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Chemical, Physical, Nutritional and Sensory Properties of High Fiber Healthy Corn Snacks

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ABSTRACT

High fiber low calorie healthy snacks were prepared using yellow corn grits incorporated with different fiber sources (soybean, carrot and pea hulls). The fibers sources were added to the yellow corn grits at 10-40% fibers to 90-60% yellow corn grits. The effects of added fibers on chemical (moisture, protein, fat, ash, crude fiber, total dietary fiber and carbohydrate), physical (expansion index, bulk density, water absorption, water solubility indexes, color attributes and breaking strength), nutritional (protein digestibility, carbohydrate digestibility and calorific value) and sensory (appearance, aroma, color, taste and texture) characteristics of extruded products were evaluated. Adding the soybean fiber, to the yellow corn grits, enhanced the sensory characteristics of the final extruded products displayed a great ability to produce an excellent extrudates compared with other fiber sources.

Keywords: extrusion, low calorie snacks
Abbreviations: BD, bulk density; **BS**, breaking strength; **CF**, crude fiber; **CV**, calorific value; **EI**, expansion index; **TDF**, total dietary fiber; **WAI**, water absorption index; **WSI**, water solubility index

INTRODUCTION

Extrusion cooking (high temperature and short time) technology has been proved as an ideal tool to produce material into acceptable product (Ding *et al*. 2005). The extruder achieves high productivity in a single processing step, which cooks, forms and enhances the cost effectiveness of the process (Harper 1978). Extrusion has been used in the cereal industry for several years to produce many foods and food ingredients such as breakfast cereals, snacks, baby foods, pasta products, extruded bread, modified starches, beverages powders, meat and cheese analogues, textured vegetable protein, and blended foods such as corn starch and ground meats (Rhee *et al*. 1999). Dietary fiber is the constituents of the plant cell wall (Hipsley 1953). There are two main types of fiber; the first type is the water-insoluble fibers (lignin, cellulose and many hemicelluloses) and second type is the water-soluble fibers (pectin, gums, certain hemicelluloses and polysaccharides). Crude fiber is the residue after a food sample is treated with a hot acid and alkaline. Crude fiber is composed primarily of the lignin and most of the cellulosic compound in the food. Dietary fiber includes all components of a food that are not broken down by enzymes in the human digestive tract (Englyst *et al*. 1995).

There is a growing interest in increasing dietary fiber content in human healthy food (Ozer *et al*. 2004). Wolthuis *et al*. (1980) investigated a group of 62 young healthy volunteers, and found at least in short term controlled experiments fiber components from vegetables and fruits had a favorable effect on the concentration of serum cholesterol. Vegetables and fruits have a high percent of soluble fiber, which can affect blood glucose and lipid metabolism (Wolever 1990). Carrot fiber in the diet has beneficial effects both on fecal bulk and on the carbohydrate and lipid metabolism (Margarets *et al*. 1994). Low calorie foods are normally formulated by substituting low calorie bulking agents such as fiber for starches and other nutritive polysaccharides (Schmidle and Labuza 1985).

The present study was undertaken to investigate the effect of different fiber sources (soybean, carrot, and pea hulls) to produce new, low calorie, fiber-rich products using thermal extrusion process.

MATERIALS AND METHODS

Yellow corn (*Zea mays* L.) grits were obtained from the Arabic Medical Food Co., Ismailia, Egypt as a ready-to-make snack. Soybean (*Glycine max*) subgenus (*Glycine canescens*) fiber was obtained from soybean pilot plant located at Agriculture Research Center (ARC), Cairo, Egypt. Carrot (*Daucus carota*) subsp. *sativus* was obtained from local market, Cairo, Egypt. De-heading and trimming of the carrots were carried out manually using a vegetable knife. The juice was extracted from the carrots (by an Omega Juicer Model 02) and the carrot residue was used in the experiments (carrot residue was dried in a cabinet drier (Memmert Oven U30) at 65°C. Pea hulls (*Pisium sativum*) subsp. *arvense* were obtained from the local market and shelled. The outer hulls were washed, cut and dried at 60°C until moisture content reached 10%. All fibers were finely ground using a laboratory grinder (Durabrand model No. TSK-9368AP) and kept for 2 weeks in capped jars at room temperature for further analysis.

Blend preparation

Individual fibers were blended with yellow corn grits at a ratio of 0:100, 20:80, 30:70 and 40:60 (w/w). For pea hulls fiber the ratio was started at 10:90 because of the low expansion of the extrudate prepared by a higher ratio (20:80). The blends were mixed for 10 min using laboratory mixer to ensure homogeneity.

