Introduction

Extrusion has been used to produce a wide variety of foods such as snacks, ready-to-eat cereals, textured vegetable protein, confectioneries, and pet foods. To increase protein content and nutritive value, various protein sources such as fish or peanut flour can be included in snack formulations prior to extrusion. Fish protein has an excellent nutritive value because it contains essential amino acids and is highly digestible (Haard 1995). Moreover, fish is a good source of fat-soluble vitamins such as vitamin E, found in flesh, and vitamin A and D, found in liver (Exler and Weihrauch 1976). Fish also contains several polyunsaturated fatty acids such as linoleic acid, eicosapentaenoic acid, and docosahexaenoic acid (Exler and Weihrauch 1976; Erickson 1992; Ackman 1995). Additionally, fish flavor is desirable in snacks produced for the international market. Peanut is a good source of protein and essential fatty acids, such as oleic acid and linoleic acid (Adsule and others 1989). Peanut oil contains 76 to 82% oleic acid, and 30 to 35% linoleic acid (Woodroof 1983). It is also an excellent source of certain minerals (for example, phosphorus, calcium, magnesium, and potassium) and vitamins (such as thiamine, riboflavin, biotin, and folic acid) (Adsule and others 1989).

Extrusion has both advantages and detrimental effects on the nutritional quality of food. The changes in the chemical and nutritional qualities during extrusion-cooking have been reviewed by Bjorck and Asp (1983), Chemtel (1986), and Camire and others (1990). Reviews on the effect of extrusion-cooking, especially on nutritional quality of plant proteins, were also reported by Phillips (1989) and on vitamin retention, as reported by Killeit (1994). Vitamins have different stability properties because of their different chemical structures (Killeit 1994). Degradation of vitamins is dependent on factors encountered during food processing and storage, such as temperature, oxygen, light, moisture, pH, and exposure time. Killeit (1994) reported that the retention of vitamins decreased during extrusion, with an increase in barrel temperature and screw speed and a decrease in moisture content, throughput, and die diameter. The present study seeks to extend these observations to a previously uninvestigated system: tapioca starch mixed with either peanut flour or fish tissue that is processed in a twin-screw machine to produce half-products, then expanded by deep-fat frying.

Vitamin A can be characterized as a long chain alcohol (Ottaway 1993). It is sensitive to oxidation in the presence of oxygen, light, heat, and catalysts of oxidation (Olson 1990; Ottaway 1993). The ester forms, such as retinyl palmitate (RP) and retinyl acetate, are more stable than retinol; therefore, they are used for food fortification (Olson 1990; Eitenmiller and Landen 1999). The beadlet forms of vitamin A are produced with gelatin, starch, gums, and other components or a combination of ingredients as encapsulating agents to add oxidation stability and modify functional properties (O’Brien and Robertson 1993).

Vitamin E is an essential nutrient which is functional as an antioxidant. In foods, tocopherols are used as antioxidants because the hydroxyl group of the chromanol ring in tocopherols acts as an electron donor or a free-radical acceptor. This reaction can delay the rate of oxidation of antioxidative species (Nawar 1985; Counsell 1993) by suppressing the formation of lipid peroxyl radicals, and preventing propagation of the chain reaction (Sherwin 1978; Burton and Ingold 1896). The antioxidant activity of γ- and β-tocopherols is higher than that of α- and β-tocopherols in most matrices (Nawar 1985; Rankin and Pike 1993; Giese 1996).

Both saponification and direct solvent extraction can be used to extract vitamins A and E from food materials prior to quantification (Ball 1988; Eitenmiller and Landen 1995, 1999). Because of simplicity, cost and time-saving abilities, direct solvent extraction is often chosen over saponification as the extraction method of choice. A solvent or solvent mixtures appropriate for vitamin A and E extraction must effectively penetrate the tissue and break lipoprotein bonds, while minimizing oxidative destruction, in order to efficiently remove vitamin components from the food matrix (Ball 1988; Eitenmiller and Landen 1995, 1999). Landen (1982) successfully developed a method for the determination of RP and α-tocopherol acetate in infant formulas, using the solvent mixture of isopropanol and methylene chloride. Vitamins were separated by high-pressure gel permeation chromatography prior to quantification on reversed-phase liquid chromatography (LC). Recently, Lee and others
(1999) analyzed all-rac-α-tocopheryl acetate, tocopherols, and RP in extruded weaning foods, using isopropanol and hexane/ethyl acetate as an extracting solvent, followed by quantification with normal-phase LC. The recoveries for RP and all-rac-α-tocopheryl acetate were 98.6% and 103.2% for extruded soybean products, respectively. Likewise, Lee and others (1998) successfully applied direct solvent extraction to the analysis of vitamin E in peanuts and tree nuts.

