Potato Peel Dietary Fiber Composition: Effects of Peeling and Extrusion Cooking Processes

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Potato peels are a potential source of dietary fiber. The abrasion peeling method used by chip manufacturers results in more starch and less dietary fiber than the steam peeling procedure used for production of dehydrated potatoes. The objective of this study was to identify differences in dietary fiber composition between these types of peels and the effects of extrusion on fiber. Peels were extruded in a twin screw extruder at barrel temperatures of 110 or 150 °C and feed moistures of 30% or 35%. Extrusion cooking reduced starch content and increased total dietary fiber in steam peels. Total dietary fiber in abrasion peels was not affected by extrusion. Extrusion increased soluble nonstarch polysaccharides in both types of peels. More glucose was recovered from insoluble fiber of extruded steam peels than from abrasion peels, suggesting that resistant starch may have been formed. Lignin increased in extruded steam peels but decreased in extruded abrasion peels.

Keywords: *Dietary fiber; starch; peeling; potato; extrusion*

INTRODUCTION

Dietary fiber-rich materials have gained popularity as food ingredients for health benefits, yet relatively little is known about the effects of food processing on fiber and its components. Extruded foods with high fiber contents include ready-to-eat breakfast cereals, snack foods, and crispbreads. Extrusion has also been used to process agricultural byproducts such as rice bran (Randall et al., 1985), corn bran (Artz et al., 1990), and potato peels (Arora et al., 1993) to improve their functionality as high-fiber ingredients. Extrusion is a high-temperature, short-time process that heats foods under pressure. Extruder operating conditions such as barrel temperature, screw configuration, screw speed, and feed moisture level affect extrudate quality by causing chemical changes in the food matrix.

The selection of a fiber analytical method should consider the specific fractions of fiber of interest, however. Different fiber methods measure different fractions of total dietary fiber. For example, the nonstarch polysaccharides procedure excludes lignin, while the AOAC enzymatic−gravimetric methods fail to distinguish among the categories of polysaccharides, including resistant starch. Significant chemical changes due to extrusion could be overlooked if an insensitive procedure is used to isolate and identify fiber. In general, extrusion appears to solubilize dietary fiber (Camire et al., 1990). However, Artz et al. (1990) found no difference in corn bran fiber after extrusion using the AOAC total dietary fiber (TDF) method. Changes in fiber solubility may have nutritional consequences, and research in this area has been inconclusive thus far.

Potato chip manufacturers typically employ abrasion peeling, while frozen and dehydrated potato processors use steam-peeling. These methods differ in the amount of tuber flesh removed with the peel and in heat exposure. The objective of this study was to evaluate the effects of peeling method on fiber composition (uronic acids, neutral sugars, and lignin) of the peel before and after extrusion, particularly with respect to interactions with starch. This information could be used to prepare peel fiber material for specific functional and nutritional applications.

MATERIALS AND METHODS

Potato Peels. Washed Idaho Russet Burbank potatoes were abrasion-peeled (AP) or steam-peeled (SP) under standard industry conditions and dried to a moisture content of 4−5% in a fluidized bed drier. The peels were ground and passed through a 0.5 mm mesh prior to shipment to the University of Maine.

Extrusion. Ground peels were passed through a K-Tron feeder at a rate of 11.4 kg/h. A Werner-Pfleiderer ZSK-30 corotating twin screw extruder with a 4 mm × 9 mm circular die was used to process peels. Barrel bore diameter was 30.9 mm. The screws were 879 mm long. Extruder screw configuration has been described previously (Arora et al., 1993). Screw speed was 300 rpm; cutter speed was 581 rpm.

Two factors were studied in addition to the peeling method: final barrel temperature (110 and 150 °C) and feed moisture (30% and 35%, dry basis). Barrel temperature varied along the length of the extruder barrel: 31−41−66−96−110−110−110 °C or 31−49−82−107−128−150−150 °C. Extruder conditions are given in Table 1. The extruder was started with cornmeal and gradually switched over to a 50−50 blend of peels and corn. Within 15 min, peels only were fed. Samples were collected when extruder operation became stable, as indicated by steady torque, usually within 10 min after parameter changeover. Extrudates were collected in duplicate into plastic bags and dried at 93 °C in a Kenmore electric oven. Dried extrudates were ground to pass a 0.5 mm screen using a Wiley mill.