Extruder description and operation

All extrusion trials were carried out with a laboratory brabender

Received: 26 April, 2009. Accepted: 11 July, 2009.

Original Research Paper

Table 1 Proximate composition of extrudates.

Sample	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Crude fiber (%)	CHO	TDF
Control	7.87 ± 0.1 fg	7.1	0.57	1.13 ± 0.0 f	0.44 ± 0.1 h	76.37	6.96
A	8.96 ± 0.0 e	10.04	2.31	1.20 ± 0.3 e	4.13 ± 0.3 f	68.44	8.96
B	9.09 ± 0.0 e	13.37	2.43	0.83 ± 0.9 g	12.05 ± 1.0 c	58.22	16.06
C	10.31 ± 0.3 d	15.64	2.88	3.06 ± 0.1 a	12.52 ± 0.7 bc	41.15	26.96
D	11.52 ± 0.0 b	8.05	0.96	2.37 ± 0.3 cd	4.19 ± 0.1 f	72.47	4.63
E	10.93 ± 0.0 c	7.02	1.45	2.60 ± 0.1 bc	8.41 ± 0.2 d	68.16	9.84
F	8.23 ± 0.2 f	5.82	1.82	2.74 ± 0.1 b	9.09 ± 0.2 d	67.13	14.26
G	12.33 ± 0.1 a	8.09	1.08	0.71 ± 0.0 g	2.95 ± 0.3 g	76.79	1.00
H	11.33 ± 0.2 bc	7.63	1.17	1.53 ± 0.0 e	6.95 ± 0.1 e	71.52	6.82
I	11.22 ± 0.2 bc	6.49	1.26	2.23 ± 0.0 d	13.50 ± 0.5 b	66.55	12.25
J	7.58 ± 0.1 g	5.32	1.63	2.39 ± 0.1 cd	17.77 ± 0.3 a	65.99	17.09

Means followed by different superscript within a column are significantly different ($p \geq 0.01$).
CHO; total carbohydrate, TDF; total dietary fiber, Control; 100% yellow corn grits, A; 20% soybean fiber, B; 30% soybean fiber, C; 40% soybean fiber, D; 20% carrot fiber, E; 30% carrot fiber, F; 40% carrot fiber, G; 10% pea hulls fiber, H; 20% pea hulls fiber, I; 30% pea hulls fiber, J; 40% pea hulls fiber

single screw extruder 20 DN model No.823500 with feeding screw model No. 629299, the die was 3 mm model No.404268 Germany, available at the Food Technology Department, Faculty of Agriculture, Suez Canal University.

Proximate composition

Moisture, protein (N* 6.25), fat, ash, crude fiber and total dietary fiber (using Sigma assay kit No.TDF-C10, this assay includes a combination of enzymatic and gravimetric methods) contents were determined according to AOAC methods (AOAC 1990). Carbohydrate content was determined by difference. Calorific value was determined according to Schwedt (1991). *In vitro* carbohydrate digestibility was determined according to Singh *et al*. (1982). *In vitro* protein digestibility was determined according to (Saunders *et al*. 1973).

Physical properties

Expansion index (EI) was calculated as the ratio of the diameter of extrudate (measured using a screw guage, micrometer, stainless steel screw (rod) accurately machined. Brass body, dull nickel-plated finish 25 mm × 1 mm pitch) to that of the die (as in the extruder description in the method section). Bulk density (BD) was determined by measuring the weight of a known volume of the product, which was recorded by sand displacement in a measuring flask (Banarjee *et al*. 2003). Water absorption index (WAI) was determined according to Anderson *et al*. (1969). For WAI the extrudate was ground to pass through a 32 mesh sieve (Retsch test sieves ASTME 11-70) (05 mm opening). Further, 2.5 g of the ground sample was dispersed in 25 ml distilled water using a glass rod to break up any lump formation. The sample was kept in a water bath for 30 min. Water was drained out and the weight of the ground extrudate sample (W) was recorded: % WAI = [(W-2.5) x 100]/W. The supernatant was dried at 110°C, weighed and expressed as WSI. Color of the extrudates was assessed according to (AOAC 1990). Color attributes L^* (lightness), a^* (redness) and b^* (yellowness) were evaluated using a Hunter laboratory scan XE. Breaking strength (BS) of the extrudates was measured according to Abdel El-Hady and Habiba (1996), using a Brabender Structograph fitted with a 500 gram-force spring and a breaking tool (spindle #61913). The travel speed was 9 mm/min. Then the averages of 10 measurements were taken for each sample.

