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The Effect of Heat Treatments on Dietary Fiber As Assessed by Chemical Analysis and Scanning Electron Microscopy

Ming-Cheng Chang
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Ming-Cheng Chang entitled "The Effect of Heat Treatments on Dietary Fiber As Assessed by Chemical Analysis and Scanning Electron Microscopy." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

William C. Morris, Major Professor

We have read this thesis and recommend its acceptance:

Carol A. Costello, John R. Mount, Mary Sue Younger

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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THE EFFECT OF HEAT TREATMENTS ON DIETARY FIBER AS ASSESSED BY CHEMICAL ANALYSIS AND SCANNING ELECTRON MICROSCOPY

A Thesis
Presented for the
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Degree
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Ming-Cheng Chang
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ABSTRACT

Today it is generally accepted by many nutritionists that dietary fiber plays an important role in human health. Increased consumption of dietary fiber is advocated for beneficial effects on human health; thus food technologists and the food industry are interested in the use of fiber as an ingredient in food products and in the manufacture of high fiber foods. Numerous researchers have concentrated on the physiological effects of dietary fiber, while few have investigated the effect different processing parameters have on dietary fiber.

Apple fiber, corn fiber, oat bran, and soy fiber were prepared and analyzed after further processing (autoclaving at 121°C for 15 minutes, 100°C for 30 minutes, and microwave heating for 5 and 10 minutes) to study the effect heat processing has on dietary fiber fractions of the products. Unprocessed samples were analyzed as controls. The samples were analyzed for insoluble, soluble, and total dietary fiber by an enzymatic-gravimetric method. Photomicrographs were taken with a scanning electron microscope.

Autoclaving significantly reduced insoluble dietary fiber of apple fiber, and total dietary fiber of apple fiber and oat bran. Microwave heat treatment resulted in a significant reduction of total dietary fiber in apple fiber and oat bran. The microwave heat also caused a decrease in the insoluble dietary fiber of oat bran, but caused an increase in the soluble dietary fiber of apple fiber. All processing treatments appeared to decrease the soluble dietary fiber

content in corn fiber. The scanning electron micrographs showed structure differences between processed and unprocessed apple, corn, oat, and soy samples. Increased processing generally produced more cracking and furrowing on the surface of the fiber which resulted in an increase in the fiber's surface area. The increased surface area was indicated in the photomicrographs.

This study demonstrates the effects heat processing has on different fiber sources. Results indicate the effect of processing on dietary fiber is dependent upon the fiber source and the processing conditions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

CHAPTER I

INTRODUCTION

Dietary fiber includes all the components of food that are not broken down by enzymes in the human digestive tract to small molecular weight compounds which are absorbed into the blood stream (Kelsay et al., 1978; Rasper, 1979; Slavin, 1987; Trowell, 1972, 1978). It is generally accepted by many nutritionists that dietary fiber plays an important role in human physiological responses (Anderson, 1985; Behall et al., 1984; Chen et al., 1981; Lithell et al., 1984; Moak et al., 1987). These responses include an increase in fecal bulk, lowering of plasma cholesterol and nutrient bioavailability, and reduced occurrence of constipation and diverticular diseases. Physiological studies in humans have shown how the effects of dietary fiber on a number of diseases can be related to the physical and chemical properties of different compounds (Cummings et al., 1978; McConnel et al., 1974).

The Federation of American Societies of Experimental Biology has recommended daily consumption of 20 to 35 grams of dietary fiber from various fruits, whole grains, and legumes (Andres, 1987). Growing consumer awareness of the nutritional attributes of dietary fiber has lead to an increased demand for high fiber products. This is already having a profound effect on food technology and the food industry. Consequently, more raw fiber is being incorporated into processed foods as a functional ingredient. However, manufacturing

and processing conditions or home preparation may affect the physical and chemical forms of the fiber which in turn may alter its physiological role in the human body (Payne, 1987; Weber and Chaudhary, 1987). Research has been conducted on various functional properties of fiber, including substitution, water holding capacity, and oil holding capacity (Babcock, 1987; Childs and Abajian, 1976; Collins and Post, 1981; Polizzoto et al., 1983). Schneeman (1986) concluded that the physical state of fiber is related to its physiological role such as binding of organic compounds, ion exchange capacity, and water holding capacity. Many studies have compared the relationship of the physiological effects to the content and chemical composition of various dietary fibers (Anderson, 1985; Anderson et al., 1987; Cummings, 1987; Mueller, et al., 1983; Rapser, 1979; Selvendran, 1984). However few studies have investigated the effect various processing techniques or heat treatments have on the dietary fiber content and the insoluble/soluble ratio in foods.

One of the objectives of this research was to investigate the effect different processing treatments have on the insoluble dietary fiber, soluble dietary fiber, and total dietary fiber content when analyzed by an enzymatic-gravimetric method (Prosky et al., 1988). Another objective was to investigate any structural differences on the surface of the fiber, that could be attributed to processing, when viewed by scanning electron microscopy. Research must still be performed on dietary fiber before we can understand its complex role in food systems and human nutrition.

CHAPTER II

REVIEW OF LITERATURE

The term dietary fiber, introduced 36 years ago by Hipsley (1953), does not describe a single chemical component, but rather a heterogeneous mixture of substances found mainly in the cell walls of plants. Trowell (1972) described dietary fiber as the skeletal remnants of plant cells that are not hydrolyzed by the alimentary enzymes of man. Trowell et al. (1976) expanded the definition to include all plant polysaccharides and lignin that are not digested in the upper gastrointestinal tract of man. The above definition only includes dietary fiber from plant cell walls. However, dietary fiber includes several complex polysaccharides: cellulose, gums, hemicellulose, lignin, mucilage, and pectic substances.

Dietary fiber is derived from various tissues of fruits, vegetables, cereals, or legumes, therefore, it is not easy to draw general conclusions about the physicochemical characteristics of dietary fiber. In addition to the chemical role played by dietary fiber in a biological system, the physical properties (particle size, surface, water-holding capacity, and ion-exchange capacity) of dietary fiber may be equally as important in the physiological role. Fiber-supplemented foods have been formulated by using dietary fiber from fruits, woods, cereals, and legumes to manufacture high fiber food ingredients which are then used in various food systems. Normally, dietary fiber is subjected to cooking or heat processing like

pressure cooking, baking, frying, microwave heating or extrusion cooking prior to consumption. Numerous researchers have concentrated on the chemical, nutritional, and epidemiological nature of dietary fiber, while few studies have investigated the effect of processing on the various fractions of dietary fiber.

1. Physiological Effects

High fiber containing foods are being promoted for various health benefits and have recently become the subject of increased public attention. The fiber present in apples and apple juice has been shown to reduce the insulin response to the sugar within it in humans (Haber et al., 1977). Bolton et al. (1981) reported that the plasma insulin and glucose response to fruit appear to be dependent on the fiber and the glucose content of fruit. Chen et al. (1981) reported that oat bran lowered plasma and liver cholesterol, and oat bran gum caused greater reductions in plasma and liver cholesterol than oat bran when fed to laboratory rats. Oat fiber products also have been shown to reduce serum cholesterol concentration in humans (Van Horn et al., 1986). Split peas and freeze-dried peas also have been reported to lower plasma cholesterol in humans (Gormley et al., 1979; Grande et al., 1965). Oats, pinto, and navy beans have demonstrated a significant cholesterol lowering effect for persons with hypercholesteremia (Anderson, 1985). However, corn bran has been shown not to lower cholesterol in humans (Munoz et al., 1979),

and cellulose has similarly not been shown to lower cholesterol levels in humans (Behall et al., 1984; Kaur et al., 1981).

In the treatment of diabetes and hyperlipidemia, some studies (Behall et al, 1984; Lithell et al, 1984) have shown that soluble fibers (e.g., guar gum, pectin, and oat bran) are more clinically effective than insoluble fibers (e.g., cellulose and wheat bran). Oat bran is a good source of water soluble fiber (Schneeman, 1987; Seibert, 1987). Fruits, whole grain products, and legumes have been recommended as excellent source of dietary fiber for weight reduction (Anonymous, 1979).

2. Application of Dietary Fiber

A variety of new "high fiber" foods have come into the market place, and are selling at increasing rates. Because of inadequate data on the physical and chemical composition of various fiber sources and the resultant physiological effect of the fiber, it is difficult to make a rational, scientific recommendation as to the quantity or type of dietary fiber that should be consumed (Bingham, 1987). Increased consumption of dietary fiber has been advocated for some beneficial effects on human health (i.e., diverticulitis, cancer, constipation, high blood cholesterol, etc.), thus some researchers have concentrated on the addition or supplementation of fiber to food products such as bread, cereal, and snacks.

Because apple has the highest crude fiber content of fruits, is produced in large quantities, and has favorable absorptive

characteristic from its high pectin content, apple fiber has been utilized in various products as a thickener or texture modifier (Duxbury, 1987; Hang, 1987; Morris, 1985). Apple fiber was found to have a higher water binding capacity than wheat and oat bran (Chen et al., 1988). Corn, high in insoluble dietary fiber, is being used frequently in snack food production (Gould, 1985). Krishnan et al. (1987) found that the bread with 10% substitution of the wheat flour with oat bran had better loaf volume, grain, and texture. Cellulose, a recognized food additive, is often used as a thickener or an emulsifier. Cellulose and the water it holds dilute the calories in products, resulting in a lower caloric content than other products with less or no fiber. Cookies and muffins are other baked products that show excellent potential for inclusion of dietary fiber as an ingredient. High-fiber bread increases water absorption in proportion to the increment of corn bran replacement of 5 to 20% wheat flour, but wild oat bran did not show the same degree of water absorption as corn due to a lower water hydration capacity (Sosulski and Wu, 1988).