Proximate Analyses. Ash was determined by AOAC method 923.03 (1990). Crude fat was determined by AOAC method 920.39C; crude protein was determined by AACC method 46−13 (1983), modified by use of a copper sulfate−sodium sulfate catalyst and a 50 mL, not 125 mL, Erlenmeyer flask to which 10 mL distilled water was added. A Fisher

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Table 1. Potato Peel Extrusion Conditions and Moisture Content after Extrusion[a]

peel method	barrel temp[b] °C	feed moisture %	melt temp °C	torque %	die pressure kPa	peel moisture[c] %
steam	110	30	146	39	115	21.7
steam	110	35	138	34	80	28.6
steam	150	30	150	37	70	23.0
steam	150	35	145	31	70	28.1
abrasion	110	30	125	43	115	26.3
abrasion	110	35	124	37	85	31.8
abrasion	150	30	151	37	70	22.5
abrasion	150	35	146	33	60	28.7

[a] Average of duplicates. [b] Final barrel temperature. [c] Average of two readings per duplicate without additional drying.

Table 2. Proximate Composition of Dried Potato Peels[a]

	peeling method	
	abrasion	steam
ash	7.73	6.01
lipid	0.56	1.07
protein ($N \times 6.25$)	16.72	18.55
moisture	5.50	3.73

[a] %, dry basis.

Table 3. Starch Content of Potato Peels

abrasion sample		steam sample	
	starch (%)[a]		starch (%)[a]
not extruded	51.03^{f}	not extruded	27.95^{d}
110 °C, 30%	51.80^{f}	110 °C, 30%	25.85^{c}
110 °C, 35%	49.72^{e}	110 °C, 35%	24.09^{b}
150 °C, 30%	51.29^{f}	150 °C, 30%	23.69^{b}
150 °C, 35%	49.77^{e}	150 °C, 35%	21.68^{a}

[a] Dry basis. Mean values followed by different letters are significantly different ($p \leq 0.05$, Fisher's least significant difference test).

Isotemp Model 350 convection oven was used to measure moisture by loss in weight after drying at 105 °C for 17 h. Moisture was calculated by AACC method 44-01 (1983). All proximate analyses were conducted in triplicate for each type of peel.

Starch. AACC method 76-11 (1983) was used to measure starch in all peels, both extruded and nonextruded. Extraction of sugars with 80% ethanol prior to analysis prevented adequate digestion. Therefore, a set of duplicate samples were prepared. One set was not digested with amyloglucosidase. The free glucose from nondigested test portions was subtracted from glucose values obtained for nonextracted, digested peels.

Dietary Fiber. AACC proposed method 32-25 was modified in our laboratory. Test portion weights (as is) were 400 mg for abrasion peels and 350 mg for steam peels to account for differences in fiber content. Two measurements of soluble and insoluble fiber were made for each test sample and extrusion duplicate. Soluble fiber was not dialyzed as recommended but was precipitated with 30 mL absolute ethanol and held for 1 h. The precipitate was washed and centrifuged as for insoluble fiber to form pellets. Soluble fiber pellets were hydrolyzed with 35 mL of 1 M H_2SO_4 in a boiling water bath for 1 h. Insoluble fiber replicates were autoclaved separately to provide an estimate of error due to autoclaving. A quantity of 2 μL of a sugar standard solution (per liter: maltose, 1 g; cellobiose, 1 g; glucose, 2 g; xylose, 1.5 g; arabinose, 1.5 g; rhamnose, 1 g; mannose, 1.5 g; galactose, 1.5 g) was added to 77 mL of 2 M H_2SO_4 as a recovery indicator for each autoclaving batch. The myoinositol standard (2 mg/mL) was added after autoclaving and filtration steps before hydrolysates were diluted with water to 100 mL.