Suknark and others (1999) previously reported the successful production of fish- and peanut-based snacks using twin-screw extrusion. These foods were found to be acceptable by consumers (Suknark and others 1998). Since such extruded foods can be used to deliver micronutrients, the objective of this study was to determine the stability of RP and tocopherols in both fish- and peanut-based foods during extrusion and frying.

**Materials and Methods**

**Tapioca starch**

Tapioca starch was obtained from National Starch and Chemical Co., Bridgewater, N.J., U.S.A.

**Minced fish**

Catfish were purchased live and filleted at the DeKalb Farmer Market in Atlanta, Georgia. Belly flaps and fillets prepared from catfish were minced in a belt-and-drum mechanical meat separator (Yasagiya Machinery Work Ltd., Yamaguchi PREF., Japan). The mince was sealed in Ziploc® bags, stored at −18°C and thawed at 7°C for 12 h, prior to use.

**Partially defatted peanut flour (PDPF)**

Partially defatted peanut flour (PDPF), obtained from Pert Laboratories, Edenton, N.C., U.S.A., was further ground in a hammer mill (Model 6×14, Champion Products, Inc., Eden Prairie, Minn., U.S.A.) which was equipped with a 1.6 mm screen. The PDPF was sealed in plastic bags and stored at 7°C until used.

**Tocopherols and RP**

Tocopherols were added to the extrusion mixtures to act as antioxidants during the production of half-products. Mixed natural tocopherols in powder form were provided by Henkel Corporation (Kankakee, Ill., U.S.A.). The powder contained at least 30% by weight of natural α-, β-, γ-, and δ-tocopherol on a gum acacia carrier. Dry vitamin A palmitate, Type 250-SD in beadlet form (250,000 IU/g) was provided by Hoffmann-La Roche Inc. (Nutley, N.J., U.S.A.). The dry vitamin A palmitate contained RP, modified starch, sucrose, fractionated coconut oil, butylated hydroxytoluene (BHT), sodium benzoate, and sorbic acid. Tocopherols were added at 0.02% by weight of the fat content of the finished products (Nawar 1985), based on preliminary experiments showing fat content in final products to be 37 to 41%. Tocopherol addition assumed a final fat content of 41%. RP was added to the ingredient mixture to provide approximately 250 retinol equivalents per serving (28 g) in the finished products. This concentration of vitamin A provides approximately 25% of the Required Daily Allowance (RDA) for adults (FAO 1996).

**Reagents and standards**

The α-, γ-, and δ-tocopherol standards, all-trans RP, and BHT were obtained from Sigma Chemical Co. (St. Louis, Mo., U.S.A.). The β-tocopherol was obtained from Henkel Corporation (La Grange, Ill., U.S.A.). All the chemicals and solvents were of high-performance liquid chromatography (HPLC) grade. Hexane, isopropanol, ethyl acetate, and anhydrous magnesium sulfate were obtained from J.T. Baker Co. (Phillipsburg, N.J., U.S.A.).

**Sample preparation**

Approximately 8-kg batches of tapioca and minced fish were prepared by blending 60% tapioca starch and 40% minced fish (4.8 kg tapioca starch and 3.2 kg minced fish). The tocopherols and RP were manually and thoroughly mixed with 20 g of tapioca starch. Then, the vitamin pre-mix was blended with additional tapioca starch until a final vitamin pre-mix of 500 g was prepared. The 500 g of vitamin pre-mix were slowly and gradually added and blended with the rest of the tapioca starch in a mixer (Model N-50G, Hobart Mfg. Co., Troy, Ohio, U.S.A.). The mixer was equipped with a flat beater and operated at low speed (Speed 1) for 15 min. Then, minced fish was added and mixed for 15 min. At this time, the mixture contained approximately 36% water. The moisture content was adjusted to 40% (wet basis) by adding water. After blending, the ingredient mixture was packed in 3.25-ml plastic bags (Curilon® Grade 863, Curwood, Oshkosh, Wis., U.S.A.) and these were stored at −18°C. Before processing, the mixtures were thawed at 7°C for 12 h. Each fish blend was prepared in duplicate batches.