3. Effects of Cooking

The effect of cooking on the fiber content of foods is still unclear (Asp et al., 1982; Matthee and Appledorf, 1978; Varo et al., 1984; Zyren et al., 1983). Since some browning products are analyzed as lignin, cooking can cause browning reactions that increase the apparent fiber content of the food. Canned vegetables may have

higher fiber contents than those of fresh vegetables because browning reactions may occur with cooking during thermal processing. Also, water may be lost from the vegetables during the processing of the canned product. Englyst et al. (1982, 1983) proposed that resistant starch is produced as a result of subjecting foods to heat or dehydration processes, conferring more ordered structures on starch molecules which are less amenable to enzyme digestion. If a food component is not digested, then it would be considered part of dietary fiber. Bjorck et al. (1984) studied the effect of extrusion cooking on wheat fiber and found that raw wheat flour had 40% soluble dietary fiber, but the extruded flour had 50 to 75% soluble dietary fiber. Thermal processing made a small amount of the starch less available to enzymes and increased the dietary fiber value (Bjorck et al., 1984; Varo et al., 1983). Jones et al. (1985) found the content of starch resistant to hydrolysis by enzymes to increase significantly by 30 to 50% in cooked versus raw potatoes.

4. Measurement of Dietary Fiber Content

The fiber content of foods or food products have historically been determined by the crude fiber procedure (AOAC, 1984). Only part of the dietary fiber (cellulose and lignin) is actually measured in this procedure. Total dietary fiber consists of nonstarch polysaccharides and lignin with smaller amount of minerals, plant lipids, protein, and other substances. Many analytical methods have been devised, reviewed and discussed (Anderson and Clydesdale,

1980; Asp et al., 1983; Englyst and Cummings, 1984; Englyst et al., 1982; Halvarson and Alstin, 1984; Monte and Vaughan, 1982; Olson et al., 1987; Prosky et al., 1984, 1985; Schneeman, 1986; Southgate, 1978; Theander and Westerlund, 1986). The method devised by Prosky et al. (1985) has been adopted by the AOAC as the official method for use in the food industry. This is significant when industry guarantees specific dietary fiber levels for its products. This allows both the supplier and the user to use common analytical methods for quality control and research purposes. The enzymatic-gravimetric method modified by Prosky et al. (1988) was used in this research to analyze insoluble, soluble, and total dietary fiber.

CHAPTER III

MATERIALS AND METHODS

1. Experimental Design

The following types of fiber were analyzed in this study: apple fiber (Tastee Apple Inc., Newcomerstown, Ohio), dry milled corn fiber (Illinois Cereal Mills Inc., Paris, Illinois), oat bran (The Quaker Oats Co., Chicago, Illinois), and soy fiber (Hi-Pro F300, Grain Processing Co., Muscatine, Iowa). The processing conditions (Table 1) were autoclaving which simulated general processing conditions (121°C, 15 minutes) and simulated general cooking conditions (100°C, 30 minutes) and microwave heating (700 Watts, 2450 MHz) for 5 and 10 minutes (Schrumpf and Charley, 1975; Varo et al., 1984). Preliminary studies indicated that the fiber could not be microwave heated for extended periods of time without severe burning of the fiber. Consequently, the optimum ratio of water to fiber was determined in preliminary studies for the microwave heat process. The optimum ratios (w/w) were: apple 4.5:1, corn 3:1, oat 3:1, soy 9:1.

The statistical design consisted of a completely randomized design. Each process was duplicated and each product was chosen randomly to be analyzed in duplicate.

Table 1–Processing conditions of products

Treatment	Temperature	Time (min.)
Autoclave[a]	121°C	15
Autoclave[a]	100°C	30
Microwave[b]	(2450 MHz)	5
Microwave[b]	(2450 MHz)	10
Unprocessed		

[a]Castle® Steam Sterilizer.
[b]Sanyo microwave oven, 700 Watts.

2. Sample Preparation

A ground homogeneous vacuum dried sample was used for all analyses. Fat content was determined to be less than 10% in a preliminary analysis thus fat extraction was not necessary before milling (Prosky et al., 1984, 1988). After the processing treatment, the samples were dried at 70°C in a vacuum oven (Precision Scientific Co., Chicago, Illinois) overnight (approximately 12 hours). Each sample was ground (Wiley mill, Emerson Electric, St. Louis, Missouri) through a screen of #40 mesh to ensure homogeneity and uniform particle size. Ground samples were stored in capped plastic containers in a desiccator at ambient temperatures for further analysis for dietary fiber. Samples were randomly selected after processing for proximate analysis.

3. Proximate Analyses

A. Ash Determination

Ash was determined by following the AOAC (1984) procedure. Approximately 2 grams ± 0.1 mg of sample was weighed in a preweighed crucible that was previously dried at 105°C and cooled in a desiccator. The sample was ingnited in a muffle furnace (Hevi Duty Electric Co., Milwaukee, Wisconsin) at 525°C for four hours. After being transferred to a desiccator, the crucible and ashed samples were cooled 2 to 3 hours and weighed to 0.1 mg. An analytical

balance (Wm. Ainsworth & Sons Inc., Denver, Colorado) was used for all weighings.

The percentage of ash was calculated as shown below.

$$\% \text{ Ash} = \frac{\text{(wt. of crucible + ash) - (wt. of crucible)}}{\text{(wt. of crucible + sample) - (wt. of Crucible)}} \times 100$$

B. Moisture Determination

The moisture determination was performed by weighing approximately 2 grams ± 0.1 mg of the unprocessed sample into a covered dish previously dried at 130°C, cooled in a desiccator and weighed. The uncovered sample in the dish and the cover were dried at 130°C for at least 1 hour. The sample was then covered before removal from the oven, transferred to a desiccator, allowed to cool and weighed ± 0.1 mg (AOAC, 1984).

The percentage of moisture was calculated as shown below.

$$\% \text{ Moisture} = \frac{\text{(wt. of sample) - (wt. of dried sample)}}{\text{(wt. of sample)}} \times 100$$

C. Crude Fat Determination

Two grams ± 0.1 mg of the sample previously dried for moisture determination was weighed into an extraction thimble. The thimble containing the sample was inserted into the holder of the ether extraction apparatus. Approximately 150 ml of hexane was added to the extraction flask, which was previously dried for about 1

hour at 150°C, and weighed. The sample was throughly extracted for 10 hours. The extraction flask containing the extracted fat was dried 1 hour at 100°C and weighed (AOAC, 1984).

The percentage fat was calculated as shown below.

$$\% \text{ Fat} = \frac{\text{(wt. of flask + fat) - (wt. of flask)}}{\text{(wt. of wet sample)}} \times 100$$

D. Determination of Protein

Approximately 1 gram ± 0.1 mg of sample was weighed into a Kjeldahl digestion flask. In addition, a one inch square of parafilm, 10 grams of sodium sulfate, 0.3 grams of copper sulfate, 2 Hengar crystals, and 4 - 5 glass boiling beads were added to the digestion flask. Twenty five ml of concentrated sulfuric acid was added carefully to the digestion flask with the sample. The sample was digested continuously for at least 15 minutes after the digestion solution became clear or blue. The digestion solution was cooled to room temperature and 250 ml of distilled water was added. The flask contents were mixed thoroughly and recooled to room temperature (AOAC, 1984).

Sixty five ml of 50% (w/w) sodium hydroxide solution was added to the flask after complete digestion of the sample. The flask was immediately connected to the distillation apparatus where the collection tube was immersed under 75 ml of boric acid containing 3 to 4 drops of indicator (2 parts Methyl Red : 1 part Methyl Blue).

Fifty ml of distillate was collected in an Erenmeyer flask containing the boric acid and indicator.

The collection flask was removed to back titrate the boric acid solution containing the trapped ammonia with a standardized 0.1N HCl solution. The volume of HCl was recorded by subtracting the amount used in the blank titration.

The percentage of protein was calculated as shown below.

$$\% \text{ Nitrogen} = \frac{(\text{ml of HCl} \times \text{normality of HCl}) \times 14.007}{\text{weight of sample (mg)}} \times 100$$

% Protein = % Nitrogen x 6.25 (Using 6.25 for protein factor in all samples)

4. Insoluble Dietary Fiber Analysis

The principle of the enzymatic-gravimetric method is that samples are gelatinized with Termamyl (heat stable alpha-amylase), and then enzymatically digested with protease and amyloglucosidase to remove protein and starch. Figure 1 shows the principal elements of the scheme for fractionating insoluble dietary fiber.

One gram ± 0.1 mg sample was weighed in duplicate into an incubation flask (TC-1000-2081, Fisher Scientific Co., Norcross, Georgia). Duplicate sample weight did not differ by more than 20 mg. For each analysis, a blank was analyzed along with each sample to measure any contribution to the residue from the reagents.

