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CORN SNACK WITH HIGH FIBER CONTENT: EFFECTS OF MATERIALS, EXTRUSION AND FRYING PARAMETERS ON THE PRODUCT QUALITY

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ABSTRACT OF DISSERTATION FOR THE DEGREE OF DOCTOR OF PHYLOSOPHY IN FOOD TECHNOLOGY

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A. INTRODUCTION

1. Research actuality

Snack foods are highly convenient in modern society since they provide calories to satisfy short-term hunger and often are eaten in a hurry. Unfortunately, extruded snack foods are poor in fiber for human diet. In addition, fried snack foods always contain antioxidants to prevent lipid oxidation during the processing and preservation. In order to enhance public awareness of health issues and clean label foods, the use of natural antioxidants in food processing has attracted great attention since the consumers prefer to use foods without synthetic additives. Recently, plenty of studies focus on the application of various dietary fiber sources into extruded snack processing. Most of the investigated fiber materials are whole grain cereal flour, cereal bran or fruit and vegetable fibers. Nowadays, commercial dietary fiber preparations are well-known in food industry such as polydextrose, resistant starch, resistant maltodextrin, inulin and gum. Their approximate composition and properties are stable and highly standardized. However, their use in extruded snack production has not been considered. On the other hand, considerable studies have been done on natural antioxidants with potato frying. Nevertheless, there is small number of studies about fried snack foods with natural antioxidants. Plant extracts or essential oils have been widely tested in food frying to prevent oil degradation. Natural antioxidants are worldwide commercialized but their impacts on oil quality during snack frying remained unclear. The general target of this research is finding a way to produce healthy corn snack without synthetic additives. Commercial dietary fibers and natural antioxidants were used in corn snack processing for improvement in quality of the snack foods.

2. Research objective

The objective of this study was to clarify the effects of commercial fiber preparations as well as the extrusion conditions on the quality of the fried corn snack. In addition, the study also focused on the effects of commercial natural antioxidants as well as the antioxidant content on the quality of palm olein oil during the frying of snack food. Finally, the obtained high fiber snack was in-vivo tested with the hyperlipidemia mice model to clarify its healthy benefits. The study consists of three sections.

3. Novel contribution of the thesis

- The influence of different fiber materials and fiber ratios on the proximate composition, physical and sensory properties of corn snack were clarified.
- The effects of extrusion parameters on the proximate composition, physical and sensory properties of high fiber snack were determined.
- The impacts of various natural essential oil as antioxidant and their content on the quality of oil in the fryer and the fried snack were evaluated. The obtained results would contribute to development in new food product as well as green processing for industrial application.

4. The design of the thesis

The thesis contains 123 pages, 30 tables, 21 figures and 223 references; included: Chapter 1: Introduction; Chapter 2: Literature review; Chapter 3: Materials and Methods; Chapter 4: Results and Discussion; Chapter 5: Conclusions and discussions; References, Annex and public journals.

B. CONTENTS OF THE THESIS

Chapter 1: Literature review

1.1. Production line of snack food with high fiber content

The technology of conventional snack food and snack food with high fiber content is absolutely similar. Although the production line is simple, various fried extruded products are produced due to difference in materials, ingredients and formulas.

1.2. Materials for production of snack with high fiber content

1.2.1. Corn meal

Among the cereal based materials, corn meal is the most common material that is used in extruded snack foods. Physical properties of maize grains are mostly associated with total amount protein in corn grain and zein protein subclasses.

1.2.2. Fiber materials

According to the American Association of Cereal Chemists (AACC), dietary fibre is the edible parts of plant or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fibre includes polysaccharides, oligosaccharides, lignin and associated plant substances.

1.2.3. Natural antioxidants

The majority of natural antioxidants are also phenolic compounds, and the most important groups of natural antioxidants are the tocopherols, flavonoids and phenolic acids, spices, herbs, tea, oils, seeds, cereals, cocoa shell, grains, fruits and vegetables are considered as sources of natural antioxidants.

1.3. Extrusion

Formation of puffed, low-density cellular materials from a hot gelatinized mass is the result of physical and chemical transformation of starchy and protein raw materials (biopolymers) into a melted mass, which becomes a final void structure due to rapid evaporative cooling. In general, the chemical or physicochemical changes in biopolymers that can occur during extrusion cooking include binding, cleavage, loss of native conformation, fragment recombination and thermal degradation.

Chapter 2: Materials and methods

2.1. Material

- ***Corn meal*** was supplied by Le Huyen Company (Dong Nai province, Vietnam); the approximate composition of corn meal (g/kg) was as follows: moisture: 123, ash: 7, protein: 60, lipid: 6, fiber: 45 and total carbohydrate: 758; the average particle size ($d_{3,2}$) was 35,8 µm.
- ***Palm olein oil*** was provided by Tuong An Vegetable Oil Joint Stock Company (Ho Chi Minh City, Vietnam); the free fatty acid content and peroxide value were 0,01 g/kg and 0,6 meq/kg, respectively.

- ***Dietary fibers***

Six commercial fiber preparations were used: polydextrose, xanthan gum, gum acacia, inulin, resistant starch and resistant maltodextrin.

- ***Antioxidants***

Five commercial natural antioxidant preparations were used: cedarwood oil, citronella oil, clove oil, nutmeg oil and rosemary oil, In addition, tocopherol and butylated hydroxytoluene were also used as positive control.

- ***Mice:*** Fifteen male Swiss albino mice (31,2 ± 0,41 g) were used for the experiments, They were provided by Ho Chi Minh City Pasteur Institute (Ho Chi Minh City, Vietnam).

2.2. Research content

2.2.1. Section 1: Use of commercial fiber preparation in the snack extrusion for improvement in the fiber content

In this study section, the impacts of different commercial fiber preparations and fiber ratios in the blend on the corn snack quality were investigated. In addition, the effects of extrusion parameters including temperature, screw speed and mixing rate on the product quality were also examined.

- Section 1.1: Effects of various commercial fiber preparations on the snack quality.
- Section 1.2: Effects of fiber preparation ratio in the mixing blend on the snack quality.
- Section 1.3: Effect of the screw speed on the snack quality.
- Section 1.4: Effects of extrusion temperature on the snack quality.

2.2.2. Section 2: Use of commercial natural antioxidants in the frying of the extruded corn snack

In this study section, the impacts of different commercial natural antioxidants on the frying oil quality during the heat treatment were investigated. In addition, the effects of antioxidant content on the quality of oil in the fryer and in the fried snack were also examined.

- Section 2.1: Effects of various natural antioxidants on the frying oil quality during the heat treatment.
- Section 2.2: Effects of antioxidant concentration in the frying oil on the oil quality.
- Section 2.3: Effects of natural antioxidant on the quality of oil in the fryer and in the fried snack during the repeated batch frying.

2.2.3. Section 3: Healthy benefits of corn snack food with high polydextrose content

In this study section, the hepatoprotective and hypolipidemic effects of the high fiber snack food on swiss albino mice were investigated.

2.3. Analytical methods

- **Chemical analysis:**
    - ✓ **Fiber**: moisture content, ash content, crude protein content, total lipid content, total dietary fiber content, total carbohydrate content.
    - ✓ **Oil**: acidic value, conjugated dienes, conjugated trienes, peroxide value,

thiobarbituric acid reactive species (TBARS) assay.

- **Physical analysis for extrudates:** expansion ratio, bulk density, crispness and hardness by texture analyzer, instrumental color, scanning electron microscopy.
- **Physico-chemical analysis for extrudates:** water solubility index (WSI), water absorption index (WAI).
- **Sensory analysis:** Hardness and crispness of the fried pellets were evaluated by using a 9 points scale method. Three replicates were run.
- **In vivo test on mice model:** serum biochemical parameters, histopathologic studies of liver.

2.4. Statistical analysis

One-way analysis of variance was performed by using the software Statgraphics Centurion XV (Manugistics Inc,, Rockville, MD, The United States). Multiple range tests with the least significant difference were used to determine which means were significantly different from others ($p < 0,05$).

Chapter 3. Result & Discussion

3.1. Use of commercial fiber preparation in the snack extrusion for improvement in the fiber content

3.1.1. Effects of various commercial fiber preparations on the snack quality

3.1.1.1. Effects of fiber types on chemical composition of the extrudate

Chemical composition of the extrudate is shown in Table 4.1.

Table 4.1. Effects of fiber types on chemical composition (g/kg) of the fried extrudate[a] (The blend consisted of 90,3% corn meal, 5,0% fiber preparation, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis).

Samples	Moisture	Ash	Protein	Lipid	Fiber	Carbo hydrate
Control	13,0±0,7[a]	6,5±0,1[a]	46,7±0,1[ac]	293,5±1,0[a]	28,2±0,4[a]	612,1
Polydextrose	9,9±1,1[b]	6,4±0,1[a]	44,1±1,0[b]	326,5±2,5[b]	62,3±1,3[b]	550,8
Xanthan gum	20,2±1,4[d]	12,2±0,2[d]	55,8±0,6[d]	190,3±1,2[e]	89,9±4,6[d]	631,6
Gum acacia	18,3±1,1[c]	12,1±0,1[d]	47,4±0,4[c]	209,1±6,6[d]	87,6±4,6[d]	625,5
Inulin	11,9±1,0[a]	7,3±0,2[b]	47,1±0,3[ac]	298,4±4,8[a]	77,9±1,9[e]	557,4
Resistant starch	11,4±1,1[ab]	7,6±0,1[e]	44,1±0,3[b]	293,9±3,0[a]	50,4±0,4[c]	592,6
Resistant.maltodextrin	11,2±1,1[ab]	7,0±0,2[c]	46,3±0,4[a]	276,2±2,4[c]	53,0±0,1[c]	606,3

[a] The data are the mean values ± standard deviation (n = 3), Values with different small letters in the same column are significantly different ($p < 0,05$).