Approximately 8-kg batches of the peanut flour mixture were prepared by mixing 60% tapioca starch and 40% PDPF without water (3.31 kg tapioca starch and 2.20 kg PDPF). Tocopherols and RP were added (as described above for the fish product). Five-hundred grams of vitamin pre-mix were slowly and gradually added and blended with the rest of the tapioca starch and PDPF in a mixer (Model N-50G, Hobart Mfg. Co., Troy, Ohio, U.S.A.) which was equipped with a flat beater, and operated at low speed (Speed 1) without water addition for 30 min. The moisture content of this blend was adjusted to 40% directly in the extruder during the extrusion process with a calibrated, proportioning pump (Type N-P31, Bran & Lubbe, Buffalo Grove, Ill., U.S.A.). This approach was used because the tapioca starch/PDPF blend became sticky and difficult to feed, if adjusted to 40% water prior to extrusion. After blending, the mixture was packaged, stored, and thawed as described for the fish-based product. Each peanut blend was also prepared in duplicate.

**Extrusion processing**

A co-rotating twin-screw extruder (Model MPF 1700-30, APV Baker Ltd., Newcastle-U-Lyne, England) with a length-to-diameter ratio of 25:1 was used. The length and diameter of the extruder barrel were 750 and 30 mm, respectively. The slit die had dimensions of 1 mm × 20 mm. The extruder had a clam-shell barrel consisting of 4 independent temperature zones controlled by electrical heating, and 1 controlled zone at the die. Cooling water was circulated through the extruder barrel jacket and the die holder to maintain temperature. The barrel at the feed hopper was not heated and was maintained at 25 to 30°C by cooling water. Dough temperature was measured by thermocouples which extended through the barrel and contacted the moving material at 3 locations. Pressure at the slit die and torque were recorded. Material was fed into the extruder inlet port with a K-Tron® volumetric feeder (Model K2VT20, K-Tron Corp., Pitman, N.J., U.S.A.). The feeder was calibrated to determine the set point to give a feed rate of 27 g/min total materials for all experimental runs. A screw configuration with feed screws and forward paddles was set up to use for both formulations (as described in the previ-
ous study by Suknark and others, 1999). The water pump was calibrated to determine the set point to give a 40% moisture content for the PDPF mixture. Each duplicated batch was extruded twice in separate runs.

Upon exiting the die, extrudates were cut into 15-cm lengths and dried in a Lincoln Impinger oven (Model 1450, Lincoln Foodservice Products, Inc., Fort Wayne, Ind., U.S.A.) at 90 °C for 10 min to remove surface moisture and prevent sticking. The extrudates were sealed in Ziploc freezer bags and stored at −18 °C prior to drying. The extrudates were cut into approximately 2.0 × 0.1 cm² pieces before being dried in a forced air oven (Blue M Electric Co., Blue Island, Ill., U.S.A.) at 50 °C for 5 h to obtain half-products with 10 to 12% moisture content.

**Deep-fat frying**

One liter of soybean oil was heated in a Kitchen Kettle fryer (Model 06000, National Presto Industries, Inc., Eau Claire, Wis., U.S.A.) for 30 min to obtain equilibrium temperature of 200 ± 5 °C. Half-products weighing 20 g each (26 to 30 pieces) were deep-fat fried for 1.5 min. After frying, the fried products were drained on paper towels and cooled at ambient temperature. Products were drained on paper towels and cooled at ambient temperature. Each (26 to 30 pieces) were deep-fat fried for 1.5 min. After frying, the fried products were drained on paper towels and cooled at ambient temperature. The extrudates were placed in air-tight glass containers, and bags, flushed with nitrogen gas, then stored at −18 °C.