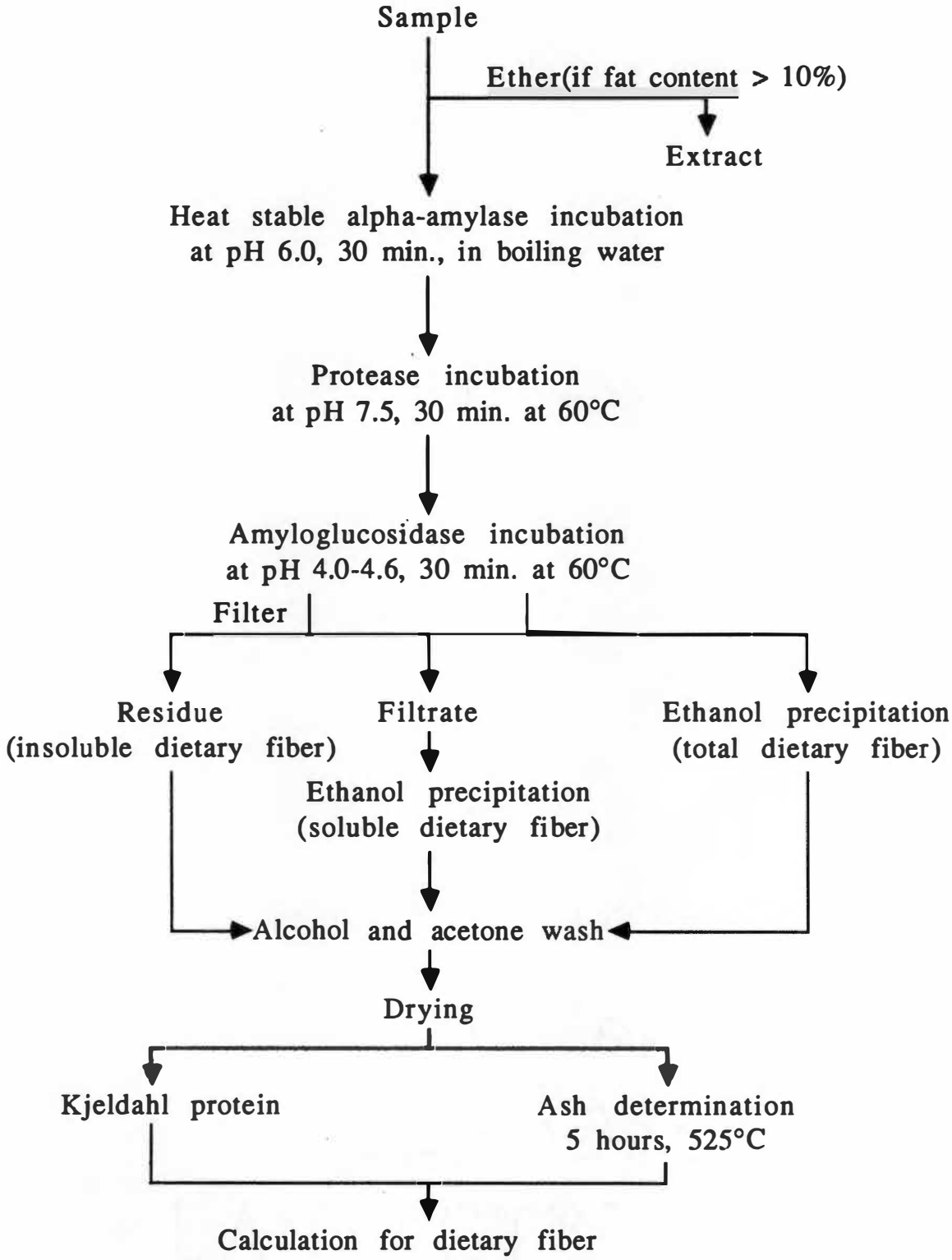

Figure 1-Analytical scheme of insoluble, soluble, total dietary fiber analysis.

To each incubation flask was added 50 ml of 0.08M, pH 6.0 phosphate buffer (1.400 gram sodium phosphate dibasic anhydrate and 9.68 gram sodium phosphate monobasic monohydrate, dilute to 1 liter with water). The pH values were checked with a pH meter (Microprocesser ionalyzer/901, Orion Research Inc., Boston, Massachusetts) and adjusted to 6.0 ± 0.2 with 0.275N sodium hydroxide solution. After adding 0.2 ml Termamyl (No. A-0164, Sigma Chemical Co., St. Louis, Missouri), each incubation flask was covered with aluminum foil and placed in a boiling water bath for 30 minutes and gently shaken by hand at 5 minute intervals.

The incubation solution was cooled to room temperature and the pH value adjusted to 7.5 ± 0.1 by adding 10 ml 0.275N sodium hydroxide solution. After adding 5 mg protease (No. P-3910, Sigma Chemical Co., St. Louis, Missouri), the incubation flasks were covered with aluminum foil and incubated for 30 minutes with continuous agitation in a 60°C water bath (1024 Shaking water bath, Tecator Co., Hoganas, Swedan).

The sample solution was cooled to room temperature and 10 ml of 0.325N hydrochloric acid solution was added to adjust the pH to 4.3 ± 0.3. To each sample solution was added 0.3 ml amyloglucosidase solution (No. A-9913, Sigma Chemical Co., St. Louis, Missouri). Incubation flasks were covered with aluminum foil and incubated at 60°C for 30 minutes with continuous agitation.

Fretted glass crucibles with Celite® (No. C-8656, Sigma Chemical Co., St. Louis Missouri) were tared to nearest 0.1 mg. A stream of distilled water was used to redistribute the bed of Celite®

in the crucible (TC-1000-1172, Fisher Scientific Co., Norcross, Georgia). Suction was applied to the crucible to "seat" the Celite®. The sample mixture was filtered with the filtration equipment (Fibertec System E 1023 Filtration Module, Tecator Co., Hoganas, Swedan) into a pre-tared incubation flask. The residue was washed twice with 10 ml of distilled water. The filtrate and water washings were saved for determination of soluble dietary fiber. The residue was washed twice with 10 ml of 95% ethyl alcohol (v/v, The Warner-Graham Co., Cockeyville, Maryland) and twice with 10 ml of acetone. After being dried in a 105°C air oven (Hevi Duty Electric Co., Milwaukee, Wisconsin) overnight, the crucibles with residue and Celite® were cooled in a desiccator and weighed to the nearest 0.1 mg. The crucible and Celite® weight was subtracted from the residue, crucible, and Celite® weight to determine weight of the residue. The residue was analyzed from one sample of the set of duplicates for protein determination as described in proximate analyses. The second residue sample, of the duplicates, was incinerated for 5 hours at 525°C for ash determination as described in proximate analyses.

Insoluble dietary fiber is calculated as the weight of the residue less the weight of the protein and ash remaining in the residue.

5. Soluble Dietary Fiber Analysis

Figure 1 shows the principal elements of the scheme for fractionating soluble dietary fiber. The soluble dietary fiber was

analyzed by adding 4 volumes of 95% ethanol preheated to 60°C to the filtrate and water washings in the insoluble dietary fiber procedure and allowing a precipitate to form at room temperature for 1 hour.

Fretted glass crucibles containing Celite® were tared to the nearest 0.1 mg. A stream of 78% ethanol and suction was used to wet and redistribute the bed of Celite® in the crucible. The enzyme digest was filtered through the filtration equipment with air back-bubbling to assist the filtration process. The residue was washed with three 20 ml portions of 78% ethanol, two 10 ml portions of 95% ethanol, and two 10 ml portions of acetone. The crucibles, with residue, were dried in a 105°C air oven overnight.

Procedures for weights of residue, protein, and ash were the same as the procedure described for the insoluble dietary fiber. Soluble dietary fiber is calculated as the weight of the residue less the weight of the protein and ash remaining in the residue.

6. Total Dietary Fiber Analysis

The procedure for analysis of total dietary fiber is shown in Figure 1. Ninety five percent ethanol preheated to 60°C was added to the enzyme digest mixture in a 4:1 ratio (v/v). The sample solution was left at room temperature for one hour to allow a precipitate to form.

Fretted glass crucibles containing Celite® were tared to the nearest 0.1 mg. A stream of 78% ethanol was used to wet and

redistribute the bed of Celite® in the crucibles. The enzyme digest was filtered through the filtration equipment with air back-bubbling to help filtration. The residue was washed with three 20 ml portions of 78% ethanol, two 10 ml portions of 95% ethanol, and two 10 ml portions of acetone. The crucibles, with residue, were dried in a 105°C air oven overnight.

Determinations of residue, protein, and ash were the same as the procedure described in the insoluble dietary fiber. Total dietary fiber is calculated as the weight of residue less weight of the protein and ash remaining in the residue.

7. Scanning Electron Microscopy

For scanning electron microscopy studies, dried samples were mounted on 12.7 mm specimen mounts; 100Å gold-palladium was evaporated onto samples using a vacuum evaporator (Denton Vacuum DV-515). Samples were observed in an ETEC Autoscan Scanning Electron Microscope, using 20 KV accelerating voltage. Photographs were taken with Polaroid Type 55 P/N film at the clearest magnification (apple, X8000; corn, oat, and soy, X4500). Differences were observed by noting different surface structure and physical appearance as shown on scanning electron micrographs (i.e., more cracking on the surface and more furrowing or irregular surface versus smooth surface).

8. Statistical Analysis

The processes were replicated twice and all analyses were done in duplicate. Analysis of variance was used to determine significant differences that could be attributed to processing conditions (SAS, 1985). The main effects of heat treatments, products, and replications were tested on insoluble, soluble, total dietary fiber, and protein. Tukey's pairwise comparison procedure was performed to note differences among means and differences between control versus all treatments, control versus autoclaved, control versus microwave heated, and autoclaved versus microwave heated products were estimated. These analyses were performed with the Statistical Analysis System.

CHAPTER IV

RESULTS AND DISCUSSION

1. Proximate Analyses

The proximate analysis results of each unprocessed product are presented in Table 2, which indicated the percentage ash, crude protein, crude fat, moisture, total dietary fiber content and smoking time under microwave treatment. Corn fiber contained a higher concentration of total dietary fiber (79.08%) and a lower ash concentration (0.91%) than soy, apple fiber, or oat bran. Oat bran and soy fiber were higher in protein and ash than apple, or corn fiber. Soy fiber contained a higher moisture level which allowed it to be heated under the microwave heat treatment for a longer period of time before smoking; whereas, apple fiber containing a lower moisture level had a shorter smoking time under the microwave heat treatment. The crude fat content of all samples were less than 10%, thus fat extraction was not necessary before milling.