Sensory evaluation

Snack samples were evaluated by 32 trained panelists according to Abu-Foul (1990). The panelists were asked to indicate their observations using a 6-point hedonic scale for appearance, aroma, color, taste and texture. Excellent and very poor were ranked as 6 and 1, respectively.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) as well as Duncan's multiple range test according to Steel and Torrie (1960).

RESULTS AND DISCUSSION

Proximate composition

Proximate composition data of extrudates are summarized in **Table 1**. It is obvious that incorporation of fiber increased the moisture content of the extrudates compared with the control. This is might due to the ability of fibers to retain water in the product. The same trend was observed for fat contents which could be explained by the fact of forming starch-lipid complex. Also, protein content showed slight decrease compared to the control. Thermal processing of plant material may increase protein insolubility. Extrudate prepared with carrot or pea hulls fiber showed significant decrease in TDF contents. These results are in agreement with those obtained by Sanberg *et al*. (1986) who reported that mild extrusion conditions did not change the content of non-starch polysaccharides but decreased amount of lignin. Fornal *et al*. (1987) found significant decrease in hemicelluloses, cellulose, and lignin in extruded starch mixtures. In contrast, extrudates prepared with soybean fiber showed an increase in the content of TDF. These results are in agreement with those obtained by Theander and Westerlund (1987). CHO of the extrudates ranged from 41.15 to 76.79% and decreased by increasing the dietary fiber content.

Calorific values and *in vitro* digestibility of extrudates are presented in **Table 2**. The combustion energy of samples fall within a narrow range and reflect the energy that could be generated under human metabolic conditions.

In vitro carbohydrates and protein digestibility

Digestibility values were affected by the incorporation of fibers (**Table 2**). The highest value was recorded for the control. Increasing the percent of fiber incorporation caused remarkable reduction in carbohydrates digestibility in all

Table 2 Calorific value *In vitro* digestibility of extrudates.

Sample	Calorific value	Protein digestibility	Carbohydrate digestibility
Control	4.13	85.61	100
A	3.81	71.73	89.83
B	3.76	80.92	77.08
C	4.07	82.86	56.38
D	4.04	85.05	94.38
E	3.69	85.09	88.77
F	3.49	84.99	87.42
G	3.74	85.88	99.46
H	4.24	87.79	93.13
I	3.87	86.54	86.67
J	3.74	83.47	85.94

Control; 100% yellow corn grits, A; 20% soybean fiber, B; 30% soybean fiber, C; 40% soybean fiber, D; 20% carrot fiber, E; 30% carrot fiber, F; 40% carrot fiber, G; 10% pea hulls fiber, H; 20% pea hulls fiber, I; 30% pea hulls fiber, J; 40% pea hulls fiber

Table 3 Physical properties of extrudates.

Sample	EI	BD (g/100 ml)	WAI (%)	WSI (%)	Color		
					L	a	b
Control	2.60 ± 0.1 a	2.6 ± 0.1 a	7.52 ± 0.2 c	18.79 ± 1.3 e	85.3	-3	27.7
A	2.36 ± 0.0 a	2.36 ± 0.0 b	7.55 ± 0.6 c	20.38 ± 0.6 d	80.5	-0.9	19.2
B	2.19 ± 0.1 c	2.19 ± 0.1 c	6.62 ± 0.2 d	22.49 ± 0.2 c	78.7	0.1	19.4
C	0.97 ± 0.0 h	0.97 ± 0.0 h	8.28 ± 0.1 a	25.57 ± 0.1 a	67.5	-0.87	18
D	2.18 ± 0.0 c	2.18 ± 0.0 c	6.57 ± 0.1 d	18.57 ± 0.2 e	76.2	-0.94	23.7
E	1.89 ± 0.0 d	1.89 ± 0.0 d	7.48 ± 0.1 c	22.28 ± 0.1 c	75.5	1.8	23.4
F	1.28 ± 0.0 f	1.28 ± 0.0 f	5.90 ± 0.4 e	26.55 ± 0.1 a	74.6	0.1	20.8
G	1.95 ± 0.0 d	1.95 ± 0.0 d	5.38 ± 0.1 f	15.86 ± 0.1 f	71.5	-2.5	23.7
H	1.58 ± 0.0 e	1.58 ± 0.0 e	6.87 ± 0.1 d	18.60 ± 0.0 e	64.1	0.2	19.5
I	1.12 ± 0.0 g	1.12 ± 0.0 g	8.14 ± 0.1 ab	20.65 ± 0.1 d	59.0	0.3	20
J	1.14 ± 0.0 g	1.14 ± 0.0 g	7.84 ± 0.1 bc	23.54 ± 0.0 b	56.3	1.33	16.8

Control; 100% yellow corn grits, A; 20% soybean fiber, B; 30% soybean fiber, C; 40% soybean fiber, D; 20% carrot fiber, E; 30% carrot fiber, F; 40% carrot fiber, G; 10% pea hulls fiber, H; 20% pea hulls fiber, I; 30% pea hulls fiber, J; 40% pea hulls fiber

samples.