The use of xanthan gum or gum acacia enhanced the moisture content of the extrudate. Nevertheless, addition of polydextrose to the blend slightly reduced the product moisture content while the extrudate with inulin, resistant starch or resistant maltodextrin had similar moisture content to the control. The use of dietary fiber material changed the ash content of the product. Similarly to ash content, the protein content in the product varied from sample to sample. However, the use of polydextrose or resistant starch decreased protein level of the extrudate. Addition of xanthan gum or gum acacia to the blend significantly reduced lipid content of the fried extrudate. Addition of fiber material to the blend highly enhanced the total fiber content of the product. Although the amount of the supplemental fiber material was fixed at 50g/kg for all samples, total dietary fiber content of the product varied from 50,4 to 89,9g/kg.

3.1.1.2. Effects of fiber types on physical properties of the product

Table 4.2 shows that the product with xanthan gum had reduced both radial and axial expansion ratio in comparison with the control sample. In addition, the use of gum acacia, inulin or resistant starch significantly decreased the radial expansion ratio but did not change the axial expansion ratio. However, the product with polydextrose had similar expansion index to the control sample.

Table 4.2. Effects of fiber types on physical properties of the fried extrudatea (The blend consisted of 90,3% corn meal, 5,0% fiber preparation, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis).

Samples	Radial expansion ratio	Axial expansion ratio	Bulk density (g/L)	Crispiness Count pick (times)	Hardness Force (g)
Control	161±7^{b}	127±5^{ad}	57,5±0,4^{a}	108± 2^{a}	520±110de
Polydextrose	157±8^{b}	130±4^{d}	56,1±0,9^{ac}	96±1^{b}	550±190^{e}
Xanthan gum	148±18^{a}	120±4^{b}	92,3±0,1^{e}	115±2^{e}	770±100^{c}
Gum acacia	150±6^{a}	124±4^{ab}	89,8±0,4^{d}	64±2^{d}	630±290^{a}
Inulin	146±4^{a}	123±6^{ab}	71,5±1,8^{b}	87±2^{c}	640±100^{a}
Resistant starch	146±11^{a}	123±8^{ab}	61,5±0,9^{f}	127±2^{f}	500±230^{d}
Resistant.maltodextrin	158±8^{b}	135±7^{c}	55,4±1,0^{c}	95±2^{b}	340±80^{b}

[a] The data are the mean values ± standard deviation (n=3). Values with different small letters in the same column are significantly different ($p < 0,05$).

Application of xanthan gum or gum acacia significantly increased the bulk density due to lower expansion ratio and higher moisture content of the products. Scanning electron micrographs show a limited number of voids as well as bubble rupture for the samples with xanthan gum (Fig. 4.1g) or gum acacia (Fig. 4.1e). Moreover, addition of polydextrose to the blend did not change the product bulk density since the expansion ratio remained constant. Samples with xanthan gum and resistant starch had higher crispness than the control while the other samples were relatively less crispy. For hardness property, the product with resistant maltodextrin had the softest texture. On the contrary, use of xanthan gum, gum acacia or inulin generated the product with harder texture. Fig. 4.1a shows that the control sample had well developed air cell with thin wall layer. The use of polydextrose (Fig. 4.1b) and resistant maltodextrin (Fig. 4.1g) also resulted in relatively well-developed bubble structure. However, inulin added sample (Fig. 4.1e) had significantly smaller air cells while xanthan gum (Fig. 4.1c) or gum acacia (Fig. 4.1d) samples had thicker cell wall with less porous structure.

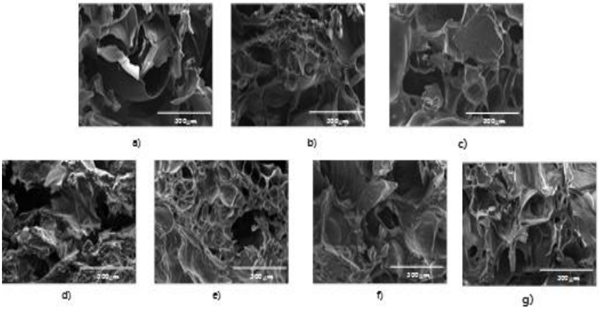

Figure 4.1. Scanning electronic micrographs of the fried extrudate with various fiber sources: a) Control, b) Polydextrose, c) Xanthan gum, d) Gum acacia, e) Inulin, f) Resistant starch, g) Resistant maltodextrin.

Addition of fiber material to the blend slightly augmented the lightness value L*, In addition, both a* and b* values were little changed when various fiber types were used in the blend (Table 4.3).

Table 4.3. Effects of various fiber types on color and sensory properties of the fried extrudatea (The blend consisted of 90,3% corn meal, 5,0% fiber preparation, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis).

Samples	L*[a]	a*[a]	b*[a]	ΔE	Hardness	Crispness
Control sample	71,3±0,9[a]	9,0±0,0[a]	36,7±0,6[a]	4,2	3,6±1,0[ab]	8,0±0,9[a]
Polydextrose	72,5±0,1[b]	9,2±0,1[a]	33,4±0,3[b]	4,2	3,9±0,6[b]	6,0±0,8[b]
Xanthan gum	76,8±0,3[c]	7,5±0,2[c]	39,1±0,3[d]	4,2	8,0±0,6[e]	2,0±0,5[f]
Gum acacia	76,6±0,6[c]	8,1±0,1[f]	38,4±0,2[c]	4,2	4,9±0,5[c]	3,0±0,9[e]
Inulin	75,2±0,1[d]	8,7±0,1[d]	38,2±0,3[c]	4,2	5,4±1,2[c]	4,0±0,9[c]
Resistant starch	77,4±0,4[c]	6,9±0,2[b]	38,2±0,3[c]	4,2	3,1±0,4[f]	8,0±0,8[a]
Resistant.maltodextrin	77,0±0,1[c]	7,8±0,1[e]	36,4±0,3[a]	4,2	2,7±0,4[d]	7,0±0,7[d]

[a] The data are the mean values ± standard deviation (n = 3). Values with different small letters in the same column are significantly different (p < 0,05).

Addition of polydextrose to the blend did not change the hardness score of the product. The hardness score was reduced when resistant starch and resistant maltodextrin were used while xanthan gum, gum acacia and inulin enhanced the hardness score. For crispness, the scores of the control and the resistant starch added sample were similar.

3.1.2. Effects of polydextrose ratio in the mixing blend on the snack quality

3.1.2.1. Effects of polydextrose ratio on chemical composition of the extrudate

Addition of polydextrose to the blend slightly reduced the product moisture content. The use of polydextrose did not change the ash content of the product (Table 4.4). However, the extrudate with polydextrose contained less protein than the control since the protein content of polydextrose (1g/kg) was much lower than that of corn meal (60g/kg). Increase in polydextrose content from 0 to 10% in the blend resulted in increased lipid content by 20% for the fried extrudate. Figure 4.2 shows that the control sample had well developed air cells with thin wall layers. However, increase in polydextrose content in the blend resulted in significantly smaller air cells and thicker cell wall with less porous structure. Table 4.4 also reveals that the higher the polydextrose content in the blend, the higher the dietary fiber content of the extrudate.

Table 4.4. Effects of polydextrose content on chemical composition (g/kg) of the fried extrudatea (The blend consisted of 95,3 to 85,3% corn meal, 0 to 1% polydextrose, 4,0% sugar and 0,7% salt).

Polydextrose content of the blend (%)	Moisture	Ash	Protein	Lipid	Fiber	Carbohydrate
0	12,9±0,8[a]	6,6±0,2[a]	45,5±0,8 [a]	294,6±10,6[a]	32,5±3,2[a]	640,3
2,5	9,8±0,1[b]	6,6±0,1[a]	44,0±0,5 [b]	312,7±13,0[ab]	46,0±0,5[b]	626,9
5,0	9,9±1,3[b]	6,6±0,1[a]	43,1±0,5 [bc]	325,2±14,5[bc]	61,7±3,2[c]	615,2
7,5	9,8±1,2[b]	6,5±0,1[a]	41,9±0,8 [cd]	336,3±7,2[cd]	75,9±2,7[d]	605,5
10,0	10,1±0,8[b]	6,5±0,1[a]	40,8±1,0 [d]	352,7±1,5[d]	86,3±1,2[e]	589,9

[a] The data are the mean values ± standard deviation (n = 3), Values with different small letters in the same column are significantly different (p < 0,05).