2. Data Analysis

The analysis of variance on the insoluble, soluble, total dietary fiber and protein are shown in Table 3. The results indicate no significant difference between the replications or heat treatments, but indicate a significant difference between different products on

Table 2–Proximate composition[a], total dietary fiber[b], and smoking time caused by microwave heat treatment of apple, corn, oat, and soy fiber

Product	Ash(%)	Crude fat(%)	Moisture(%)	Crude protein(%)	Total dietary fiber(%)[b]	Smoking time(min.)
Apple fiber	1.91±0.03	4.14±0.18	6.07±0.12	4.11±0.16	54.47±0.80	2
Corn fiber	0.91±0.04	2.51±0.20	8.39±0.11	3.55±0.19	79.08±0.45	7
Oat bran	3.55±0.20	5.17±0.08	9.78±0.11	17.33±0.18	21.32±0.27	5.5
Soy fiber	3.63±0.22	1.73±0.08	10.87±0.07	21.38±0.16	60.88±0.49	8.5

[a]Values represent the mean ± standard deviation of 4 determinations; expressed on wet weight basis.

[b]Values represent the mean ± standard deviation of 2 determinations; expressed on dry weight basis.

Table 3–F ratios of insoluble, soluble, total dietary fiber, and crude protein

Source of variation	df	F ratio			
		Insoluble dietary fiber	Soluble dietary fiber	Total dietary fiber	Crude protein
Total	79				
Replication	1	0.85(.361)[a]	3.91(.053)	**5.63(.021)**	0.49(.487)
Product(P)	3	**3398.89(.0001)**	**361.73(.0001)**	**4147.32(.0001)**	**39838.35(.0001)**
Treatment(T)	4	0.11(.98)	1.17(.333)	**3.51(.0122)**	0.59(.673)
Interaction(PxT)	12	**2.39(.0014)**	**3.18(.0015)**	**3.96(.0002)**	**3.04(.0022)**

[a]Parentheses show the significance level.

insoluble, soluble dietary fiber, and protein content. The results also indicate a significant interaction between products and processing treatments for all four analyses (Table 3). The analysis of variance on total dietary fiber showed significant differences between two replications. This variance may be due to the different amounts of Celite® in the filtration crucibles and the fact that both the insoluble and soluble fraction are present during the filtration process. The soluble fraction is very viscous and resulted in slow filtration times.

The interactions of products and processing treatments on contents of insoluble, soluble, total dietary fiber, and protein are discussed in the following sections.

3. Insoluble Dietary Fiber

The differences between insoluble dietary fiber content of apple, corn, oat, and soy fiber are seen in Table 4. Figure 2 shows the processing effects on the insoluble fraction of products. All heat treatments tended to decrease the insoluble dietary fiber content of apple fiber and oat bran as compared to the control. This effect of heat on the insoluble dietary fiber was similar to that previously reported in potatoes, carrots, and broccoli (Hughes et al., 1975; Ooraikul, et al., 1974; Schrumpf and Charley, 1975). Autoclaving at 121°C, 15 minutes significantly decreased the insoluble dietary fiber content of the apple fiber (Table 4). Microwave heat treatment for 5 and 10 minutes resulted in significant reductions in the insoluble dietary fiber content of oat bran. All heat treatments tended to

Table 4–Effect of heat treatments on percent insoluble dietary fiber in apple fiber, corn fiber, oat bran, and soy fiber

Product	Control	Autoclaved		Microwave heated	
		121°C 15 min	100°C 30 min	5 min	10 min
Apple fiber	39.17±1.29[a]	**36.00±2.51[b]**	37.23±1.18[ab]	36.90±0.31[ab]	36.36±0.13[ab]
Corn fiber	78.25±1.40[a]	79.15±1.12[a]	77.93±0.77[a]	77.78±0.14[a]	79.81±4.06[a]
Oat bran	13.10±2.23[a]	10.18±2.06[a]	9.89±1.10[ab]	**9.38±0.91[b]**	**8.89±0.54[b]**
Soy fiber	53.15±4.07[a]	56.82±2.18[a]	57.79±0.73[a]	57.73±3.97[a]	57.78±4.48[a]

[ab]Values represent the mean ± standard deviation of 4 determinations expressed on dry weight of product. Means within the same row with different superscripts are significantly different by Tukey's test at 5% significance level.

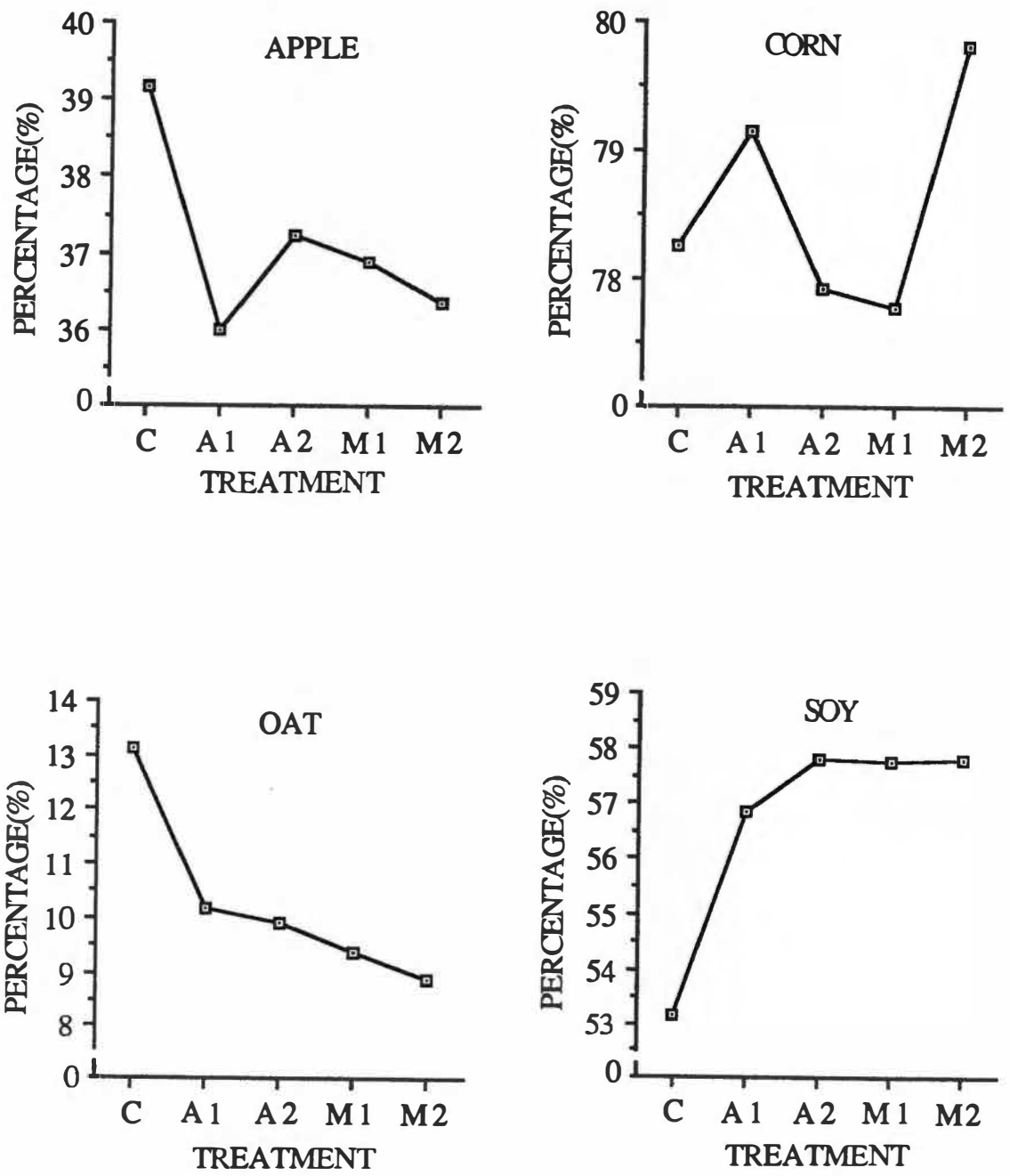

Figure 2–Effect of heat treatments on insoluble dietary fiber of apple, corn, oat, and soy. C, control; A1, autoclave 121°C, 15 minutes; A2, autoclave 100°C, 30 minutes; M1, microwave 5 minutes; M2, microwave 10 minutes.

increase the insoluble dietary fiber of soy (Fig. 2). Due to the higher protein content in soy, thermal processing may have caused Maillard reaction products to be formed, thus possibly increasing the insoluble and total dietary fiber values. It was noted, during the fiber analysis, that the processed sample solutions were darker and deeper in color than the unprocessed sample solutions. No significant differences were observed, due to processing conditions, for the insoluble fraction of soy fiber. There was also a trend, in corn, for the insoluble fraction to increase as the processing condition became more severe (i.e., autoclave, 121°C, 15 min. and microwave 10 min.) as shown in Fig. 2. No significant differences were observed, due to processing conditions, for the insoluble fraction of corn fiber.

Comparing all heat treatments to the control, there is a significant reduction in the insoluble dietary fiber of apple fiber ($p = 0.004$) and oat bran ($p = 0.001$), but a significant increase ($p = 0.042$) in the insoluble dietary fiber of soy fiber (Table 5). Autoclaving caused a significant reduction in the insoluble fraction of apple fiber ($p = 0.0071$) and oat bran ($p = 0.005$) when compared to the control. Autoclaving caused no significant differences in the insoluble fraction of corn or soy fiber when compared to the control. Comparing the results of the microwave process to the control showed a significant decrease in the insoluble fraction of apple fiber ($p = 0.0074$) and oat bran ($p = 0.0008$), but a significant increase ($p = 0.0495$) in the insoluble fraction of soy fiber. No significant differences were observed, between the two different processing methods, in the insoluble fraction of all samples.