Increasing the fiber content caused a parallel increase of the protein digestibility ranging from 71.73 to 87.79% for all samples (**Table 2**). The extrusion process caused denaturation of protein due to the high temperature, high pressure and low moisture present during this process. Increasing the fiber percent caused a slight decrease in *in vitro* protein digestibility. An opposite trend was observed for soybean fiber, due to the nature of protein present as well as to the possible interaction between protein and the other components e.g. lipid (Bhattacharya and Hanaa 1988).

Physical analyses

EI: Starch granules are gelatinized and dispersed during extrusion, giving rise to formation of a continuous phase of the melt inside the extruder. Fibers such as bran are part of the dispersed phase of extrudates, embedded in the starchy continuous phase (Guy 2001). Expansion in extruded snacks can occur in both lateral and longitudinal directions during extrusion but generally it has been expressed as radial expansion in many studies (Ozer *et al*. 2004). Expansion, crispiness and extent of cooking are important parameters of a cereal-based extruded product (Ozer *et al*. 2004). The effect of dietary fiber and content on EI of extrudates is summarized in **Table 3**. The EI of starch depends mainly on its degree of gelatinization (Chinnaswamy and Bhattacharya 1983), which may be influenced by temperature, shear rate and moisture content of the feed material. Since the product was cut at a fixed speed the length and diameter of extrudate indicated the extent of its longitudinal and radial expansion. Increasing dietary fiber content in formulas resulted in decreased diameter of the extrudates, which is in agreement with the finding of a previous study (Anderson *et al*. 1991). Fibers are chemically unaltered by extrusion and affect expansion. Fibrous fragments disrupt the starchy film of air cell walls, reducing their formation, swelling, and altering air cell size (Huber 2001). Soybean fiber displayed the lowest reduction of expansion at an equivalent ratio compared with other tested sources. Pea hulls fiber showed the greatest reduction in expansion compare with other samples. This is because of the fibrous nature of the pea hulls fiber, which disrupts the matrix and hence cannot maintain the air pocket formed during flashing off the superheated vapor.

Bulk density for extrudates: Increasing the fiber content increased the bulk density of the extrudates, as shown in **Table 3**. Anderson *et al*. (1981) reported similar results for an extruded wheat starch bran product.

WAI and WSI of extrudates: Increasing the fiber content increased the WSI and WAI of the extrudates, as shown in **Table 3**. High WAI is an indicator of good starch digestibility as it implies a good extent of gelatinization and dextrinisation (Guha *et al*. 1997). Extrusion resulted in a greater increase in of WAI for corn grits extrudate values. For the extrudates supplemented with fiber a higher gelatinized starch in extrudate samples probably contributed to higher water absorption. Un-gelatinized starch, in its granular from will absorb only a small amount of water and is ordinarily found in discrete particles (Wang *et al*. 1993). Mok *et al*. (1984) reported that extrusion cooking did not affect water absorption capacity of wheat bran significantly perhaps because of its relatively low starch content. Increasing the WSI for extruded samples might be related to the lower molecular weight of components released from starch granules as well as the dietary fiber components. The WSI may be used to estimate the suitability of using extruded starchy products in suspensions or solution. Moreover, progressive degradation of starch is suggested is due to the increase in water solubility with a corresponding reduction in the water absorption capacity (Mok *et al*. 1984). This means that subsequent macromolecular degradation continues to increase the WSI but the swollen particles are no longer sedimented by the test to contribute to WAI. These results are in agreement with those obtained by Jin *et al*. (1994).

Color of extrudates: Color is a significant factor in consumer acceptance of foods and consumers automatically associate certain color characteristics with product quality. A significant difference of extrudates color is reported in **Table 3**. Samples with higher fiber concentration were generally 10-20 units lower than corn grits samples. The decrease in lightness with increasing fiber might have resulted from more browning reaction. This lightness reduction was more pronounced in pea hulls fiber-enriched extrudates. Comparison of the degree of redness of extrudates indicated that extrudates prepared using fibers within the tested range were significantly redder than those of extrudates prepared using corn only. The higher values of extrudates may also be attributed to the presence of the red to brown pigments that naturally exist in the fiber. So, the colors of extrudates were mainly influenced by the initial color of the fiber. Values of b of extrudates ranged from 27.7 to 16.78. Extrudates tend to have lower b values indicating a lower degree of yellowness than those of corn extrudates. The reduction in yellowness with increasing fiber contents might have been caused by the pigments present in the fiber ingredients that had much less yellowness. Furthermore, the reduction in the degree of yellowness was less in extrudates prepared with carrot fiber, which may be due to the additional concentration of carotene pigments. El-Samahy *et al*. (2007) used orange-yellow and red cactus pear pulps to produce a product of rice-based extrudates. They found the same trend in the extrudate samples.