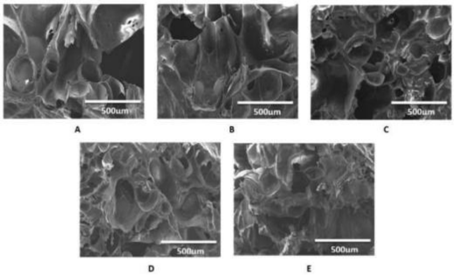

Figure 4.2: Scanning electronic micrographs of the fried extrudate with various polydextrose contents. The polydextrose content (% of dry weigh basis) in the blend was: A) 0; B) 2,5; C) 5,0; D) 7,5 and E) 10,0 %

3.1.2.2. Effects of polydextrose ratio on physical properties of the extrudate

In Table 4.5, it can be noted that increase in polydextrose content from 0 to 10% in the blend reduced both radial and axial expansion ratio by 13% and 9%, respectively. Figure 4.2 indicates smaller air cells for the snack samples with higher polydextrose content. However, the use of polydextrose at 10% increased the bulk density by 22% due to the lower expansion ration of the product. Increase in polydextrose content from 0 to 7,5% in the blend gradually augmented hardness of the extrudate. The sudden decrease in hardness at 10% polydextrose added sample is probably due to the collapsed inner cell structure as well as the smaller air bubble (Fig. 4.2E). The crispiness gradually declined with the increase in polydextrose content of the extrudate.

Table 4.5: Effects of polydextrose content on physical properties of the fried extrudate[a] (The blend consisted of 95,3 to 85,3% corn meal, 0 to 10% polydextrose, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis).

Polydextrose content of the blend (%)	**Radial expansion ratio (%)**	**Axial expansion ratio (%)**	**Bulk density (g/L)**	**Hardness, Force (g)**	**Crispiness, Count pick (times)**
0	164,9±8,6[a]	137,6±20,6[a]	55,8±1,19[a]	445±66[a]	109±2,2[a]
2,5	161,7±10,1[a]	135,5±13,4[ab]	56,6±1,22[ab]	497±39[b]	101±4,7[b]
5,0	160,8±9,8[a]	132,2±7,5[abc]	58,9±1,79[b]	511±67[b]	95±2,4[c]
7,5	155,8±11,6[b]	130,3±21,3[bc]	64,2±1,62[c]	521±51[b]	92±4,5[d]
10,0	143,2±13,8[c]	125,7±9,3[c]	67,9±1,04[d]	388±23[c]	68±5,9[e]

[a] The data are the mean values ± standard deviation (n=3). Values with different small letters in the same column are significantly different (p < 0,05).

The lightness value L* slightly increased when the polydextrose content of the extrudate increased. Moreover, the product samples with high polydextrose content had increased b* value and reduced a* value in Table 4.6.

Table 4.6. Effects of polydextrose content on color and sensory properties of the fried extrudate[a]

Polydextrose content (%)	**L***	**a***	**b***	**Δ E**	**Hardness**	**Crispness**
0	69,0±1,4[a]	9,2±0,40[a]	34,5±1,3[a]	4,15±0,03[a]	3,6±1,0[a]	7,6±1,3[a]
2,5	69,5±0,9[a]	9,1±0,21[a]	35,0±0,8[a]	4,16±0,02[ab]	3,6±0,7[a]	7,0±0,8[b]
5,0	69,9±1,7[a]	8,9±0,40[a]	35,7±1,4[a]	4,16±0,02[ab]	3,9±1,5[ab]	6,1±0,9[c]
7,5	70,2±2,3[a]	8,0±0,21[b]	36,1±2,2[a]	4,15±0,02[ab]	5,3±1,3[c]	5,9±0,8[c]
10,0	73,5±0,6[b]	7,3±0,25[c]	38,8±0,7[b]	4,18±0,01[b]	4,3±1,1[b]	5,0±0,8[d]

[a] The data are the mean values ± standard deviation (n = 3). Values with different small letters in the same column are significantly different (p < 0,05).

Increase in polydextrose content in the blend from 0 to 7,5% gradually enhanced the hardness score of the product. For crispness, the score gradually decreased as the polydextrose content of the product increased.

3.1.3. Effects of extrusion screw speed on the snack quality

3.1.3.1. Effects of extrusion screw speed on approximate composition of the fried extrudate

Table 4.7 shows that increase in screw speed resulted in increase in moisture content of the fried extrudate. When the screw speed increased from 150 to 180 rpm, the lipid content of the extrudate gradually decreased. Figure 4.3a-d reveals that the air cell wall in the extrudate became thinner and less compact while the air bubble size became larger when the screw speed increased from 150 to 180 rpm. Nevertheless, further increase in screw speed from 180 to 190 rpm led to more coalesced structure and thicker cell wall of the obtained product (Figure 4.3e). Table 4.7 also presents that the ash, protein and fiber content of the product remained constant as the extrusion screw speed was varied.

Table 4.7. Effects of extrusion screw speed on approximate composition (g/kg) of the fried extrudate[a] (The blend consisted of 87,8% corn meal, 7,5% polydextrose, 4,0% sugar and 0,7% salt).

Screw speed (rpm)	Moisture	Ash	Protein	Lipid	Fiber
150	8,1±0,8[a]	6,5±0,2[a]	41,1±0,9[a]	348,2±1,2[a]	75,6±1,0[a]
160	9,4±0,3[b]	6,5±0,1[a]	41,8±1,5[a]	346,0±1,5[a]	75,5±2,1[a]
170	11,2±0,4[c]	6,4±0,2[a]	42,7±1,5[a]	328,6±0,3[b]	75,2±2,1[a]
180	12,7±0,5[d]	6,4±0,3[a]	42,9±1,0[a]	329,5±0,9[b]	74,7±1,2[a]
190	12,5±0,7[d]	6,5±0,1[a]	43,0±1,7[a]	322,9±5,6[c]	75,7±3,3[a]

[a] The data are the mean values ± standard deviation (n = 3). Values with different small letters in the same column are significantly different (p < 0,05).

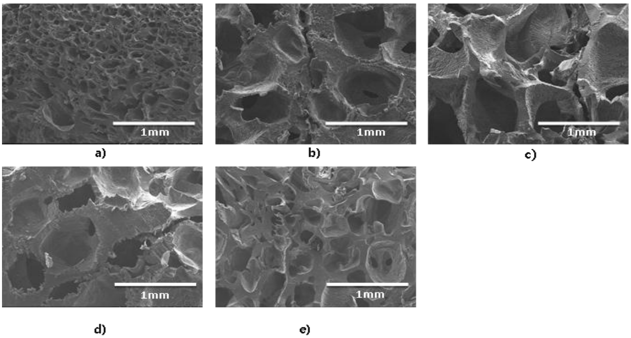

Figure 4.3: Scanning electronic micrographs of the fried extrudate on screw rpm variables: a) 150rpm, b) 160rpm, c) 170rpm, d) 180rpm e) 190rpm.

3.1.3.2. Effects of extrusion screw speed on physical properties of the fried extrudate

Table 4.8 shows the effects of screw speed on expansion ratio of the fried extrudate. When the screw speed increased from 150 to 180 rpm, both radial and axial expansion ratio were gradually increased by 18% and 7%, respectively. However, further increase in screw speed from 180 to 190 rpm significantly reduced the expansion ratio of the extrudate. When the screw speed was increased from 150 to 190 rpm, the bulk density of the product was gradually decreased by 39%.

Table 4.8. Effects of extrusion screw speed on physical properties of the fried extrudate[a] (The blend consisted of 87,8% corn meal, 7,5% polydextrose, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis).

Screw speed (rpm)	Radial expansion ratio	Axial expansion ratio	Bulk density (g/L)	Hardness Force (g)	Crispiness Count pick (times)
150	143±17[a]	136±9[a]	100±1 [a]	736±23[a]	69±2[a]
160	149±7[ac]	138±6[ab]	68±2[e]	556±27[e]	78±5[b]
170	164±11[b]	141±5[b]	65±1[d]	490±11[b]	97±3[d]
180	169±11[b]	145±6[c]	58±1[c]	448±27[c]	120±12[c]
190	153±12[c]	139±7[ab]	61±1[b]	478±26[b]	100±4[d]

[a] The data are the mean values ± standard deviation (n=3). Values with different small letters in the same column are significantly different (p < 0,05).

Changes in instrumental textural properties of the product under different extrusion screw speeds are also visualized in Table 4.8. The hardness of the extrudate was reduced as the screw speed increased from 150 to 180 rpm. Decreased bulk density and decreased thickness of air cell wall resulted in decreased hardness of the obtained extrudate (Figure 4.3 and Table 4.8). However, further increase in screw speed from 180 to 190 rpm increased the hardness of the product. The crispness gradually increased with the increase in screw speed.

3.1.3.3. Effects of extrusion screw speed on sensory score of the fried extrudate

The hardness and crispness scores are presented in Table 4.9. The hardness score decreased by 48% when the screw speed increased from 150 to 180 rpm. However, increase in screw speed from 180 to 190 rpm resulted in a significant increase in hardness score of the extrudate. The crispness score was significantly improved as the screw speed rose from 150 to 180 rpm but decreased as the screw speed varied from 180 to 190 rpm.

Table 4.9. Effects of extrusion screw speed on sensory score of the fried extrudate[a] (The blend consisted of 87,8% corn meal, 7,5% polydextrose, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis).

Screw speed (rpm)	150	160	170	180	190
Hardness	8,4±0,69^{b}	5,3±0,72^{c}	5,7±0,81^{c}	4,4±1,10^{d}	6,6±0,9^{e}
Crispiness	4,8±0,41^{b}	5,5±0,52^{cd}	5,6±0,51^{d}	6,1±0,76^{e}	5,1±0,80^{c}

[a] The data are the mean values ± standard deviation (n = 3). Values with different small letters in the same row are significantly different (p < 0,05).

3.1.3.4. Effects of extrusion screw speed on instrumental color, water absorption index (WAI), water solubility index (WSI) of the fried extrudate and specific mechanical energy of the extrusion process

The L* value slightly increased when the screw speed increased. The a* value decreased when the screw speed rose from 150 to 160 rpm (Table 4.10).