Table 5–Comparison of means[a] of heat treatments on percent insoluble dietary fiber of apple fiber, corn fiber, oat bran, and soy fiber

Product	Control[b] vs All treatments[c]	Control[b] vs Autoclaved[d]	Control[b] Microwave heated[e]	Autoclaved[d] vs Microwave heated[e]
Apple fiber	39.17:36.62(**.004**)[f]	39.17:36.61(**.0071**)	39.17:36.63(**.0074**)	36.61:36.63(.979)
Corn fiber	78.25:78.67(.709)	78.25:78.54(.811)	78.25:78.79(.657)	78.54:78.79(.801)
Oat bran	13.10:9.58(**.001**)	13.10:10.04(**.005**)	13.10:9.13(**.0008**)	10.04:9.13(.255)
Soy fiber	53.15:57.53(**.042**)	53.15:57.30(.073)	53.15:57.75(**.0495**)	57.30:57.75(.799)

[a]Values represent percent insoluble dietary fiber expressed on dry weight of product.
[b]n = 4.
[c]n = 16; represents combination of both microwave heat and autoclave treatments.
[d]n = 8; represents combination of both autoclave treatments.
[e]n = 8; represents combination of both microwave heat treatmemts.
[f]Parentheses show the significance level.

The effect of further processing on the insoluble fraction of these four fiber sources indicates that heat treatment is most effective in decreasing the insoluble fraction in those fibers that were lowest in the insoluble component (apple 39.17%, oat 13.10%). When the insoluble fraction made up more than one half of the fiber source (corn 78.25%, soy 53.15%) there was no significant change of the insoluble fraction when the fiber was heat treated. However, there was a trend for the insoluble component in soy fiber to increase with further processing. This may be due to an increase in Maillard reaction products. Consequently, the effects of a heat treatment appears to be dependent on the fiber source and the relative quantities of insoluble dietary fiber.

4. Soluble Dietary Fiber

The effect of the heat treatments on soluble dietary fiber are presented in Table 6. When compared to the control, there was an increase in the soluble fraction of the apple fiber due to the heat treatments, but a reduction was seen in the soluble dietary fiber of corn, and soy fiber as shown in Fig. 3. Autoclaving at 121°C, 15 minutes and microwave heating for 10 minutes decreased the soluble dietary fiber; however, autoclaving at 100°C, 30 minutes did increase the soluble dietary fiber in oat bran compared to control. These were not significantly different from the control (Table 6). Microwave heat treatment for 5 and 10 minutes produced significant increases in the soluble dietary fiber content of the apple fiber. All

Table 6–Effect of heat treatments on percent soluble dietary fiber in apple fiber, corn fiber, oat bran, and soy fiber

Product	Control	Autoclaved		Microwave heated	
		121°C 15 min	100°C 30 min	5 min	10 min
Apple fiber	9.38±0.79[a]	12.11±2.21[ab]	11.38±0.36[ab]	**13.37±1.39[b]**	**13.38±1.76[b]**
Corn fiber	0.70±0.12[a]	**0.21±0.20[b]**	**0.15±0.14[b]**	**0.24±0.04[b]**	**0.18±0.19[b]**
Oat bran	5.64±1.74[a]	4.45±1.21[a]	6.17±0.44[a]	5.55±2.17[a]	4.63±2.02[a]
Soy fiber	7.35±1.38[a]	6.88±0.51[a]	6.63±0.25[a]	6.91±0.36[a]	7.16[a]±0.19[a]

[ab]Values represent the mean ± standard deviation of 4 determinations expressed on dry weight of product. Means within the same row with different superscripts are significantly different by Tukey's test at 5% significance level.

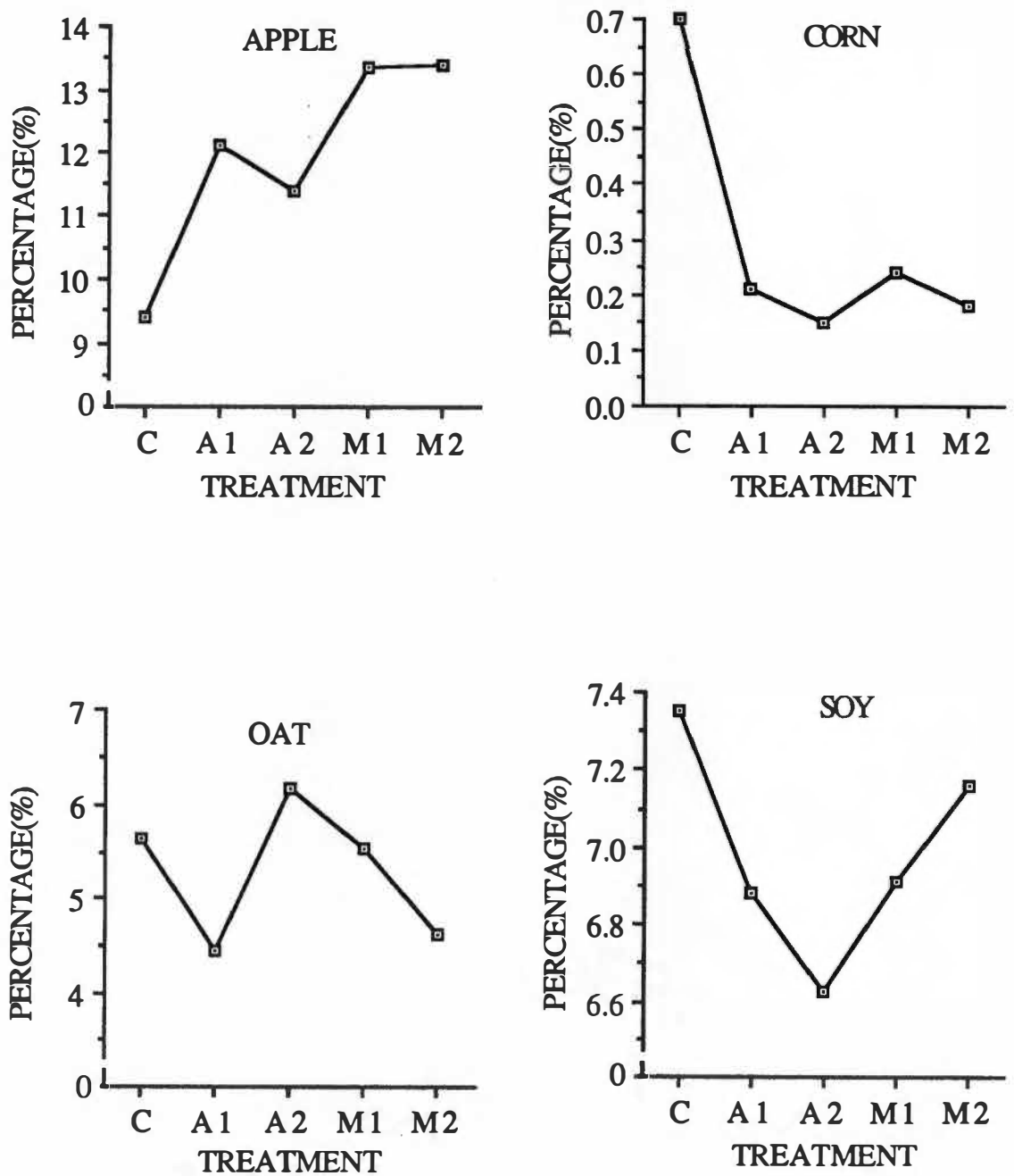

Figure 3–Effect of heat treatments on soluble dietary fiber of apple, corn, oat, and soy. C, control; A1, autoclave 121°C, 15 minutes; A2, autoclave 100°C, 30 minutes; M1, microwave 5 minutes; M2, microwave 10 minutes.

heat treatments resulted in a significant reduction of the soluble dietary fiber content in corn. However, it should be noted that the soluble fraction in corn is very low. Varo et al. (1984) concluded that autoclaving may hydrolyze some of the water soluble components and decrease the soluble fraction in tomatoes. The data show no apparent change of the soluble dietary fiber content in oat bran and soy fiber during processing. Zyren et al. (1983) made a similar conclusion in processed apple, carrots, lima beans, peas, spinach, and sweet potatoes.

Comparison of the soluble fraction in heat treated samples to the control samples shows a significant increase ($p = 0.0021$) in the apple fiber, a significant reduction ($p = 0.0001$) in the corn fiber, and no significant change in the oat bran or soy fiber (Table 7). When comparing the autoclave and the microwave heat treatment to the controls, soluble dietary fiber increased significantly in the apple fiber, was reduced significantly in corn fiber, and resulted in no significant change in the oat bran and soy fiber. The microwave heat treatment tended to increase the soluble dietary fiber content of the apple more than did the autoclave treatment.

These results illustrate the effect of different processing conditions on soluble dietary fiber components from different products. The soluble fraction in apple and corn were significantly affected by further processing, with this fraction being increased in the apple and decreased in the corn. The soluble fraction in oat bran and soy fiber were not significantly effected by further processing. Consequently, the effect of processing on the soluble dietary fiber

Table 7–Comparison of means[a] of heat treatments on percent soluble dietary fiber of apple fiber, corn fiber, oat bran, and soy fiber

Product	Control[b] vs All treatments[c]	Control[b] vs Autoclaved[d]	Control[b] vs Microwave heated[e]	Autoclaved[d] vs Microwave heated[c]
Apple fiber	9.38:12.56(**.0021**)[f]	9.38:11.75(**.0228**)	9.38:13.37(**.0007**)	11.75:13.37(**.049**)
Corn fiber	0.70:0.19(**.0001**)	0.70:0.18(**.0001**)	0.70:0.21(**.0001**)	0.18:0.21(.738)
Oat bran	5.64:5.20(.443)	5.64:5.31(.595)	5.64:5.09(.385)	5.31:5.09(.673)
Soy fiber	7.35:6.89(.257)	7.35:6.75(.182)	7.35:7.03(.465)	6.75:7.03(.437)

[a]Values represent percent soluble dietary fiber expressed on dry weight of product.
[b]n = 4.
[c]n = 16; represents combination of both microwave heat and autoclave treatments.
[d]n = 8; represents combination of both autoclave treatments.
[e]n = 8; represents combination of both microwave heat treatmemts.
[f]Parentheses show the significance level.

fraction also appears to be dependent upon the fiber source and the processing method.