BS of the extrudates: The results are presented in **Table 4** with respect to the effect of fiber source on BS of extrudates: at a low fiber percent the product behaves similar with all fiber sources while at a higher fiber percent carrot showed the lowest BS (230 BU at 40%) this is a result of its

Table 4 Breaking strength (BU) of extrudate.

% of incorporation	Breaking Strength (BS)		
	Soybean fiber	Carrot fiber	Pea hulls fiber
10%	-	-	>1000
20%	>1000	>1000	>1000
30%	830	>1000	540
40%	800	230	420

microstructure which can be represented at relatively week cells embedded in a strong continuous matrix. Bhattacharya and Hanaa (1988) stated that the extrudate component interaction during extrusion were responsible for changing shear strength.

Sensory evaluation: Sensory evaluation was conducted to evaluate differences in typical appearance, aroma, color, taste and texture. Thirty-two trained panelists were evaluated the prepared snacks. Sensory data are summarized in **Table 5**. The appearance of extrudates has a great effect on the overall acceptability of the product. Extrudates of excellent characteristics should possess an evenly distributed golden color and should be free of cracked surfaces and flour particles. Moreover, surfaces should look shiny and feel smooth. It was noted that as the amount of fiber in the extrudate increased the appearance sensory score decreased. Extrudates made with pea hulls fiber received significantly lower scores compared with the equivalent portion of fiber used. Panelists scored the aroma of extrudate made with soybean or carrot fiber significantly higher than extrudate prepared with pea hulls fiber. These extrudates smell acceptable and possess a pleasant aroma. Panel members detected a non-typical aroma for the extrudate made with pea hulls fibers, which was possibly the cause of decrease in its acceptability. However, preference for quality of food appears to be dependent on the context in which the cultural preference differences are evident, most probably as a function of the different dietary experiences of different cultures (Prescott and Bell 1995).

With regard to color, extrudates prepared with 20% soybean fiber received the highest score after control. Panelists scored the aroma of extrudate made with soybean or carrot fiber significantly higher than of extrudate prepared with pea hulls fiber. These extrudate smell acceptable and possess pleasant aroma. With regard to color, extrudates prepared with 20% soybean fiber received the highest score after control.

CONCLUSION

Results from this study demonstrated that healthy high fiber low calorie snacks could be prepared from the incorporation of some fiber sources to yellow corn grits. The type and/or the ratio of added fiber also affected the properties of extrudates. Furthermore, extrudates made with soybean and carrots received significantly higher scores compared with others.

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Table 5 Sensory evaluation of extrudates.

Product	Overall acceptability	Appearance	Aroma	Color	Taste	Texture
Control	90.81 a	18.53 a	17.53 a	18.58 a	17.94 a	18.22 a
A	65.77 b	13.06 b	12.78 b	13.53 b	12.59 b	13.81 b
B	63.25 b	12.50 bc	12.75 b	11.97 bc	12.56 b	13.47 b
C	38.54 de	7.00 ef	9.13 d	6.47 e	8.26 d	7.66 e
D	60.91 b	12.69 b	12.50 bc	12.81 bc	11.50 bc	11.41 cd
E	62.29 b	12.0 bc	12.75 b	12.63 bc	12.25 b	12.63 bc
F	62.10 b	10.9 c	13.13 b	11.53 c	12.41 b	14.09 b
G	47.32 d	8.69 d	10.63 cd	8.5 d	9.59 d	9.91 d
I	40.00 de	5.78 f	9.56 d	6.56 e	8.44 d	9.66 d
J	47.08 cd	7.59 de	11.09 bcd	7.69 de	10.09 cd	10.62 d

Control; 100% yellow corn grits, A; 20% soybean fiber, B; 30% soybean fiber, C; 40% soybean fiber, D; 20% carrot fiber, E; 30% carrot fiber, F; 40% carrot fiber, G; 10% pea hulls fiber, H; 20% pea hulls fiber, I; 30% pea hulls fiber, J; 40% pea hulls fiber

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