**Experimental design**

Two formulations, a fish mixture and a PDPF mixture, were extruded, using the optimum condition of temperature and screw speed (which were selected from the consumer acceptances in a previous study) (Suknark and others 1998). Tocopherols and RP were added to duplicate formulations. The fish formulation was extruded at temperature in the last two zones, near the die and at the die, of 97 °C at screw speed of 265 rpm. The PDPF formulation was extruded at temperature in the last two zones, near the die and at the die, of 100 °C at screw speed of 250 rpm. The temperatures of the first (near the feed hopper), second, and third zones were set at 60, 90, and 120 °C, respectively. Moisture content of the mixtures was adjusted to 40% (wet basis) and the feed rate was 27 g/min.

The mixtures of raw materials, the extrudates immediately after extrusion, the half-products (extrudates dried at 50 °C), and the fried products were sampled and sealed in Ziploc freezer bags, flushed with nitrogen gas, then placed in air-tight glass containers, and stored at −18 °C. Samples of soybean oil before and after frying were placed in screw-cap test tubes, flushed with nitrogen gas, then stored at −18 °C. All analyses were conducted in duplicate on samples from each extrusion run.

**Proximate analysis of extruded products**

The half-products and fried products were analyzed for proximate composition. Moisture content was determined according to Procedure 925.09 of the AOAC (1995). Fat content was extracted with petroleum ether for 18 h, using a Goldfisch extractor (Model 35001, Laboratory Construction Co., Kansas City, Mo., U.S.A.), according to Procedure 30.25 of the AACC (1976).

**Water activity**

Water activity in half-products and fried products was determined using an AquaLab Water Saturated magnesium chloride and sodium chloride solution was used to calibrate the equipment.

**Tocopherol and RP analysis**

In the tocopherols’ and RP’s standards preparation, purity and stability of the standards were measured by a Beckman DU-64 Spectrophotometer® (Fullerton, Calif., U.S.A.). The specific extinction coefficient (E 1%1 cm) of the all-trans RP standard in isopropanol, which exhibits the maximum ultraviolet (UV) absorption, is 960 at 326 nm (Olson, 1990). The E 1%1 cm of α-, β-, γ-, and δ-tocopherol’s standard in ethanol are 71 at 294 nm, 86.4 at 297 nm, 92.8 at 298 nm, and 91.2 at 298 nm, respectively (Scott 1978).

Stock standard solutions were prepared by an accurately weighed standard and dissolved in hexane with 0.01% BHT. Each stock standard was prepared separately. The working standard solution of tocopherols was prepared from a stock standard solution diluted with hexane-BHT solution containing 4 combined tocopherols. The RP working standard solution was prepared separately by diluting stock solution with 0.01% BHT in hexane.

**HPLC quantification**

The normal-phase HPLC system consisted of an LC-6A pump equipped with an RF-10A spectrofluorometric detector (Shimadzu Corp., Columbia, Md., U.S.A.), and a SpectraSeries AS100 autosampler (Thermo Separation Products Inc., Calif., U.S.A.), and a 25 cm × 4 mm, 5 µm Lichrosorb Si60 column (Hibar Fertigsaule RT., Darmstadt, E.R. Germany) which was equipped with a pre-column packed with Perisorb A 30-40 µm (Darmstadt, E.R. Germany). The isocratic mobile phase contained 0.9% isopropanol in n-hexane, obtained from J.T. Baker Chemical Co., Phillipsburg, N.J., U.S.A.. The flow rate was 1.0 mL/min. The mobile phase was filtered using a 0.22 µm nylon membrane filter.
Sensory and Nutritive Qualities of Food

during extrusion was 39%.

tocopherol in fish extrudate was significant decrease in tocopherols occurred during extrusion.

tocopherol forms were found in the mixture of fish-and-tapioca starch raw material, which was fortified with mixed natural tocopherols. Gamma-tocopherol was found in the highest amount (7.02 mg/100 g) in the PDPF-and-tapioca starch mixture. The α-, γ-, and δ-tocopherols were reduced significantly (p < 0.05) during extrusion. Moreover, the γ- and δ-tocopherols decreased more than the α- and β-tocopherols (which was similar to the findings in the fish extrudate). However, the reduction of tocopherols in the peanut extrudate was lower than the reduction of tocopherols in the fish extrudate during extrusion. The reduction of α-, β-, γ-, and δ-tocopherols in peanut extrudate during extrusion was 18, 11, 28, and 30%, respectively. The reduction of total tocopherol in the peanut product during extrusion was 27%. The varying stability of the various forms of tocopherol is a complex function of the matrix and processing conditions. An insignificant loss of all tocopherol forms was found in the peanut half-products during drying (similar to the results noted for the fish half-products). Fried peanut snacks contained the highest amount of tocopherols within the series, as was true with the fish snacks.