Lignin residues in the glass filtration crucibles were washed with 50 mL of 80% ethanol to remove residual sugars (Flint and Camire 1992). Uronic acids were measured as in AACC 32-25. Reducing sugars in hydrolysates were measured colo-

Table 4. Dietary Fiber Composition of Potato Peels[a]

	soluble				insoluble			
	reducing sugar	uronic acid	lignin	total fiber	reducing sugars	uronic acid	lignin	total fiber
Abrasion Sample								
raw	1.38 ± 0.44^{a,b}	1.22 ± 0.24^{a}	0.00 ± 0.00^{a}	2.60 ± 0.68^{a}	11.00 ± 0.33^{c}	7.20 ± 0.61^{c,d}	5.80 ± 0.18^{c}	24.00 ± 0.76^{c}	26.60 ± 0.09^{a}
110 °C, 30%	1.72 ± 0.20^{b}	3.30 ± 0.37^{b}	0.00 ± 0.00^{a}	5.02 ± 0.54^{b}	9.84 ± 0.68^{b}	5.78 ± 0.18^{b}	4.31 ± 0.46^{a,b}	19.93 ± 0.79^{b}	24.94 ± 0.99^{a}
110 °C, 35%	1.54 ± 0.21^{a,b}	3.57 ± 0.65^{b}	0.00 ± 0.00^{a}	5.11 ± 0.43^{b}	10.32 ± 0.16^{b,c}	6.52 ± 0.56^{c}	3.92 ± 0.20^{a}	20.77 ± 0.60^{b}	25.88 ± 1.01^{a}
150 °C, 30%	1.98 ± 0.70^{b}	4.82 ± 0.50^{d}	0.00 ± 0.00^{a}	6.79 ± 0.58^{c,d}	9.39 ± 0.75^{a}	4.95 ± 0.51^{a}	4.24 ± 0.55^{a,b}	18.59 ± 1.09^{a}	25.38 ± 1.35^{a}
150 °C, 35%	1.79 ± 0.59^{b}	4.37 ± 0.44^{c,d}	0.00 ± 0.00^{a}	6.16 ± 0.17^{c}	9.46 ± 0.64^{a}	5.55 ± 0.61^{a,b}	4.76 ± 0.72^{b}	19.76 ± 1.04^{a,b}	25.92 ± 1.13^{a}
Steam Sample									
raw	1.68 ± 0.53^{b}	3.70 ± 0.35^{b,c}	0.00 ± 0.00^{a}	5.38 ± 0.88^{b,c}	21.48 ± 0.93^{d}	10.11 ± 0.52^{e}	19.52 ± 0.16^{d}	51.11 ± 1.29^{d,e,f}	56.5 ± 2.17^{b}
110 °C, 30%	0.87 ± 0.13^{a}	5.69 ± 0.04^{e}	0.00 ± 0.00^{a}	6.55 ± 0.54^{c,d}	21.88 ± 0.14^{d}	10.40 ± 0.06^{e}	18.64 ± 0.90^{d}	50.92 ± 0.99^{f}	57.47 ± 0.45^{b,c}
110 °C, 35%	1.38 ± 0.07^{a,b}	5.61 ± 0.40^{e}	0.20 ± 0.28^{c}	7.19 ± 0.74^{d,e}	21.67 ± 0.11^{d}	9.93 ± 0.78^{e}	21.36 ± 0.59^{e}	52.95 ± 0.30^{e,f}	60.13 ± 0.44^{d,e}
150 °C, 30%	2.02 ± 0.44^{b}	6.00 ± 0.30^{e}	0.01 ± 0.01^{b}	8.03 ± 0.44^{e}	21.32 ± 0.10^{d}	7.73 ± 0.31^{d}	22.17 ± 0.51^{e,f}	51.22 ± 0.51^{d,e}	59.24 ± 0.47^{c,d}
150 °C, 35%	1.52 ± 0.31^{a,b}	5.60 ± 0.48^{e}	0.09 ± 0.19^{b,c}	7.22 ± 0.43^{d,e}	21.82 ± 0.26^{d}	9.87 ± 0.48^{e}	22.41 ± 0.73^{f}	54.10 ± 1.46^{f}	61.32 ± 1.50^{e}

[a] Percentage dry basis. Means ± standard deviations followed by different letters within the same column are significantly different ($P < 0.05$, LSD test).