Table 4.10. Effects of extrusion screw speed on instrumental color, WAI and WSI of the fried extrudate and specific mechanical energy (SME) of the extrusion process[a] (The blend consisted of 87,8% corn meal, 7,5% polydextrose, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis).

Screw speed (rpm)	L*	a*	b*	WAI	WSI	SME (KJ/Kg)
150	65,5±0,5^{a}	8,9±0,3^{a}	32,5±0,5^{a}	253± 4^{a}	12,8± 0,4^{a}	226±1^{a}
160	67,9±0,2^{bc}	7,2±0,1^{b}	32,3±0,7^{a}	284±4^{b}	13,9± 0,6^{b}	230±2^{a}
170	66,7±0,5^{b}	7,4±0,4^{b}	32,2±1,2^{a}	296± 5^{c}	16,7± 0,3^{d}	236±1^{c}
180	68,5±0,7^{c}	7,6±0,1^{b}	32,9±0,9^{a}	296±5^{c}	18,8±0,6^{c}	244±2^{d}
190	67,8±0,6^{bc}	7,3±0,3^{b}	31,7±1,0^{a}	327±7^{d}	19,9±0,3^{e}	265±4^{e}

[a] The data are the mean values ± standard deviation (n = 3). Values with different small letters in the same column are significantly different (p < 0,05).

Increase in screw speed from 150 to 190 rpm enhanced the water absorption index of the product. Moreover, the water solubility index also gradually increased when the screw speed rose from 150 to 190 rpm. The specific mechanical energy of the extrusion process is also increased by 17%.

3.1.4. Effects of extrusion temperature on the snack quality

3.1.4.1. Effects of extrusion temperature on the chemical composition of the extrudate

Table 4.11 shows that increase in extrusion temperature decreased the moisture content of the extrudate. Increase in die temperature from 60 ± 1 to 100 ± 1 °C gradually decreased the lipid content of the extrudate. Figure 4.4A-E revealed that the air cell wall in the extrudate became thinner and less compact while the air bubble size became larger when the die temperature increased from 60 ± 1 to 100 ± 1 °C. Nevertheless, further increase in die temperature led to more porous structure and thicker cell wall of the obtained product (Figure 4.4F).

Table 4.11. Effects of extrusion temperature on chemical composition (g/kg) of the fried extrudate[a] (The blend consisted of 87,8% corn meal, 7,5% polydextrose, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis, The barrel temperature (^oC) at zone 1, 2, 3 and 4 was fixed at 48 ± 1, 60 ± 1, 77 ± 1 and 93 ± 1, respectively; the temperature of zone 6 and the die temperature were similar).

Barrel temperature (°C)		Moisture	Ash	Protein	Lipid
Zone 5	Zone 6				
70±1	60±1	13,3±0,1[a]	6,3±0,1[a]	39,3±0,57[a]	367,0±2,8[a]
80±1	70±1	12,6±0,3[b]	6,4±0,2[a]	39,9±0,85[a]	351,0±3,5[b]
90±1	80±1	11,3±0,1[c]	6,3±0,1[a]	40,8±0,92[a]	339,5±3,7[c]
100±1	90±1	11,0±0,2[d]	6,1±0,0[a]	41,1±0,99[a]	338,7±5,0[c]
110±1	100±1	8,7±0,1[e]	6,1±0,0[a]	40,9±1,34[a]	332,3±2,5[d]
120±1	110±1	8,1±0,2[f]	6,3±0,2[a]	40,9±0,42[a]	340,3±2,7[c]

[a] The data are the mean values ± standard deviation (n = 3). Values with different small letters in the same column are significantly different (p < 0,05).

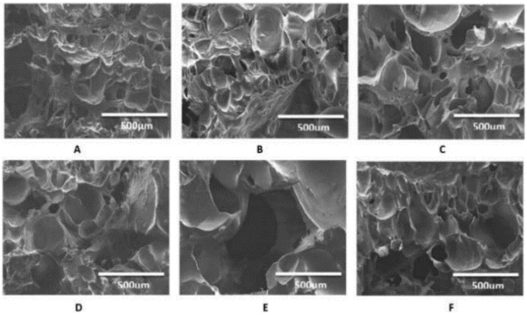

Figure 4.4: Scanning electronic micrographs of the fried extrudate with 7,5 % polydextrose content and various die temperatures: A) 60, B) 70, C) 80, D) 90, E) 100 and F) 110^oC.

3.1.4.2. Effects of extrusion temperature on the physical properties of the extrudate

When the die temperature increased from 60 ± 1 to 100 ± 1°C, the radial and axial expansion ratio gradually increased while the bulk density decreased (Table. 4.12). However, further increase in die temperature from 100 ± 1°C to 110 ± 1°C significantly reduced the expansion ratio and increased the bulk density of the extrudate. It can be noted that larger air cells and thinner cell wall in the extrudate were observed at higher extrusion temperature (Figure 4.4A-E). Changes in instrumental textural properties of the product under different extrusion temperatures are also visualized in Table 4.12. Both hardness and crispness of the extrudate were enhanced as the die temperature increased from 60 ± 1°C to 100 ± 1°C.

Table 4.12. Effects of barrel temperature on physical properties of the fried extrudate[a] (The blend consisted of 87,8% corn meal, 7,5% polydextrose, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis).

Barrel temperature °C)		Radial expansion ratio (%)	Axial expansion ratio (%)	Bulk density (g/L)	Hardness, Force (g)	Crispiness, Count pick (times)
Zone 5	Zone 6					
70±1	60±1	137,8±10,5[a]	123,2±5,60[a]	69,40±0,82[a]	510±36,6[a]	74±5,4[a]
80±1	70±1	143,9±9,70[b]	126,0±4,44[b]	66,34±1,50[b]	541±51,3[bc]	84±4,5[b]
90±1	80±1	148,9±6,7[c]	128,7±5,31[c]	58,03±0,43[c]	569±53,2[cd]	94±5,3[c]
100±1	90±1	149,5±7,7[c]	129,1±6,96[c]	58,31±0,21[c]	573±69,9[d]	92±10,0[c]
110±1	100±1	151,3±6,0[c]	127,7±4,92[bc]	57,50±0,58[c]	578±58,3[d]	98±10,7[d]
120±1	110±1	145,1±9,0[b]	121,5±9,15[a]	66,30±0,78[b]	516±72,9[ab]	86±4,1[b]

[a] The data are the mean values ± standard deviation (n=3). Values with different small letters in the same column are significantly different (p < 0,05).

3.1.4.3. Effects of extrusion temperature on sensory score of the fried extrudate

The hardness score increased by 79% when the die temperature increased from 60 ± 1°C to 80 ± 1°C. However, increase in die temperature to 100 ± 1°C and 110 ± 1°C resulted in a significant decrease in hardness score of the extrudate (Table 4.13). The crispness score significantly improved as the die temperature rose from 60 ± 1°C to 80 ± 1°C but decreased as the temperature varied from 100 ± 1°C to 110 ± 1°C (Table 4.13).

Table 4.13. Effects of barrel temperature on sensory properties of the fried extrudate[a] (The blend consisted of 87,8% corn meal, 7,5% polydextrose, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis).

Zone 5	**70±1**	**80±1**	**90±1**	**100±1**	**110±1**	**120±1**
Zone 6	**60±1**	**70±1**	**80±1**	**90±1**	**100±1**	**110±1**
Hardness	3,8±0,8 [a]	5,6±1,0[c]	6,8±0,9[d]	6,5±1,1[d]	4,6±1,2[b]	4,2±1,2[ab]
Crispiness	4,7±1,1[a]	5,8±0,9[b]	7,2±0,8[d]	6,6±0,8[c]	5,6±0,8[b]	4,2±1,0[a]

[a] The data are the mean values ± standard deviation (n = 3). Values with different small letters in the same column are significantly different (p < 0,05).

3.1.4.4. Effects of extrusion temperature on instrumental color, water absorption index, water solubility index of the fried extrudate and specific mechanical energy of the extrusion process

Increase in die temperature from 60 ± 1°C to 100 ± 1°C gradually increased the water absorption index (Table 4.14). Water solubility index also gradually increased when the die temperature rose from 60 ± 1°C to 100 ± 1°C (Table 4.14). The L* and a* value decreased with the increase in die temperature while b* value which determines the extent of redness of the sample increased (Table 4.14). The specific mechanical energy also increased by 12,3%.

Table 4.14. Effects of barrel temperature on WAI, WSI, Color & SME of the fried extrudate[a] (The blend consisted of 87,8% corn meal, 7,5% polydextrose, 4,0% sugar and 0,7% salt; the ratio was calculated on dry weight basis).