During extrusion, the fish and peanut mixtures were extruded under slightly different conditions. The fish mixture was extruded at a temperature in the last two zones of 97 °C at screw speed of 285 rpm, whereas the peanut mixture was extruded under conditions of 100 °C and 250 rpm. These conditions were chosen based on observations made during preliminary studies. However, the exiting product temperature from the extruder of both formulations was observed to be in the range of 91 to 93 °C. A lower reduction of tocopherol in peanut extrudate compared to fish extrudate during extrusion was probably due to the difference in fatty acid composition in the different raw materials. The most predominant fatty acids occurring in fin-fish were reported to be palmitic acid (C16:0), oleic acid (C18:1), and the highly polyunsaturated fatty acid in the n-3 family, such as eicosapentaenoic acid (C20:5) and docosahexaenoic acid (C22:6) (Exler and Weihrauch 1976).

Erickson (1992) reported that the predominant fatty acid in the total lipid fraction for three catfish strains was oleic acid, and the predominant polyunsaturated fatty acids were linoleic acid (C18:2) and docosahexaenoic acid. Fish oil contains more highly polyunsaturated fatty acids that are more susceptible to oxidation, which results in the reduction of tocopherol (Machlin 1990; Li and others 1996). The susceptibility to rancidity and the rate of autoxidation increase as the number of double bonds increases in the fatty acid (Machlin 1990; Erickson 1992).

Hakansson and others (1987) studied the effect of extrusion-cooking on vitamin E in white flour from wheat with two conditions: mild condition (148 °C and 24.6% moisture content), and severe condition (197 °C and 14.6% moisture content). These two extrusions were conducted at a screw speed of 200 rpm and feed rate of 318 g/min. They found that the losses of both α-tocopherol and α-tocotrienol in the mild and severe conditions were about 85 to 87% and 94%, respectively. The losses of β-tocopherol and β-tocotrienol were about 63 to 67% in the mild condition and 78% in the severe condition, which were lower than in the α-tocopherol and α-tocotrienol. The loss of α- and β-tocopherols in that study was higher than those in the fish and peanut extrudates of this study.

### Table 1—Tocopherols (mg/100 g) and retinyl palmitate (mg/100 g) of fish snack products in different steps of extrusion process

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tocopherol</th>
<th>Retinyl palmitate</th>
<th>Raw material</th>
<th>α</th>
<th>β</th>
<th>γ</th>
<th>δ</th>
<th>Total tocopherol</th>
<th>Retinyl palmitate*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>mixture</td>
<td>1.67 b</td>
<td>0.25 b</td>
<td>7.02 b</td>
<td>3.75 b</td>
<td>12.79 b</td>
<td>2.65 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.23)</td>
<td>(0.02)</td>
<td>(0.15)</td>
<td>(0.07)</td>
<td>(0.07)</td>
<td>(0.28)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>Extradate</td>
<td>1.28 c</td>
<td>0.18 c</td>
<td>4.17 c</td>
<td>2.24 c</td>
<td>7.75 c</td>
<td>1.44 b</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>immediately</td>
<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.31)</td>
<td>(0.12)</td>
<td>(0.46)</td>
<td>(0.11)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>after extrusion</td>
<td>1.22 c</td>
<td>0.15 c</td>
<td>4.12 c</td>
<td>2.17 c</td>
<td>7.66 c</td>
<td>1.34 b</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half-product</td>
<td>(0.04)</td>
<td>(0.01)</td>
<td>(0.24)</td>
<td>(0.13)</td>
<td>(0.42)</td>
<td>(0.08)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fried product</td>
<td>2.70 a</td>
<td>0.57 a</td>
<td>25.61 a</td>
<td>13.54 a</td>
<td>42.30 a</td>
<td>1.38 b</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.08)</td>
<td>(0.07)</td>
<td>(0.14)</td>
<td>(0.26)</td>
<td>(0.43)</td>
<td>(0.04)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Numbers in parentheses represent the standard deviations. Means within the same column with different letters are significantly different (p < 0.05).