Table 5. Peeling Method and Extrusion Effects on Fiber Components of Potato Peels

		probabilities of a greater F value[a]								
		soluble				insoluble				
factor	degrees of freedom	reducing sugars	uronic acids	lignin	total fiber	reducing sugars	uronic acids	lignin	total fiber	TDF
peeling method (P)	1	0.083	0.000	0.065	0.000	0.000	0.000	0.000	0.000	0.000
barrel temp (T)	1	0.015	0.001	0.550	0.000	0.036	0.000	0.000	0.529	0.057
feed moisture (M)	1	0.611	0.372	0.780	0.356	0.289	0.001	0.003	0.000	0.000
$P \times T$	1	0.255	0.010	0.550	0.096	0.249	0.234	0.001	0.014	0.160
$P \times M$	1	0.586	0.679	0.078	0.634	0.730	0.668	0.006	0.052	0.007
$T \times M$	1	0.144	0.156	0.488	0.009	0.706	0.004	0.104	0.408	0.567
$P \times T \times M$	1	0.154	0.575	0.488	0.353	0.154	0.002	0.002	0.715	0.910
error	20									

[a] Probabilities ≤0.05 are considered significant.

Table 6. Monosaccharide Composition of Dietary Fiber of Abrasion-Peeled Potatoes

BT[a]	MC[b]	type[c]	rhamnose	arabinose	xylose	galactose	glucose
110	30	I	ND	0.70	0.28	2.04	6.03
110	30	S	ND	ND	ND	ND	0.28
110	35	I	0.07	0.97	0.57	1.99	6.63
110	35	S	ND	ND	ND	ND	0.23
150	30	I	ND	0.88	0.13	1.66	5.67
150	30	S	ND	ND	ND	ND	2.22
150	35	I	ND	1.02	0.42	1.77	6.29
150	35	S	ND	ND	ND	ND	0.42
not extruded		I	ND	0.97	ND	2.06	5.71
not extruded		S	ND	ND	ND	ND	ND

[a] Barrel temperature. [b] % moisture. [c] Insoluble (I) or soluble (S) dietary fiber. [d] None detected.

Table 7. Monosaccharide Composition of Dietary Fiber of Steam-Peeled Potatoes

BT[a]	MC[b]	type[c]	rhamnose	arabinose	xylose	galactose	glucose
110	30	I	0.18	1.75	1.56	1.53	13.86
110	30	S	ND	ND	ND	ND	ND
110	35	I	0.25	2.00	1.65	1.88	15.81
110	35	S	ND	ND	ND	ND	ND
150	30	I	0.32	2.00	1.69	1.84	16.13
150	30	S	ND	ND	ND	0.44	ND
150	35	I	0.22	2.09	1.83	1.80	16.16
150	35	S	ND	ND	ND	0.40	ND
not extruded		I	0.27	2.07	1.77	2.41	14.60
not extruded		S	ND	ND	ND	ND	ND

[a] Barrel temperature. [b] % moisture. [c] Insoluble (I) or soluble (S) dietary fiber. [d] None detected.

rimetrically (Englyst and Cummings 1988) and by gas chromatography (GC).

Analysis of Sugar Composition. Hydrolysates of the fiber precipitates were stored at −14 °C. After thawing at 4 °C, insoluble fiber hydrolysates were filtered through Gelman nylon 0.45 μM acrodisks and passed through a Waters C18 Plus sep-pack to remove proteins and other compounds that might interfere with sugar analysis. The resulting filtrates were as clear as soluble fiber hydrolysates. Filtrates were derivatized into alditol acetates according to AACC 32-25.

A Hewlett-Packard 3396A integrator and a HP Model 5890 gas chromatograph were used with a Supleco SP 2330 glass capillary 30 m long, 0.75 mm i.d. column with a 0.20 μm thick coating. Gas chromatograph conditions were as specified in AACC 32-25 with the exception that hydrogen, not helium, was used as the carrier gas.

Statistical Analysis. Extruded samples were compared as a 2 × 2 × 2 factorial (peeling method × barrel temperature × feed moisture) analysis of variance and Fisher's least significant difference test (LSD) at the 5% level of significance. The factorial treatments were combined into six treatments and compared with nonextruded peels as a one-way analysis of variance with mean separation by Fisher's LSD at $P < 0.05$.

RESULTS AND DISCUSSION

Proximate Composition. Abrasion peels (AP) contained more ash and moisture, but steam peels (SP) contained greater lipid and protein concentrations (Table 2). Carbohydrate content, determined by difference, was 70% and 72% for AP and SP, respectively.