Zone 6 (°C)	WAI	WSI	L*	a*	b*	SME (kJ/kg)
60±1	292,3±6,8[a]	12,1±0,06[a]	79,13±1,96[a]	6,36±0,24[a]	35,53±1,34[a]	203,4±3,4[a]
70±1	291,3±0,1[a]	13,71±0,18[b]	77,48±0,52[ab]	6,14±0,44[a]	36,84±1,17[a]	210,1±2,3[b]
80±1	299,9±4,5[b]	14,09±0,04[c]	76,25±1,26[b]	6,11±0,26[ab]	39,56±1,29[b]	221,0±2,5[c]
90±1	303,7±1,8[bc]	17,25±0,28[d]	75,17±0,49[bc]	5,58±0,18[c]	41,33±0,81[bc]	225,2±4,7[cd]
100±1	315,9±0,5[d]	17,63±0,08[e]	73,42±2,23[c]	5,66±0,23[bc]	42,53±0,94[c]	228,4±4,4[d]
110±1	309,1±1,7[c]	14,65±0,04[f]	72,73±1,74[c]	5,54±0,13[c]	43,31±1,59[c]	219,1±2,7[c]

[a] The data are the mean values ± standard deviation (n = 3). Values with different small letters in the same column are significantly different ($p < 0,05$),

3.2. Use of commercial natural antioxidants in the frying of the extruded corn snack

3.2.1. Effects of natural antioxidants on the palm olein oil quality during the heat treatment

Slight increase in acidity during the heating was observed for all oil samples. At the end of the heating, the acidity of the control sample was significantly higher than that of all antioxidant added samples. The lowest acidity was reported for nutmeg oil. The acidity of the oil sample with nutmeg oil was 44% lower than that of the control (Table 4.15).

Table 4.15 shows that the conjugated diene content was low at the beginning of the process but tended to increase with the increase in heating cycles. Notably, the lowest conjugated diene contents at the end of the heat treatment were reported for the oil samples with nutmeg and rosemary oil. At the end of the heat treatment, the lowest conjugated trienes content was reported for the oil sample with nutmeg oil; this value was 28% lower than that of the control sample which had the highest conjugated trienes concentration (Table 4.15).

At the beginning of the heating, all oil samples had similar peroxide value. During the first step of the heat treatment, increase in peroxide value was observed for all samples. Nevertheless, the lowest maximum peroxide value was reported for the sample with nutmeg oil while the control sample and the sample with cedarwood oil had the highest value. During the second step of the heat treatment, the peroxide value reduced sharply for all samples excluding the sample with tocopherol the peroxide value of which remained constant.

No statistical difference in malonaldehyde content among all samples ($p > 0,05$) was observed at the beginning of the heat treatment whereas the malonaldehyde content gradually increased as the heating time increased due to oxidative degradation of the palm oil. Particularly, the malonaldehyde content of the sample with nutmeg oil was 56% lower than that of the control sample.

At the beginning of the heating, the color of the oil samples was slightly different since the antioxidant preparations used in this study had various colors (Table 4.15). At the end of the heat treatment, the L* and a* value of all samples were decreased. In addition, a decrease in redness was also noted for all samples, the yellow color was increased throughout the heating process.

3.2.2. Effects of nutmeg concentration on the palm olein oil quality during the heat treatment

During the treatment time, the acidity content of all samples was gradually increased. The higher the concentration of nutmeg oil is, the lower the acidity of palm olein oil is at the end of the heat treatment (Table 4.16). The conjugated dienes and trienes content of all samples gradually increased from 0 to 30 hours of the heat treatment (Table 4.16). As the nutmeg concentration in the blended oil was increased, the formation of conjugated dienes and trienes was significantly decreased. The lowest values were reported for the sample of 4 and 5 g/kg sample and these values were 38% and 61%, respectively lower than that of the control sample. Table 4.18 also shows that the initial peroxide value of all samples was insignificantly different ($p > 0,05$). The maximum peroxide value of the control samples was 1,8 and 2,2 times higher than that of the sample with 1 and 2 g/kg nutmeg oil with palm olein oil, respectively. In addition, as the nutmeg oil concentration increased from 3 to 5 g/kg palm olein oil, gradual increase in peroxide value during the heat treatment was clearly observed for all samples. As the treatment time increased, the malonaldehyde content of all samples gradually increased (Table 4.18). As the nutmeg oil concentration increased from 0 to 5 g/kg, the malonaldehyde content at the end of the heat treatment significantly ($p < 0,05$) decreased. The L* and a* values of all oil samples decreased during the heating process, while the b* value increased (Table 4.16).

3.2.3. Effects of nutmeg oil on the palm olein oil quality during the extrudate frying

The acidity was gradually increased for the both samples (Fig. 4.5a). At the end of the fifth day, the acidity of the control sample was 63% higher than that of the nutmeg oil added sample. Figure 4.5b and 4.5c showed that the conjugated dienes and trienes contents were gradually increased from day 0 to day 5. At the end of the extrudate frying, the conjugated diene and triene contents of nutmeg added sample was 22% and 42%, respectively lower than that of the control sample. Figure 4.5d showed that the peroxide value of the control sample was increased from day 0 to day 3 which was the end of the first stage; then it came to the second stage when the peroxide value was gradually decreased by the end of the frying test. Whereas, the peroxide value of the nutmeg added sample was gradually increased from the beginning to the end of the frying test. The malonaldehyde content was gradually increased from day 0 to day 5 for both the control and nutmeg added sample (Fig 4.5e).

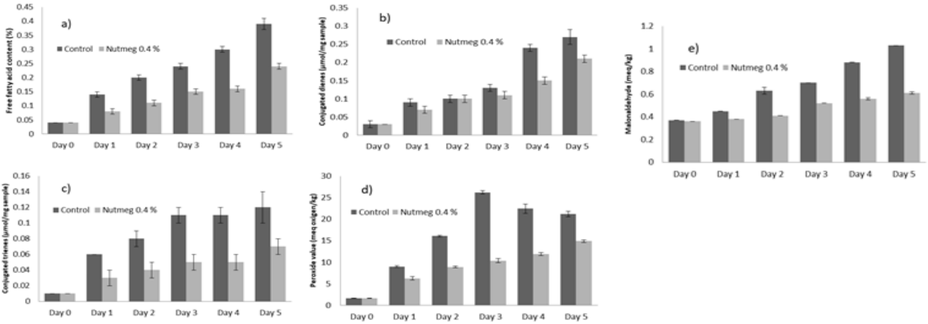

Figure 4.5: Effects of nutmeg oil on the stability of palm olein oil during the extrudate frying (for 15 batches per day and for 5 consecutive days): a) Free fatty acid, b) Conjugated dienes, c) Conjugated trienes, d) Peroxide value, e) Malonaldehyde content.

Table 4.15. Quality changes in palm olein oil during the heat treatmen with various antioxidants