* Mean values in fat-free dry basis

### Results and Discussion

**The direct solvent extraction of tocopherols and RP in extruded samples, using hot isopropanol and hexane/ethyl acetate at the ratio of 85:15, proved to be a reliable method of sample extraction. This method eliminated saponification which hydrolyzes the ester linkage and produces some interfering compounds in the extract (Tuan and others 1989), and emulsion.

Recovery of tocopherols in the samples was 100.43 ± 8.02%. Recovery of RP was 95.85 ± 4.28%.

**Effect of extrusion and frying on vitamin E**

In the fish snack, the content (dry basis) of individual tocopherols (α-, β-, γ-, and δ-tocopherol) and total tocopherol are shown in Table 1. All tocopherol forms were found in the mixture of fish-and-tapioca starch raw material, which was fortified with mixed natural tocopherols. Gamma-tocopherol was found in the highest amount (7.02 mg/100 g) and β-tocopherol was found in the lowest amount (0.25 mg/100 g). A significant decrease in tocopherols occurred during extrusion (Table 1). Decreases were about 40% for γ- and δ-tocopherols and 23 and 28% for α- and β-tocopherols, respectively. The reduction of total tocopherol in fish extrudate during extrusion was 39%.

With the exception of β-tocopherol, the loss of tocopherols during drying was in the range of 1 to 5%. The contents of all tocopherols in half-products were not significantly different (p > 0.05) from the extrudates. After frying at 200 °C for 1.5 min, the fish snacks contained all tocopherols at a significantly higher level than samples at other points of the process, because samples absorbed the soybean oil.

In the peanut snack, the individual tocopherol and total tocopherol contents (dry basis) of the peanut snack are given in Table 2. It shows the significant difference of the vitamin content during snack production. γ-tocopherol was found in the highest amount (8.6 mg/100 g) and β-tocopherol in the lowest amount (0.27 mg/100 g) in the PDPF-and-tapioca starch mixture. The α-, γ-, and δ-tocopherols were reduced significantly (p < 0.05) during extrusion. Moreover, the γ- and δ-tocopherols decreased more than the α- and β-tocopherols (which was similar to the findings in the fish extrudate). However, the reduction of tocopherols in the peanut extrudate was lower than the reduction of tocopherols in the fish extrudate during extrusion. The reduction of α-, β-, γ-, and δ-tocopherols in peanut extrudate during extrusion was 27%. The varying stability of the various forms of tocopherol is a complex function of the matrix and processing conditions. An insignificant loss of all tocopherol forms was found in the peanut half-products during drying (similar to the results noted for the fish half-products). Fried peanut snacks contained the highest amount of tocopherols within the series, as was true with the fish snacks.

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Table 2—Tocopherols (mg/100 g) and retinyl palmitate (mg/100 g) of peanut snack products in different steps of extrusion process

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tocopherol</th>
<th>Total tocopherol</th>
<th>Retinyl palmitate*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>α</td>
<td>β</td>
<td>γ</td>
</tr>
<tr>
<td>Raw material mixture</td>
<td>1.60 b</td>
<td>0.27 b</td>
<td>8.58 b</td>
</tr>
<tr>
<td>Extrudate immediately</td>
<td>1.32 c</td>
<td>0.24 bc</td>
<td>6.15 c</td>
</tr>
<tr>
<td>fried product</td>
<td>1.26 c</td>
<td>0.20 c</td>
<td>6.03 c</td>
</tr>
<tr>
<td>Half-product</td>
<td>0.08</td>
<td>0.02</td>
<td>0.21</td>
</tr>
<tr>
<td>Fried product</td>
<td>0.08</td>
<td>0.02</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Numbers in parentheses represent the standard deviations. Means within the same column with different letters are significantly different (p ≤ 0.05).