Starch. AP had about twice as much starch as did SP (Table 3), since more potato flesh is removed during the abrasion process. AP extruded at 35% moisture had lower starch levels than did raw (nonextruded) AP or AP extruded at 30% moisture. Feed moisture, barrel temperature, and the interaction of the peeling method with barrel temperature were significant effects. Starch loss due to extrusion was greater in SP than for AP. The brief exposure to steam during peeling may have partially gelatinized starch molecules, thereby facilitating degradation during extrusion.

Dietary Fiber Components. Soluble reducing sugars in fiber decreased only in SP extruded at 110 °C and 30% moisture content (m.c.) (Table 4); for all other extruded samples soluble sugars increased. Barrel temperature was the only significant factor for soluble sugars, but peeling method and barrel temperature significantly affected insoluble sugar composition (Table 5). Insoluble sugars were reduced in extruded AP, but no difference was found between extruded and raw SP. Lue et al. (1991) reported decreased insoluble fiber after extrusion with no net change in total fiber content of cornmeal and sugar beet fiber mixtures. Rhamnose,

arabinose, xylose, and glucose were relatively higher in SP than in AP (Tables 6 and 7).

Extrusion significantly increased uronic acids in the soluble fiber portion. Insoluble uronic acids were significantly reduced in most AP samples, but only SP extruded at 150 °C and 30% m.c. were significantly different from raw SP. Barrel temperature had a greater effect on AP. No change in total uronic acids after extrusion has been reported previously for wheat flour (Theander and Westerlund 1987), cornmeal, oatmeal, or potato peels (Camire and Flint 1991), but Ralet et al. (1990) found lower soluble glucuronic acid levels in extruded wheat bran. Uronic acids in cereals are recovered from hemicelluloses, not pectins, while pectins are the primary source of acid sugars in potatoes. The branched structure of pectin may be more susceptible to shear during extrusion. A similar change occurs during starch extrusion; amylopectin is more prone to shear-induced depolymerization than is amylose (Camire et al., 1990). Extrusion-induced changes in pectin structure could produce functional and nutritional changes as a consequence. Gourgue et al. (1994) reported dramatic increases in water-soluble uronic acids after extrusion of orange and lemon peels that were associated with increased viscosities. No effect on in vitro starch hydrolysis or glucose diffusion was found.

Soluble lignin recovered from a few samples may have been artifacts of the analysis. Extrusion increased total soluble fiber by about 3% in all test samples except SP extruded at 110 °C and 30% m.c. Lignin decreased in extruded AP but increased in SP extruded at 110 °C and 35% m.c. and at 150 °C. Lignin increased in wheat brans extruded under conditions leading to high specific mechanical energy (Ralet et al., 1990). This increase suggests that high shear within the extruder modifies carbohydrates and other compounds into new materials that are as insoluble and resistant to digestion by enzymes and acid as is lignin. Since the Klason lignin procedure does not identify "true" lignin, further study of the identity of these newly formed compounds should be pursued.

Total insoluble fiber decreased in AP. Total dietary fiber in AP was not affected by extrusion. Fiber became more soluble with no net loss or gain in the sum of insoluble and soluble components. Extrusion increased total dietary fiber in all SP except those processed at 110 °C and 30% m.c. The net gain, however, was only 3−4%. Starch loss in SP ranged from 2 to 6%, and formation of resistant starch or starch−fiber complexes during extrusion may be responsible for some of the lost starch. Lignin was the largest single contributor to total dietary fiber increases.

The physiological implications of ingesting extrusion-modified fiber are not clear. Serum and liver cholesterol levels were lower in rats fed extruded wheat, oats, or barley, as compared with rats fed raw grains or a no-grain diet (Wang and Klopfenstein, 1993). Extrusion did not significantly alter TDF, IDF, or SDF but did increase the viscosity of suspensions of those grains. Information on the distribution of specific fiber fractions was not available. Soluble fiber increased slightly in extruded potato peels, but in vitro bile acid binding was more strongly correlated with IDF (Camire et al., 1993). Extrusion did not affect the ability of the potato peels in this study to bind the carcinogen benzo[*a*]pyrene (Camire et al., 1995).

Extrusion cooking conditions modify dietary fiber composition, but the presence of other macromolecules influences changes as well. Knowledge of the prior processing history may be important in predicting the compositional changes due to extrusion. Further information is needed before a suitable predictive model can be developed. In particular, the interactions between starch and fiber molecules should be critically evaluated.

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