB snack bar were less than 0.05 mg MDA/kg sample. The TBARS values were less than the rancidity threshold (1–2 mg MDA/kg sample) for food products, especially corn snacks (Etemadian et al., 2018).

4.4 Microbiological test

The microbiological results showed that yeast and mold and total plate count (TPC) were detected less than 10 CFU/g, while MPN *E. Coli* was detected at less than 2 for both C and HFSB during storage. Based on the Thai Community Product Standard (TCPS 709/2004), these formulated products were safe for consumption because yeast and mold was lower than 102 CFU/g and TPC was also lower than 1×10^3 CFU/g.

4.5 Shelf-life determination

As mentioned previously, this research mainly aimed to develop a snack bar with high dietary fiber content to increase fiber intake. The product was carefully prepared using necessary hygienic steps to obtain a shelf-stable product. Commercially, this product could be stored at room temperature (in Thailand around 30 °C). For shelf-life prediction, the selection of a cut-off point should be considered, which is associated with the maximum deterioration. Some parameters, such as color and sensory acceptability, should be considered because they are correlated to the quality of the product. Total color difference (*E*) and sensory scores tested by 30 panelists using 9-point hedonic scale and difference from control (DFC) test were used as cut-off points to calculate the shelf-life. The total color difference (*E*) was considered at 3.7 as this level can be interpreted as a visible difference by human eyes

(Eliades et al., 2004). For the 9-point hedonic scale, the overall acceptability score should be higher than 6.0 (like slightly), meaning the product is accepted by panelists (Giménez et al., 2012). Based on Freitas and Costa (2006), the product will be rejected if the score for difference from control (DFC) is 3 or above. The Q10 equation was used for predicting the product shelf-life at 30 °C. The shelf-life prediction for the C and HFSB snack bar stored at 30 °C was 11 weeks. Padmashree et al. (2012) suggested that cereal snack bars packed in metallized polyester films have limited shelf-life of around 3 to 4 months. However, higher temperature during transportation and storage should also be considered due to the shelf-life of these products being shorter than that obtained from calculation.

5. Conclusion

Jerusalem artichoke powder (JAP) and low-fat desiccated coconut (LFDC) helped to increase the total dietary fiber by 3.7 times. Thus, the developed high fiber snack bar (HFSB) could be classified as a high fiber food product. However, the addition of JAP and LFDC contributes to certain changes in the physicochemical properties and stability of the snack bar. For shelf-life prediction by Q10 test, the C and HFSB snack bar could be kept at 30 °C for 11 weeks. Modified packaging should be considered in further experiments in order to help extend the shelf-life of the snack bar.

Acknowledgments

The authors gratefully acknowledge to Faculty of Graduate Studies, Mahidol University for financial support. The authors also would like to thank Institute of Nutrition, Mahidol University for supporting the laboratory instruments.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Cite this article as: Pratiwi IA, Kemsawasd V, Winuprasith T. Storage Stability of High Fiber Snack Bar. GHMJ (Global Health Management Journal). 2019; 3(3):124-137. doi:10.35898/ghmj-33456