5. Total Dietary Fiber

The effects of processing on the total dietary fiber are seen in Table 8. It indicates a significant decrease in total dietary fiber of apple and oat bran (Fig. 4). Whereas there is no significant difference, but a trend for the total dietary fiber to increase in soy fiber (Table 8). Autoclaving at 100°C for 30 minutes, and treating in the microwave oven for 5 and 10 minutes showed a significant reduction in the total dietary fiber content of apple. Autoclaving tended to decrease the total dietary fiber and microwave heat tended to increase the total dietary fiber in corn fiber. Autoclaving at 121°C, 15 minutes and microwave heat treatment at 5 and 10 minutes yielded a significant reduction in total dietary fiber content of oat bran. All heat treatments produced no significant difference in the total dietary fiber content of soy fiber.

When comparing all heat treatments to the control, total dietary fiber of apple ($p = 0.0003$) and oat ($p = 0.0003$) showed a significant reduction, whereas soy fiber showed a significant increase ($p = 0.03$), and corn fiber showed no significant change (Table 9). The results indicate that a significant reduction in the total dietary fiber content occurs in apple ($p = 0.001$), corn ($p = 0.0457$), and oat fiber ($p = 0.0027$) when autoclaved. Results, comparing microwave heated samples to control samples, illustrate how total dietary fiber

Table 8–Effect of heat treatments on percent total dietary fiber in apple fiber, corn fiber, oat bran, and soy fiber

Product	Control	Autoclaved		Microwave heated	
		121°C 15 min	100°C 30 min	5 min	10 min
Apple fiber	51.01±4.02^{a}	47.76±1.90^{ab}	**46.71±0.13^{b}**	**47.70±1.35^{b}**	**45.78±0.77^{b}**
Corn fiber	78.47±0.78^{abc}	77.00±1.39^{bc}	76.51±0.89^{c}	80.19±2.27^{a}	79.70±3.74^{ab}
Oat bran	22.02±1.80^{a}	**17.34±3.42^{b}**	19.24±0.88^{ab}	**16.57±0.38^{b}**	**16.97±0.70^{b}**
Soy fiber	62.26±1.65^{a}	63.54±1.00^{a}	63.79±0.78^{a}	64.29±1.20^{a}	64.02±1.28^{a}

^{abc}Values represent the mean ± standard deviation of 4 determinations expressed on dry weight of product. Means within the same row with different superscripts are significantly different by Tukey's test at 5% significance level.

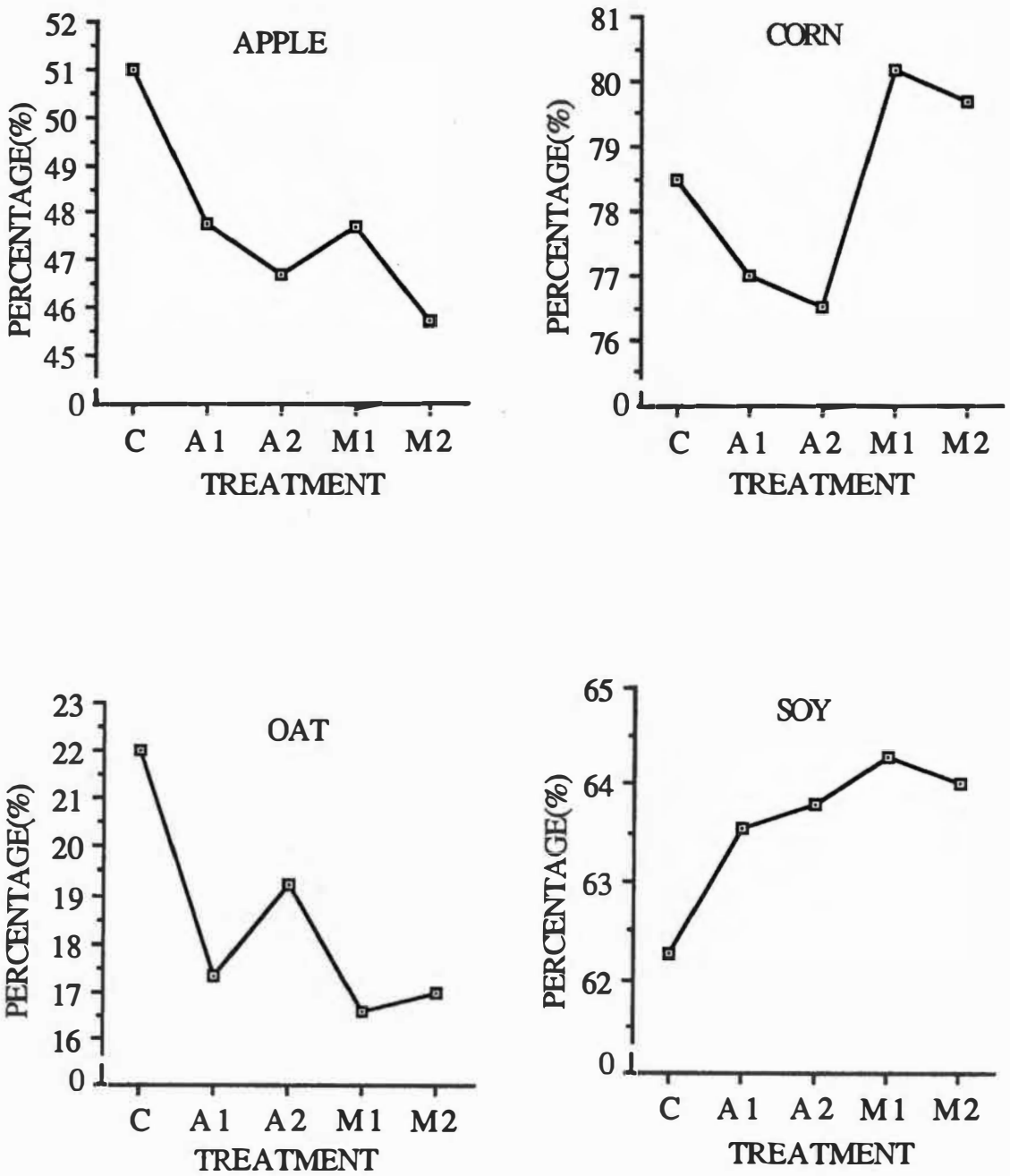

Figure 4–Effect of heat treatments on total dietary fiber of apple, corn, oat, and soy. C, control; A1, autoclave 121°C, 15 minutes; A2, autoclave 100°C, 30 minutes; M1, microwave 5 minutes; M2, microwave 10 minutes.

Table 9–Comparison of means[a] of heat treatments on percent total dietary fiber of apple fiber, corn fiber, oat bran, and soy fiber

Product	Control[b] vs All treatments[c]	Control[b] vs Autoclaved[d]	Control[b] vs Microwave heated[e]	Autoclaved[d] vs Microwave heated[e]
Apple fiber	51.01:46.99(**.0003**)[f]	51.01:47.24(**.001**)	51.01:46.74(**.0003**)	47.24:46.74(.514)
Corn fiber	78.47:78.35(.866)	78.47:76.75(**.0457**)	78.47:79.94(.081)	76.75:79.94(**.0002**)
Oat bran	22.02:17.53(**.0003**)	22.02:18.29(**.0027**)	22.02:16.77(**.0002**)	18.29:16.77(.092)
Soy fiber	62.26:63.91(**.03**)	62.26:63.66(.082)	62.26:64.15(**.0243**)	63.66:64.15(.439)

[a]Values represent percent total dietary fiber expressed on dry weight of product.
[b]n = 4.
[c]n = 16; represents combination of both microwave heat and autoclave treatments.
[d]n = 8; represents combination of both autoclave treatments.
[e]n = 8; represents combination of both microwave heat treatmemts.
[f]Parentheses show the significance level.

decreased significantly in apple fiber ($p = 0.0003$) and oat bran ($p = 0.0002$), but was increased significantly ($p = 0.0243$) in soy fiber. When comparing samples autoclaved to those microwave heated, no significant difference was observed in the total dietary fiber content of apple, oat and soy fibers, but a significant difference ($p = 0.0002$) was seen in corn fiber (Table 9).

These results indicate the effect of heat treatment on total dietary fiber from different samples. The processing methods did not result in the same effect on different samples. Autoclaving tended to reduce the total dietary fiber content, while baking decreased the total dietary fiber content in tomatoes (Varo et al., 1984). The effect of processing on the total dietary fiber appears to be dependent upon the fiber source and the processing method.

6. Crude Protein

Results of processing treatments on the protein content are seen in Table 10. They indicate a significant reduction in protein content of the soy fiber processed by the microwave heat 10 minutes when compared to the control. Autoclaving and the microwave heat showed no significant reduction in the protein content of oat bran; however, there was a significant difference ($p = 0.038$) between the two types of processing (Table 11). Autoclaving ($p = 0.0219$) and the microwave heat ($p = 0.0042$) showed a significant decrease in the protein content of soy fiber. This may have changed more due to the higher protein content of soy fiber. The fact that the insoluble

Table 10–Effect of heat treatments on percent crude protein in apple fiber, corn fiber, oat bran, and soy fiber

Product	Control	Autoclaved		Microwave heated	
		121°C 15 min	100°C 30 min	5 min	10 min
Apple fiber	4.27±0.17[ab]	4.35±0.11[a]	4.14±0.09[ab]	4.23±0.03[ab]	4.07±0.09[b]
Corn fiber	3.78±0.16[a]	3.89±0.07[a]	3.85±0.15[a]	3.85±0.02[a]	3.98±0.18[a]
Oat bran	19.24±0.17[a]	19.16±0.47[a]	19.34±0.35[a]	19.55±0.12[a]	19.62±0.11[a]
Soy fiber	23.97±0.17[a]	23.53±0.30[ab]	23.46±0.46[ab]	23.42±0.15[ab]	**23.26±0.38**[b]

[ab]Values represent the mean ± standard deviation of 4 determinations expressed on dry weight of product. Means within the same row with different superscripts are significantly different by Tukey's test at 5% significance level.