Characteristic	Hour	Control	Cedarwood	Citronella	Clove	Nutmeg	Rosemary	Tocopherol	BHT
Free fatty acid content (%)	**0h**	0,05±0,01^{a,A}	0,04±0,01^{a,A}	0,05±0,00^{a,A}	0,04±0,01^{a,A}	0,04±0,01^{a,A}	0,05±0,01^{a,A}	0,05±0,01^{a,A}	0,05±0,01^{a,A}
	6h	0,10±0,01^{b,D}	0,09±0,01^{b,C}	0,05±0,01^{a,A}	0,06±0,01^{b,A}	0,06±0,01^{b,AB}	0,06±0,00^{b,AB}	0,08±0,01^{b,C}	0,07±0,01^{b,B}
	12h	0,17±0,01^{c,F}	0,10±0,01^{b,E}	0,09±0,01^{b,DE}	0,06±0,00^{b,A}	0,08±0,00^{c,BC}	0,08±0,01^{c,B}	0,10±0,01^{c,E}	0,09±0,01^{c,CD}
	18h	0,22±0,01^{d,E}	0,15±0,01^{c,D}	0,14±0,00^{c,C}	0,12±0,01^{c,B}	0,10±0,00^{d,A}	0,12±0,01^{d,B}	0,14±0,01^{d,C}	0,11±0,01^{d,B}
	24h	0,26±0,01^{e,A}	0,21±0,00^{d,B}	0,16±0,01^{d,CD}	0,17±0,01^{d,C}	0,15±0,01^{e,D}	0,16±0,01^{e,C}	0,16±0,01^{e,C}	0,16±0,01^{e,CD}
	30h	0,36±0,01^{f,G}	0,33±0,01^{e,E}	0,34±0,01^{e,F}	0,31±0,00^{e,D}	0,20±0,01^{f,A}	0,24±0,01^{f,B}	0,29±0,01^{f,C}	0,27±0,01^{f,C}
Conjugated Dienes $\varepsilon^{1\%}_{1cm(\lambda 232)}$ (µmol/mg sample)	**0h**	0,03±0,00^{a,AB}	0,03±0,00^{a,AB}	0,03±0,01^{a,AB}	0,03±0,01^{a,AB}	0,03±0,00^{a,AB}	0,03±0,01^{a,A}	0,03±0,00^{a,AB}	0,04±0,01^{a,B}
	6h	0,08±0,00^{b,C}	0,06±0,01^{b,A}	0,06±0,01^{ab,A}	0,07±0,00^{b,AB}	0,07±0,01^{b,AB}	0,06±0,01^{b,A}	0,07±0,00^{ab,AB}	0,07±0,01^{b,BC}
	12h	0,09±0,01^{b,AB}	0,08±0,01^{c,AB}	0,09±0,00^{ab,BC}	0,10±0,01^{c,C}	0,08±0,00^{c,A}	0,08±0,01^{c,AB}	0,08±0,00^{abc,A}	0,09±0,01^{c,AB}
	18h	0,13±0,01^{c,C}	0,12±0,01^{d,BC}	0,12±0,01^{bc,AB}	0,12±0,01^{d,BC}	0,11±0,00^{d,A}	0,11±0,01^{d,AB}	0,12±0,01^{bc,AB}	0,11±0,01^{d,AB}
	24h	0,18±0,01^{d,D}	0,17±0,01^{e,B}	0,18±0,00^{c,A}	0,17±0,01^{e,CD}	0,13±0,00^{e,C}	0,13±0,01^{e,AB}	0,15±0,01^{c,A}	0,14±0,01^{e,D}
	30h	0,25±0,00^{e,G}	0,24±0,01^{f,F}	0,22±0,00^{bc,E}	0,22±0,00^{f,E}	0,17±0,00^{f,A}	0,18±0,01^{f,B}	0,21±0,00^{bc,D}	0,20±0,01^{f,C}
Conjugated trienes $\varepsilon^{1\%}_{1cm(\lambda 268)}$ (µmol/mg sample)	**0h**	0,01±0,01^{a,A}	0,01±0,00^{a,A}	0,02±0,02^{a,A}	0,01±0,01^{a,A}	0,01±0,00^{a,A}	0,01±0,00^{a,A}	0,01±0,01^{a,A}	0,01±0,00^{a,A}
	6h	0,05±0,00^{b,A}	0,04±0,01^{b,AB}	0,03±0,01^{ab,C}	0,03±0,00^{ab,BC}	0,03±0,00^{b,BC}	0,03±0,01^{b,BC}	0,03±0,00^{ab,BC}	0,03±0,02^{ab,BC}
	12h	0,08±0,02^{c,A}	0,08±0,00^{c,A}	0,05±0,02^{b,BC}	0,04±0,01^{b,C}	0,04±0,01^{b,C}	0,06±0,01^{c,AB}	0,04±0,01^{b,C}	0,05±0,01^{b,BC}
	18h	0,11±0,01^{d,AB}	0,12±0,02^{d,A}	0,07±0,01^{c,DE}	0,08±0,02^{c,CDE}	0,06±0,01^{c,E}	0,10±0,02^{d,ABC}	0,08±0,01^{c,CDE}	0,09±0,02^{c,BCD}
	24h	0,15±0,00^{e,A}	0,16±0,01^{e,A}	0,10±0,02^{d,CD}	0,13±0,01^{d,B}	0,09±0,01^{d,D}	0,11±0,01^{d,CD}	0,13±0,01^{d,B}	0,12±0,02^{d,BC}
	30h	0,18±0,01^{f,AB}	0,19±0,02^{f,A}	0,16±0,01^{e,BC}	0,15±0,02^{e,CD}	0,13±0,02^{e,D}	0,15±0,02^{e,C}	0,17±0,02^{e,ABC}	0,16±0,01^{e,C}
Peroxide value (meq oxigen/kg)	**0h**	1,68±0,16^{a,A}	1,55±0,11^{a,A}	1,63±0,17^{a,A}	1,58±0,31^{a,A}	1,62±0,23^{a,A}	1,67±0,01^{a,A}	1,62±0,34^{a,A}	1,61±0,25^{a,A}
	6h	4,95±0,67^{b,BC}	5,44±0,50^{b,C}	4,54±0,54^{ab,ABC}	4,97±1,01^{b,BC}	3,86±0,14^{b,A}	3,57±0,50^{b,A}	4,33±0,50^{ab,AB}	4,05±0,40^{b,AB}
	12h	13,56±1,17^{c,F}	9,67±1,22^{c,E}	7,47±0,72^{bc,CD}	8,39±0,67^{c,DE}	4,55±0,28^{c,A}	5,82±1,03^{c,AB}	6,84±0,72^{abc,BC}	6,17±0,79^{c,BC}
	18h	25,39±1,52^{f,E}	24,66±1,5^{f,E}	16,48±0,92^{c,C}	19,63±0,74^{e,D}	7,23±0,22^{d,A}	8,37±0,68^{d,A}	13,48±1,66^{c,B}	9,00±0,86^{d,A}
	24h	22,15±0,95^{e,D}	20,21±1,02^{e,CD}	14,57±1,19^{c,B}	18,89±0,98^{e,C}	11,1±0,36^{f,A}	13,22±1,09^{f,B}	12,88±1,45^{c,AB}	13,29±1,57^{f,B}
	30h	19,67±1,27^{d,E}	16,0±0,96^{d,D}	13,68±1,45^{bc,C}	15,79±1,41^{d,D}	8,90±0,14^{e,A}	10,87±0,37^{e,B}	14,03±0,75^{bc,C}	10,75±0,63^{e,B}
TBARS (meq/kg)	**0h**	0,36±0,00^{a,A}	0,36±0,00^{a,A}	0,36±0,00^{a,A}	0,37±0,00^{a,A}	0,36±0,04^{a,A}	0,37±0,00^{a,A}	0,36±0,00^{a,A}	0,36±0,01^{a,A}
	6h	0,50±0,00^{b,C}	0,51±0,01^{b,C}	0,58±0,00^{b,D}	0,59±0,01^{b,D}	0,37±0,00^{a,A}	0,46±0,01^{b,B}	0,38±0,01^{b,A}	0,39±0,04^{b,A}
	12h	0,69±0,01^{c,H}	0,54±0,00^{c,D}	0,64±0,00^{c,G}	0,63±0,00^{c,F}	0,41±0,00^{b,B}	0,47±0,01^{b,C}	0,40±0,00^{c,A}	0,57±0,01^{c,E}
	18h	0,75±0,00^{d,F}	0,65±0,00^{d,E}	0,65±0,00^{d,E}	0,65±0,00^{d,E}	0,42±0,00^{b,A}	0,52±0,01^{c,B}	0,59±0,01^{d,D}	0,58±0,00^{c,C}
	24h	0,88±0,01^{e,G}	0,81±0,00^{e,F}	0,70±0,00^{e,E}	0,67±0,00^{e,D}	0,46±0,00^{c,A}	0,63±0,01^{d,C}	0,61±0,00^{e,B}	0,61±0,01^{d,B}
	30h	1,11±0,01^{f,G}	0,95±0,00^{f,F}	0,71±0,00^{f,D}	0,74±0,01^{f,E}	0,49±0,01^{d,A}	0,68±0,00^{e,C}	0,65±0,00^{f,B}	0,65±0,00^{e,B}
Color **L***	**0h**	86,00±0,01^{f,F}	83,77±0,01^{f,E}	83,17±0,04^{f,D}	77,62±0,06^{d,A}	86,73±0,02^{e,G}	77,5±0,05^{f,A}	80,57±0,02^{f,B}	81,65±0,57^{f,C}
	30h	78,4±0,02^{a,F}	74,28±0,02^{a,E}	69,49±0,01^{a,A}	70,67±0,56^{a,C}	79,32±0,04^{a,G}	72,58±0,01^{a,D}	74,27±0,05^{a,E}	70,24±0,07^{a,B}
a*	**0h**	-1,89±0,00^{f,B}	-1,57±0,05^{f,E}	-1,65±0,01^{e,C}	-1,61±0,01^{f,D}	-1,88±0,01^{e,B}	-2,32±0,01^{e,A}	-1,49±0,01^{e,F}	-1,86±0,02^{e,B}
	30h	-4,03±0,03^{a,E}	-3,82±0,08^{a,C}	-3,47±0,03^{a,F}	-4,69±0,03^{a,B}	-3,9±0,01^{a,D}	-4,1±0,01^{a,C}	-4,89±0,04^{a,A}	-4,1±0,02^{a,C}
b*	**0h**	6,76±0,08^{a,E}	5,11±0,01^{a,D}	4,17±0,01^{a,A}	4,05±0,14^{a,A}	6,83±0,02^{a,E}	7,46±0,09^{a,F}	4,74±0,01^{a,C}	4,55±0,02^{a,B}
	30h	14,61±0,03^{f,D}	16,20±0,10^{f,E}	11,6±0,16^{f,A}	11,65±0,24^{f,A}	14,88±0,05^{e,D}	13,82±0,05^{e,C}	13,95±0,27^{f,C}	13,38±0,56^{d,B}

Table 4.16: Effects of nutmeg content in palm olein oil during frying process (g nutmeg oil/kg palm olein oil)