* Mean values in fat-free dry basis

Table 3—Tocopherols (mg/100 g) of soybean oil before and after frying fish and peanut snack products

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tocopherol</th>
<th>Total tocopherol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>α</td>
<td>β</td>
</tr>
<tr>
<td>Oil before frying</td>
<td>6.16 a</td>
<td>0.49 a</td>
</tr>
<tr>
<td>Oil after frying</td>
<td>5.77 b</td>
<td>0.49 a</td>
</tr>
<tr>
<td>fish snack</td>
<td>5.83 b</td>
<td>0.49 a</td>
</tr>
<tr>
<td>peanut snack</td>
<td>0.12</td>
<td>0.49 a</td>
</tr>
</tbody>
</table>

Numbers in parentheses represent the standard deviations. Means within the same column with different letters are significantly different (p ≤ 0.05).

Effect of frying on vitamin E in soybean oil

The tocopherol content of soybean oil (before and after frying) of the sample is presented in Table 3. The predominant tocopherol homologue detected in soybean oil was γ-tocopherol which was followed by δ-, α- and β-tocopherols, respectively. After soybean oil was heated at 200 °C for 30 min to obtain equilibrium temperature, the half-products were fried for 1.5 min. A significant reduction of total tocopherol content in soybean oil occurred during use (Table 3). The reduction of tocopherols ranged from 2 to 9%.

Effect of extrusion and frying on vitamin A

In the fish snack, RP contents in the samples were calculated based on a fat-free dry basis. RP in the raw fish mixture, which was fortified with dry vitamin A palmitate, decreased significantly during extrusion. The reduction of RP was about 46% (a reduction of 2.65 to 1.44 mg/100 g, as shown in Table 1). Drying at 50 °C for 5 h and frying at 200 °C for 1.5 min did not significantly affect the contents of the RP. Extrudate immediately after extrusion, half-product, and fried product contained a significantly lower RP content than the raw material mixture. Measured on a fat-free basis, the products contained 1.38 mg/100 g RP, which was a 48% reduction from the initial amount in the raw material. Retinol was not detected in the samples at any point in the fish snack production, as indicated by its absence in chromatograms. Therefore, extrusion did not hydrolyze the ester linkage of RP.

In the peanut snack, extrusion and drying did significantly affect the RP content (fat-free dry basis) in the samples (Table 2). The reduction of RP in peanut extrudates during extrusion and drying was 20 and 12%, respectively. The fat-free fried product contained 2.00 mg/100 g RP (dry basis) which was about a 27% reduction from the initial amount in the raw material. Retinol was also not found in any samples of peanut production.

Vitamin A is susceptible to oxidation in the presence of oxygen, and the development of off-flavors accompanies its degradation (Arya and Thakur 1990). Lee and others (1978) studied the stability of vitamin A and provitamin A (carotenoid) during extrusion at a cooking temperature of 130 °C and a screw speed of 700 to 1,000 rpm. They reported that β-carotene destruction was about 75% after extrusion, which made it uneconomical to add a provitamin A source before extrusion. The retention of vitamin A acetate and vitamin A palmitate were 90 to 100 and 52 to 91%, respectively. Low screw speeds provided long extrusion residence time and increased vitamin A destruction at 130 °C. Cheftel (1986) noted that an increase in screw speed at low moisture content probably increased vitamin destruction, because shear force increased temperature. However, an increase in screw speed at high moisture content might decrease the vitamin destruction due to the significant effect from short residence time.

Chemical and nutritional qualities of extruded products

Fat content, moisture content, and water activity of half-products and fried products are presented in Table 4. Both fish and peanut half-products contained low fat content of 3.84 and 4.69%, respectively. Water activity of half-products (0.60 to 0.66) were higher than fried products (0.15 to 0.16). Fish and peanut fried products had high fat content (37%). Tocopherol and vitamin A in fish snacks per serving (25 to 28 g) were about 15, and 14 to 15% of the RDA, respectively. Tocopherol and vitamin A in peanut snacks per serving (25 to 28 g) were about 16, and 22% of RDA, respectively.

Conclusions
ed fatty acids in fish. A direct solvent extraction, using isopropanol and hexane/ethyl acetate as an extracting solvent, efficiently extracted both tocopherols and RP simultaneously.

References


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