Table 11–Comparison of means[a] of percent heat treatments on crude protein of apple fiber, corn fiber, oat bran, and soy fiber

Product	Control[b] vs All treatments[c]	Control[b] vs Autoclaved[d]	Control[b] vs Microwave heated[e]	Autoclaved[d] vs Microwave heated[e]
Apple fiber	4.27:4.20(.244)[f]	4.27:4.24(.661)	4.27:4.15(.098)	4.24:4.15(.127)
Corn fiber	3.78:3.89(.132)	3.78:3.87(.259)	3.78:3.91(.103)	3.87:3.91(.500)
Oat bran	19.24:19.42(.286)	19.24:19.25(.939)	19.24:19.58(.072)	19.25:19.58**(.038)**
Soy fiber	23.97:23.42**(.0055)**	23.97:23.49**(.0219)**	23.97:23.34**(.0042)**	23.49:23.34(.324)

[a]Values represent percent crude protein expressed on dry weight of product.
[b]n = 4.
[c]n = 16; represents combination of both microwave heat and autoclave treatments.
[d]n = 8; represents combination of both autoclave treatments.
[e]n = 8; represents combination of both microwave heat treatmemts.
[f]Parentheses show the significance level.

dietary fiber level of soy fiber increased supports the hypothesis that the processing treatments have increased the Maillard reaction products in this sample. These Maillard reaction products are being measured as part of the insoluble dietary fiber. No significant difference was observed in the protein content of apple, corn, and soy fiber between the two different processing methods.

7. Scanning Electron Micrograph

Scanning electron micrographs were taken to illustrate the processing effect on the surface of the fiber's microstructure. Figure 5 shows scanning electron micrographs of apple fiber before and after processing. After autoclave or microwave heat treatment of apple fiber, cracks were observed in the micrographs on the surface of the fiber. It is postulated that the cracks in the fiber source may be attributed to the higher pressure of autoclaving, steam, or dehydration during the microwave heat processing. During processing, more surface area appears to develop, as exemplified by the increased furrowing appearance of the fiber. The same processing effect on microstructure of the fiber was observed on the scanning electron micrographs of corn, oat, and soy fiber (Fig. 6 - 8). Increased processing produced more cracking on the surface and more furrowing on the surface of the corn fiber as shown on Fig. 6. Processing resulted in a rougher and more irregular surface in oat bran, but no cracking was observed on the surface of the processed oat bran (Fig. 7). Autoclaving produced more of an irregular surface

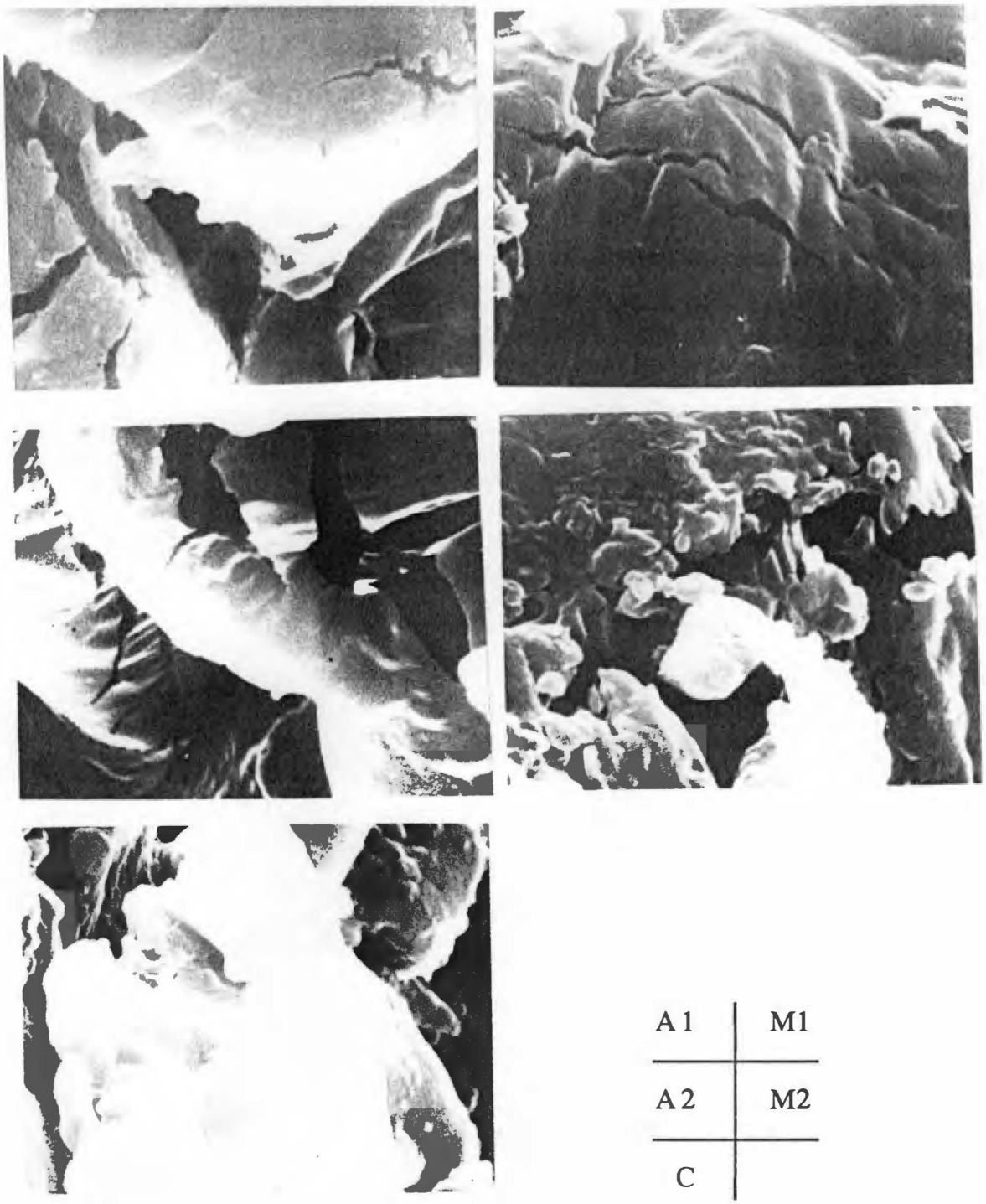

Figure 5–Scanning electron micrograph of apple fiber (X8000). C, control; A1, autoclave 121°C, 15 minutes; A2, autoclave 100°C, 30 minutes; M1, microwave 5 minutes; M2, microwave 10 minutes.

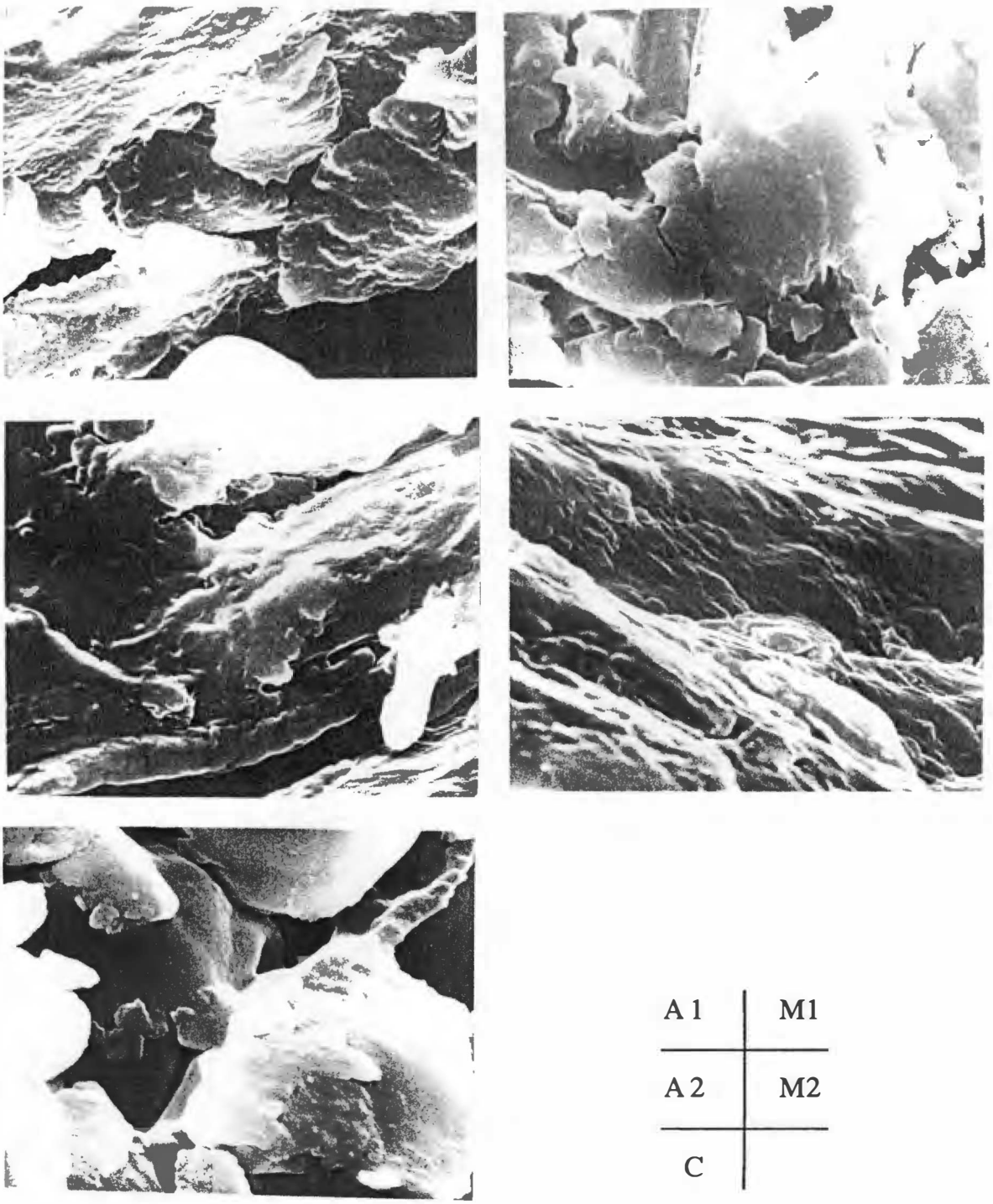

Figure 6–Scanning electron micrograph of corn fiber (X4500). C, control; A1, autoclave 121°C, 15 minutes; A2, autoclave 100°C, 30 minutes; M1, microwave 5 minutes; M2, microwave 10 minutes.