Characteristic	Hour	0	1	2	3	4	5
Free fatty acid content (%)	0h	0,04±0,01^{a,AB}	0,04±0,01^{a,A}	0,04±0,00^{a,AB}	0,04±0,01^{a,AB}	0,04±0,00^{a,AB}	0,05±0,01^{a,B}
	6h	0,11±0,00^{b,D}	0,08±0,00^{b,C}	0,06±0,01^{b,B}	0,06±0,01^{b,B}	0,05±0,01^{ab,A}	0,05±0,01^{a,A}
	12h	0,17±0,00^{c,E}	0,09±0,01^{c,D}	0,08±0,01^{c,C}	0,07±0,01^{b,BC}	0,06±0,01^{b,AB}	0,05±0,01^{a,A}
	18h	0,21±0,01^{d,D}	0,13±0,01^{d,C}	0,11±0,01^{d,B}	0,10±0,01^{c,AB}	0,09±0,01^{c,A}	0,09±0,02^{b,A}
	24h	0,27±0,01^{e,E}	0,19±0,01^{e,D}	0,16±0,01^{e,C}	0,16±0,01^{d,C}	0,14±0,01^{d,B}	0,12±0,01^{c,A}
	30h	0,35±0,01^{f,D}	0,26±0,01^{f,C}	0,19±0,01^{f,B}	0,20±0,01^{e,B}	0,18±0,01^{e,A}	0,17±0,01^{d,A}
Conjugated dienes $\varepsilon^{1\%}_{1cm(\lambda 232)}$ (µmol/mg sample)	0h	0,03±0,01^{a,B}	0,03±0,01^{a,A}	0,03±0,00^{a,AB}	0,03±0,00^{a,AB}	0,03±0,00^{a,AB}	0,03±0,00^{a,AB}
	6h	0,08±0,01^{b,D}	0,07±0,00^{b,CD}	0,07±0,01^{b,C}	0,06±0,01^{b,B}	0,05±0,00^{b,AB}	0,05±0,01^{b,A}
	12h	0,08±0,01^{b,B}	0,08±0,01^{c,B}	0,08±0,01^{c,B}	0,08±0,01^{c,AB}	0,07±0,01^{c,AB}	0,07±0,01^{c,A}
	18h	0,13±0,01^{c,C}	0,13±0,01^{d,C}	0,11±0,01^{d,B}	0,10±0,01^{d,B}	0,09±0,00^{d,A}	0,10±0,01^{d,AB}
	24h	0,19±0,01^{d,D}	0,17±0,01^{e,C}	0,13±0,00^{e,B}	0,13±0,00^{e,B}	0,11±0,01^{e,A}	0,11±0,01^{e,A}
	30h	0,24±0,01^{e,D}	0,22±0,01^{f,C}	0,17±0,01^{f,B}	0,16±0,01^{f,AB}	0,15±0,01^{f,A}	0,15±0,00^{f,A}
Conjugated trienes $\varepsilon^{1\%}_{1cm(\lambda 268)}$ (µmol/mg sample)	0h	0,01±0,00^{a,A}	0,01±0,00^{a,A}	0,01±0,00^{a,A}	0,01±0,00^{a,A}	0,01±0,01^{a,A}	0,01±0,00^{a,A}
	6h	0,05±0,00^{b,A}	0,04±0,00^{b,B}	0,03±0,00^{b,C}	0,03±0,00^{b,C}	0,02±0,01^{a,D}	0,02±0,00^{b,D}
	12h	0,08±0,00^{c,A}	0,06±0,00^{c,B}	0,04±0,00^{c,C}	0,05±0,01^{c,D}	0,03±0,00^{b,E}	0,03±0,01^{b,F}
	18h	0,10±0,01^{d,A}	0,08±0,01^{d,B}	0,06±0,00^{d,C}	0,08±0,00^{d,B}	0,04±0,01^{c,D}	0,05±0,01^{c,D}
	24h	0,15±0,01^{e,A}	0,12±0,01^{e,B}	0,09±0,00^{e,C}	0,09±0,01^{d,C}	0,07±0,00^{d,D}	0,07±0,00^{d,D}
	30h	0,18±0,01^{f,A}	0,15±0,01^{f,B}	0,13±0,01^{f,C}	0,10±0,01^{e,D}	0,08±0,00^{e,E}	0,07±0,01^{d,E}
Peroxide value (meq oxigen/kg)	0h	1,62±0,01^{a,A}	1,60±0,1^{a,A}	1,52±0,19^{a,A}	1,66±0,04^{a,A}	1,58±0,04^{a,A}	1,61±0,07^{a,A}
	6h	4,90±0,05^{b,D}	4,12±0,49^{b,C}	3,84±0,16^{b,BC}	3,36±0,47^{b,B}	2,64±0,06^{b,A}	2,68±0,04^{b,A}
	12h	13,17±0,20^{c,C}	8,81±0,73^{c,B}	4,52±0,98^{b,A}	4,16±0,04^{c,A}	3,71±0,33^{c,A}	3,62±0,45^{c,A}
	18h	25,33±0,86^{f,D}	14,32±0,8^{f,C}	7,57±0,62^{c,B}	7,78±0,42^{d,B}	5,43±0,42^{d,A}	5,76±0,04^{d,A}
	24h	21,47±0,35^{e,D}	12,65±0,69^{e,C}	11,30±0,75^{e,B}	8,68±0,08^{e,A}	7,95±0,41^{e,A}	7,85±0,94^{e,A}
	30h	19,31±0,79^{d,C}	10,09±1,03^{d,B}	8,93±0,43^{f,A}	8,90±0,14^{e,A}	8,60±0,20^{f,A}	8,48±0,45^{e,A}
Malonaldehyde (meq/kg oil)	0h	0,37±0,01^{a,B}	0,36±0,00^{a,A}	0,36±0,00^{a,A}	0,37±0,00^{a,B}	0,36±0,00^{a,A}	0,36±0,00^{a,A}
	6h	0,50±0,01^{b,D}	0,40±0,01^{b,C}	0,38±0,00^{b,B}	0,37±0,00^{a,A}	0,37±0,00^{b,A}	0,37±0,00^{b,A}
	12h	0,70±0,01^{c,D}	0,41±0,00^{c,C}	0,42±0,01^{c,C}	0,39±0,00^{b,A}	0,40±0,00^{c,B}	0,39±0,00^{c,A}
	18h	0,75±0,00^{d,D}	0,44±0,00^{d,C}	0,43±0,00^{d,B}	0,40±0,00^{c,A}	0,40±0,00^{c,A}	0,40±0,01^{d,A}
	24h	0,90±0,01^{e,E}	0,48±0,00^{e,D}	0,46±0,00^{e,C}	0,41±0,00^{d,B}	0,40±0,00^{c,A}	0,40±0,00^{d,A}
	30h	1,11±0,00^{f,E}	0,53±0,00^{f,D}	0,49±0,00^{f,C}	0,42±0,00^{e,B}	0,41±0,00^{d,A}	0,41±0,00^{e,A}
Color L*	0h	86,02±0,01^{a,A}	86,31±0,12^{a,B}	86,71±0,01^{aCD}	86,64±0,01^{a,C}	86,77±0,01^{a,D}	86,72±0,02^{a,CD}
	30h	78,45±0,03^{f,A}	79,08±0,09^{f,B}	79,33±0,02^{f,C}	79,29±0,01^{e,C}	80,39±0,12^{e,D}	81,96±0,03^{e,E}
Color a*	0h	-1,89±0,01^{a,A}	-1,71±0,05^{a,C}	-1,87±0,01^{a,A}	-1,82±0,01^{a,B}	-1,72±0,01^{a,C}	-1,78±0,01^{a,D}
	30h	-4,01±0,01^{f,A}	-4,15±0,01^{f,B}	-3,91±0,01^{f,C}	-3,60±0,01^{f,D}	-3,59±0,02^{e,D}	-3,53±0,02^{f,E}
Color b*	0h	6.76±0.08^{a,B}	6.62±0.05^{a,A}	6.83±0.02^{a,BC}	6.92±0.10^{a,C}	7.16±0.03^{a,D}	7.13±0.09^{a,D}
	30h	14.66±0.10^{f,A}	14.68±0.09^{f,A}	14.86±0.07^{f,B}	15.07±0.08^{f,C}	15.16±0.12^{e,C}	15.36±0.02^{f,D}

3.3. Hypolipidemic and hepato-protective effects of high polydextrose extruded corn snack on swiss albino mice

3.3.1. Feed and energy intake

The statistical analysis showed that the average feed intake among the three groups was similar (Fig. 4.6a). However, the energy intake was significantly different among the three clusters (Fig. 4.6b).

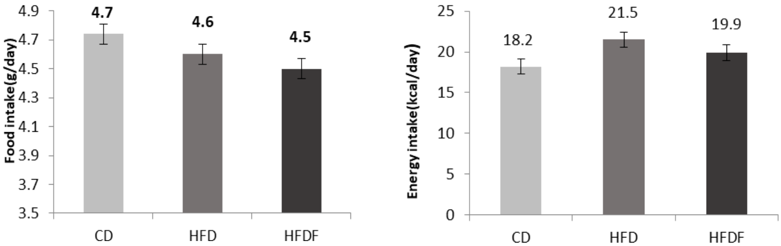

Figure 4.6. *Daily feed and energy intake of Swiss albino mice during the twelve week experiment (CD: Control diet group, HFD: High-fat diet group, HFFD: High-fat and fiber diet group).*

3.3.2. Effects of high polydextrose snack on body weight

At the beginning of the experiment, the three mice groups showed insignificant difference in body weight (Table 4.17). The final body weight of polydextrose diet mice was slightly higher than that of the control diet group. The weight of the high fat diet mice was roughly 12,9 % and 6,7 % higher than that of the control diet and high fat and fiber diet mice, respectively.

Table 4.17. Change in body weight of mice during the twelve weeks

Time (weeks)	Control diet group	High fat diet group	High-fat and fiber diet group
0 (*)	30,88±0,51^{aA}	31,37±0,41^{aA}	31,23±0,3^{aA}
2	31,37±0,55^{abA}	32,68±0,53^{bB}	32,01±0,31^{bA}
4	31,80±0,55^{bcA}	33,80±0,52^{cB}	32,69±0,28^{cC}
6	32,32±0,51^{cdA}	35,04±0,66^{dB}	33,55±0,36^{dC}
8	32,91±0,55^{deA}	36,22±0,6^{eB}	34,56±0,34^{eC}
10	33,46±0,48^{efA}	37,42±0,79^{fB}	35,25±0,37^{fC}
12	33,94±0,52^{fA}	38,32±0,64^{gB}	35,93±0,35^{gC}

The data are mean value ± standard deviation (n = 5). Values with different lowercase letters in the same column are significantly different ($p < 0,05$). Values with different uppercase letters in the same row are significantly different ($p < 0,05$), 0 (*) means the initial moment of the experiment.