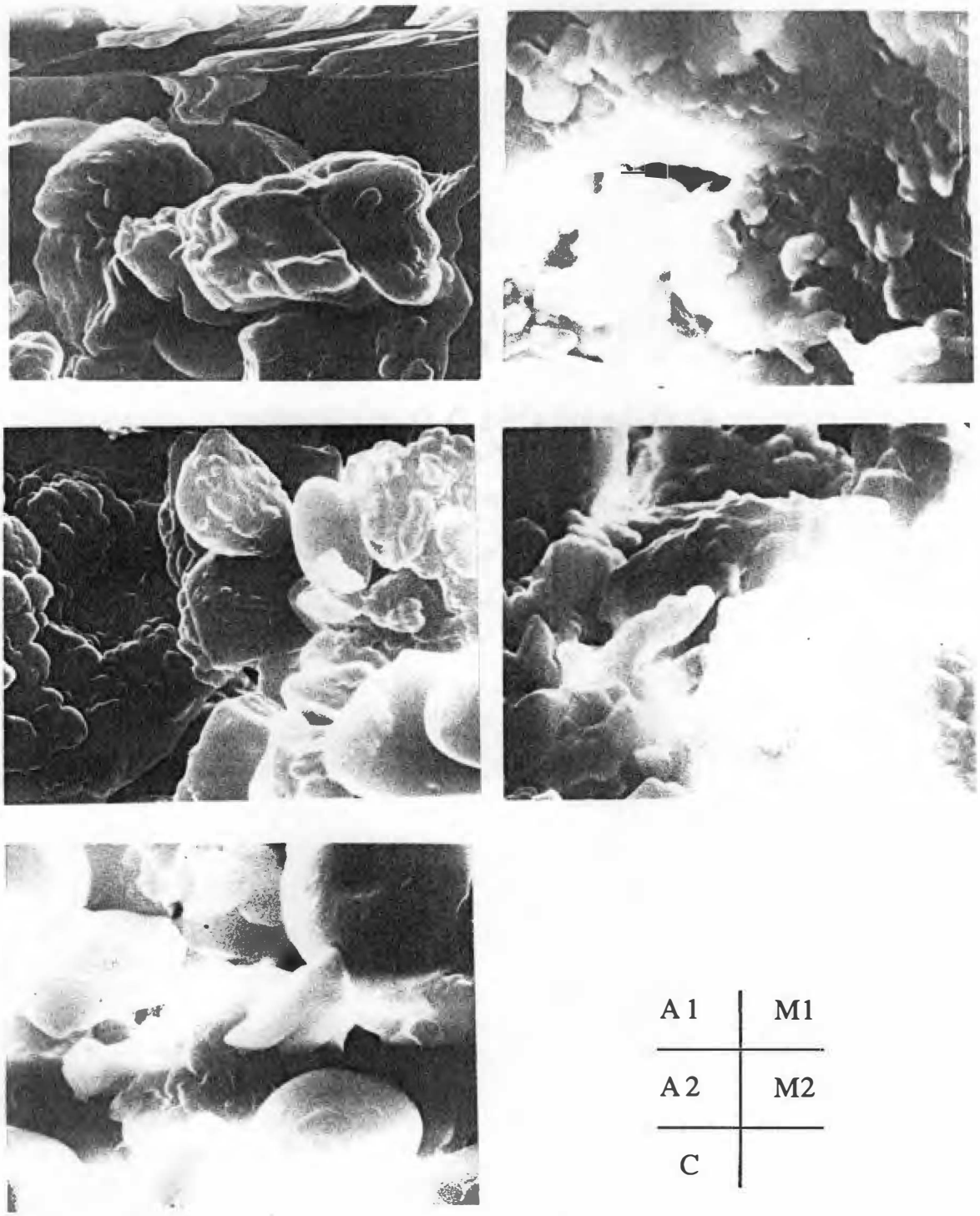

Figure 7–Scanning electron micrograph of oat bran (X4500). C, control; A1, autoclave 121°C, 15 minutes; A2, autoclave 100°C, 30 minutes; M1, microwave 5 minutes; M2, microwave 10 minutes.

Figure 8–Scanning electron micrograph of soy fiber (X4500). C, control; A1, autoclave 121°C, 15 minutes; A2, autoclave 100°C, 30 minutes; M1, microwave 5 minutes; M2, microwave 10 minutes.

and more furrowing in the soy fiber; microwave heat treatment produced more cracking and irregular surfaces in the soy fiber as viewed on the Fig. 8. In general, micrographs of apple, corn, oat, and soy reflect the surface area to be increased when the fibers are further processed. This is indicated by observing the increased furrowing and more irregular surface on the fibers that have been further processed. These physical changes on the surface of the fiber may have significant physiological implications (i.e., water holding capacity, bile salt binding, mineral binding, or binding of other organic compounds).

CHAPTER V

CONCLUSIONS

This study demonstrated the effect processing treatments have on different fiber sources. The results indicated that the same processing treatments have different effects on the insoluble, soluble, and total dietary fiber content of different fiber sources. The research also showed that processing conditions affected the content of total dietary fiber and the insoluble/soluble ratio. This has been supported by other researchers, where boiling and pressure cooking increased the acid and neutral detergent fiber in potatoes (Johnston and Oliver, 1982). Autoclaving tended to reduce the total dietary fiber content, while baking had been shown to increase the total dietary fiber in tomatoes (Varo et al., 1984). Cooking in water increased the soluble dietary fiber (pectic substance) in potatoes (Hughes et al., 1975); however, microwave cooking and boiling did not show evident changes in the soluble dietary fiber (pectin) of apple, lima beans, peas, and potatoes (Zyren et al., 1983). The microwave heat treatment resulted in an increase in the total dietary fiber content of broccoli, but decreased the total dietary fiber content of carrots (Schrumpf and Charley, 1975). Matthee and Appledorf (1978) reported that the increase in neutral detergent fiber might be due to a liberation of cellulose.

The decrease in the total dietary fiber content of apple and oat fiber is a result of the decreased amount of insoluble dietary fiber.

The total dietary fiber, in apple and oat, decreased after processing; however, the soluble dietary fiber content increased. This is primarily due to the large decrease in the insoluble fraction. This change in the insoluble dietary fiber content would explain the observed changes in the total dietary fiber of the processed apple, oat, and soy fiber. Apple fiber is chemically defined as having more soluble dietary fiber than other products studied in this research. Corn fiber is predominately comprised of the insoluble fraction. Oat bran is lower in total dietary fiber and in the insoluble fraction. Oat bran is also not as pure of fiber source as the other products studied due to its residual protein and starch content. Soy fiber contains more of the insoluble and soluble fraction, however, it is also higher in protein. It is also of interest to note that in the highest protein containing fiber, soy, the protein content decreased and the insoluble dietary fiber level increased. This supports the theory that we may be measuring an increased level of Maillard reaction products as dietary fiber, after the fiber has been further heat treated. The effect of further processing on the insoluble and soluble fractions appeared to be dependent upon the fiber source and the processing method. To further evaluate the effect of processing, individual chemical components of the fiber fraction need to be analyzed on fibers that have been more severely processed.

This study was also designed to investigate the microstructure of the surface of the fibers in relation to their changes during processing by utilizing the scanning electron microscopy. The changes in fiber surface structure shown in the micrographs may be caused

by high pressure or dehydration. The processed fiber's micrographs indicate an increase in their furrowed appearance, resulting in an increased surface area. However, it was not possible to distinguish between times or temperatures within a specific process, nor was it possible to distinguish physical differences between the fibers subjected to the microwave heat or autoclave. Observation of the micrographs suggests that the greatest differences exist between the nonprocessed fiber and the processed fiber, irrespective of the type or degree of processing conducted in these trials.

Mongeau and Brassard (1982) found the smaller particle sizes of wheat bran to lower the bile salt binding capacity in vitro. This indicates the physical state of the fiber may be related to its physiological role such as water holding capacity, binding of organic compounds, or ion exchange capacity which are all associated with the nutritional characteristics of various fiber sources (Schneeman, 1986). Further research is needed to better define the relationship of the physical state of dietary fiber to the physiological effects of processed and unprocessed fibers.

With increased emphasis on new and innovative dietary fiber ingredients in the food industry, there is a need for data on the effect food processing has on the insoluble, soluble, and total dietary fiber content of these new ingredients. Consequently, the true physiological effect of the fiber sources, after they have been further processed, remains a fertile area for further research.

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