3.3.3. Effects of high polydextrose snack on serum parameters of the mice

The serum triglyceride content of mice in high fat diet group was 2,6 and 2,0 times higher than that in the control diet and the high fat and fiber diet group, respectively (Table 4.18). Not surprisingly, the total cholesterol and low density lipoprotein cholesterol concentrations in the serum of the high-fat diet group were 1,3 and 2,0 times, respectively higher than those of the high fat and fiber diet group (Table 4.18). In addition, the high density lipoprotein cholesterol content in the serum of high fat diet group was meaningfully lower than that of the control diet and the high fat and fiber diet group. As a consequence, the high fat and fiber diet reduced hyperlipidemia in mice. Table 4.18 also shows that the glucose level of high fat diet group and high fat and fiber diet group were 2,6 and 1,6 times, respectively higher than that of the control diet group.

Table 4.18. Serum lipid profile and glucose concentration of mice in the three diet groups

Mice group	**Triglyceride (mg/dL)**	**Total cholesterol (mg/dL)**	**HDL-cholesterol (mg/dL)**	**LDL-cholesterol (mg/dL)**	**Glucose (mmol/L)**
CD	129,90±21,87[a]	148,89±10,11[a]	82,08±8,62[b]	41,50±5,7[a]	59,83±13,16[a]
HFD	334,62±32,44[b]	224,82±10,82[c]	57,0±6,19[a]	101,47±8,67[c]	158,39±21,61[c]
HFFD	164,21±13,15[c]	177,8±9,66[b]	94,43±9,45[c]	51,41±3,15[b]	97,38±8,85[b]

The data are mean value ± standard deviation (n = 5). Values with different small letters in the same column are significantly different (p < 0,05). CD: Control diet group, HFD: High-fat diet group, HFFD: High-fat and fiber diet group, HDL- and LDL-cholesterol is high density lipoprotein and low density lipoprotein cholesterol, respectively.

3.3.4. Effects of high polydextrose snack on liver function

The aspartate aminotransferase and alanine aminotransferase levels of mice treated with high fat diet were 79% and 83%, respectively higher than those of mice with the control diet (Table 4.19). Nevertheless, the mice with the high fat and fiber diet and the control diet had statistical similarity in alanine aminotransferase and aspartate aminotransferase activities.

Table 4.19. Liver weight, fat mass, AST and ALT of the mice

Mice group	**Liver weight(g)**	**Fat mass(g)**	**AST (U/L)**	**ALT (U/L)**
CD	1,44± 0,05 [a]	0,42±0,09[a]	132,1±28,25[a]	64,74±9,26[a]
HFD	2,17±0,14[c]	1,00±0,18[c]	236,58±15,5[b]	118,54±22,68[b]
HFDF	1,59±0,06[b]	0,73±0,08[b]	144,28±25,89[a]	59,26±12,72[a]

The data are the mean values ± standard deviation (n = 5). Values with different small letters in the same column are significantly different (p < 0,05); CD: Control diet group, HFD: High fat diet group, HFFD: High fat and fiber diet group, AST: aspartate aminotransferase, ALT: alanine aminotransferase.

The liver weight of the high fat diet fed mice was 51 % and 36 % higher than that of the control diet fed and high fat with fiber fed mice, respectively (Table 4.19). In addition, fat mass of the of high fat diet fed mice was 138 % and 37 % higher than that of the control diet and high fat and fiber diet fed mice, respectively. This result indicates that dietary fiber diet reduces the risk of hepatic steatosis in mice.

3.3.5. Effects of high polydextrose snack on fat accumulation and liver structure

At the end of the twelve week experiment, epididymal fat accumulation of the high fat diet group was higher than that of the control diet group (Fig 4.7). Supplementation with the high fat and fiber diet obviously decreased the adipocyte size in the liver tissue. Hematoxylin and eosin stained paraffin sections indicated normal hepatic architecture in clear hepatic sinusoid and clear hepatic lobule in the livers of the control diet fed mice (Fig 4.8a) whereas pathological symptoms were indicated in the high fat diet fed mice. With large and abundant lipid droplets in parenchymal cells, the liver cell appeared to have serious fatty degeneration along with inflammatory cell infiltration (Fig 4.8b). When the mice were fed with snack enriched in polydextrose for twelve weeks, the liver cell degeneration was ameliorated (Fig. 4.8c). Consequently, high polydextrose snack food had a positive effect on hepatic fatty degeneration in high fat diet mice.

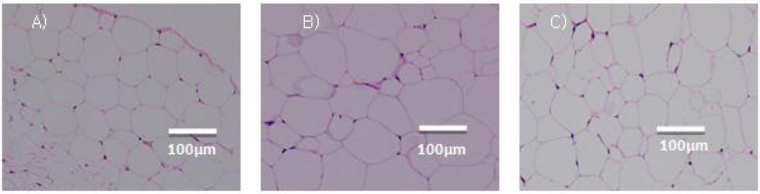

Figure 4.7. Histological analysis of epididymal fat tissue of three groups. Epididymal adipose segment; the tissues were magnified by 200 times; A) control diet group; B) high fat diet group; C): high-fat and fiber diet group.

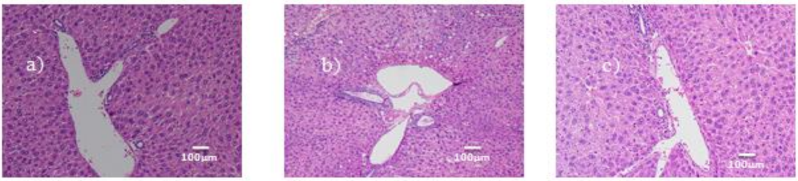

Figure 4.8. Micrographs of liver tissue of mice for 3 groups (×100); a) control diet group, b) high fat diet group, c) high fat diet and fiber diet group

CHAPTER 4. CONCLUSIONS & DISCUSSIONS

4.1. Conclusions

From the fundamental science point of view, it can be concluded that addition of commercial fiber preparations such as polydextrose, xanthan gum, gum acacia, inulin, resistant starch and resistant maltodextrin to the extrusion blend changed physical and sensory properties of the obtained snack but the color of the product remained almost constant.

When the polydextrose content in the blend varied from 0 to 10%, the bulk density of the fried extrudate increased by 22% while its radial expansion ratio and crispness decreased by 13% and 38%, respectively; the increase in fiber and lipid content was also quantified by 166% and 20%, respectively in comparison with that of the control sample.

When the screw speed was increased from 150 to 180 rpm, the radial expansion ratio and the crispness of the fried extrudate were enhanced by 18% and 73%, respectively while the bulk density and the hardness were reduced by 42% and 39%, respectively. The increase in screw speed resulted in increasing the water absorption index and the water solubility index of the product. The specific mechanical energy of the extrusion process also increased with the increasedscrew speed.

Increase in the die temperature from 60 to 100^{o}C reduced the product bulk density by 17% whereas enhanced the radial expansion ratio, the hardness and the crispness by 9,8%, 13% and 32%, respectively; high die temperature also resulted in large air cells and thin cell walls in the product texture as well as high absorption and water solubility index of the snack food.

The use of commercial oil preparations including citronella, nutmeg, clove and rosemary oil successfully prevented lipid oxidation of palm olein oil during the heating and extrudate frying process. Citronella, nutmeg, clove and rosemary oil preparations significantly retarded the formation of conjugated dienes and trienes as well as primary and secondary oxidation products of palm olein oil. Notably, the addition of nutmeg oil to palm olein oil resulted in the best oxidation stability among the tested natural antioxidant preparations. As the nutmeg oil concentration in the blend oil was higher, the prevention of oil oxidation during the heat treatment was better. The nutmeg oil concentration of

4 g/kg palm olein oil was able to maintain oxidation stability of the palm olein oil when the extrudate was fried for 15 batches and for 5 consecutive days. The quality of palm olein oil in the fryer and the fried extrudate was insignificantly different.

From the applied science point of view, it can be concluded that the appropriate ratio of polydextrose in the mixing blend, extrusion die temperature and screw speed were 7,5%, 100℃ and 180 rpm, respectively. The appropriate concentration of nutmeg oil in the palm olein oil during the snack frying was 0,4%.

The use of snack food enriched in polydextrose resulted in significant reduction of the body weight of mice induced by the high fat diet. The high fat and fiber diet also decreased the liver weight, the accumulation of lipid droplets in liver and the liver damage of the hyperlipidemic mice. On the other hand, use of high polydextrose snack in the high fat diet reduced the content of triglyceride, total cholesterol and low density lipoprotein cholesterol as well as the alanine aminotransferase and aspartate aminotransferase activities in the mice serum. Moreover, the diet with polydextrose added snack increased the high density lipoprotein cholesterol content in the mice serum. Accordingly, the diet with polydextrose added snack generated hepatoprotective and hypolipidemic effects on the hyperlipidemic mice.

4.2. Suggestion

Several research topics can be suggested to improve the quality of the high polydextrose snack and to diversify product development:

- Study on chemical transformations of fibers during the extrusion to clarify the effects of fiber material on the product texture.
- Study on the effects of feed moisture content on the quality of high fiber snack.
- Optimization of extrusion conditions by response surface methodology for improving physical properties of the high fiber snack.
- Replacement of frying by drying operation and investigating the effects of drying conditions on the quality of high fiber snack food.

PUBLISHED JOURNALS

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   Corn snack with high fiber content: Effects of different fiber types on the Product quality. *LWT - Food Science and Technology*, Vol. 96, pp.1–6 (SCI, Food Science, Q1)
2. Jin Han Yang, Thi Thu Tra Tran, Van Viet Man Le (2020)
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3. Jin Han Yang, Thi Thu Tra Tran, Van Viet Man Le (2019)
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