

AN ABSTRACT TO THE THESIS OF

Emily S. Loghmani for the degree of Master of Science

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Title: EFFECT OF COOKING ON THE FIBER CONTENT OF

CAULIFLOWER AND CARROTS

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Dr. Lorraine Miller

This study investigated the effect of cooking on the neutral detergent fiber (NDF) content of cauliflower and carrots. For each replication the vegetable was divided in half to serve as its own control. One half was used raw and the other half was cooked in 60 ml of distilled water for 7 to 8 minutes. Internal temperature of the cooked samples verified a uniform cooking process. Moisture and NDF were determined in both raw and cooked samples. A texture reading, determined by shear force, was also done on the cooked samples. The resulting NDF residues from the raw and cooked samples were used to compare water-absorbing capacity and ash content.

In terms of 100 g dry weight, NDF decreased in cooked cauliflower from 19.13 to 17.22 g ( $p < 0.05$ ) and increased in cooked carrots from 9.47 to 10.54 g ( $p < 0.05$ ). The exact opposite was observed for water-absorbing capacity. It increased in cooked cauliflower and

decreased in cooked carrots. Ash content showed large variations but a general increase in both vegetables after cooking. No positive relationship was found between texture and NDF in the cooked vegetables.

These observations confirm the complex nature of dietary fiber. Results suggest that although cooking affected the NDF in selected vegetables, the quantity of the change was not large enough to alter dietary fiber's physiological effect in the body.

Effect of Cooking on the Fiber Content  
of Cauliflower and Carrots

by

Emily S. Loghmani

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Professor of Foods and Nutrition  
in charge of major

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Head of Department of Foods and Nutrition

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Dean of Graduate School

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Typed by Emily S. Loghmani

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# EFFECT OF COOKING ON THE FIBER CONTENT OF CAULIFLOWER AND CARROTS

## INTRODUCTION

The use of fiber to prevent non-infectious diseases of the large intestine, coronary heart disease and diabetes has been advocated by Burkitt, Walker and Painter (1974). Since their epidemiological studies were published in the early 1970's, researchers have investigated the hypothesis that fiber in our diet is involved in the preservation of health and that lack of fiber is involved in disease (Colmey, 1978).

Early studies measured crude fiber: that portion of plant tissues which resisted degradation by acid and alkaline treatment (Williams and Olmsted, 1935). As the interest in fiber increased, several new methods to determine the fiber in food have been proposed. Dietary fiber, the term presently being used by many researchers, is defined as that portion of the plant cell which is not digested by the endogenous secretions of the human gastrointestinal tract (Trowell and Southgate, 1976). The major constituents of dietary fiber are cellulose, hemicellulose, lignin and pectin. They are primarily located in the plant cell wall and are presently being measured by neutral detergent fiber (NDF) and acid detergent fiber (ADF) methods developed by Van Soest (1963a). These methods utilize a detergent solution to separate the fibrous components of the plant cell; NDF determines cellulose, hemicellulose and lignin, ADF

determines cellulose and lignin. Another procedure that is used is the fractionation method developed by Southgate (1969).

A review of the studies which have been done to investigate the physiological functions of dietary fiber shows that a variety of foods are used to provide the subjects' diets with dietary fiber (Spiller, Shipley and Blake, 1978). These include bran, purified cellulose, pectin, whole grain breads and cereals and assorted fruits and vegetables. Looking specifically at vegetables, the pretreatment and the form in which they are given vary from a freeze-dried powder to a serving of raw or cooked vegetables. The differences in results may be due to these inconsistencies because it is unclear whether or not processing will affect the fiber content of the samples.

Few studies have dealt with the effect of cooking on dietary fiber in vegetables. Weier and Stocking (1949) and Sterling (1955) discussed the textural changes produced by cooking vegetables. They both reported a loss of cell turgidity and a decrease in cellular adhesion due to the softening of the pectin in the middle lamella. Simpson and Halliday (1941) reported that cooking caused the breakdown of the cell wall and the beginning of cellulose hydrolysis. McConnell, Eastwood and Mitchell (1974) studied physical properties of fiber and compared them in raw and cooked vegetables. Hellendorn (1978) hypothesized that increased

water-holding capacity in cooked vegetables promoted the cleavage of hydrogen bonds and subsequent cellulose solubilization.

The purpose of the present study was to test the hypothesis that the percent of dietary fiber, as measured by NDF in cauliflower and carrots, will remain the same whether the vegetable is raw or cooked. Any changes in NDF that may occur in the cooked vegetables will be determined by comparing water-absorbing capacity and ash content in the raw and cooked acetone-dried NDF residue. The texture of the cooked vegetables was also examined in order to learn the relationship between texture, as determined by shear force, and the NDF measurement.

## REVIEW OF LITERATURE

Organization of the Plant Cell Wall

The cell wall is organized in the living plant cell to provide a supportive structure and a porous membrane for the selective interchange of liquids into and out of the cell. The young cell has a thin outer layer or primary cell wall surrounding the protoplasm. Its structural components are equal portions of cellulose, hemicellulose and pectin with a small amount of protein organized into a single macromolecule by numerous covalent and noncovalent bonds (Keegstra et al., 1973).

A thin layer of pectic substances, called the middle lamella, surrounds the walls of adjoining cells. Formed during cell division, the middle lamella functions as an intercellular cement. Its binding strength is increased as the pectic substances combine with calcium and magnesium ions (Sterling, 1963).

As the plant matures, the primary wall becomes more rigid and a secondary wall is deposited. This secondary wall is thicker and contains an increased amount of cellulose on which lignin is deposited. The presence of lignin increases the firmness, toughness and overall strength of the cell (Theander, 1977). This and other aspects of the structural nature of the plant cell wall are discussed in more detail by Keegstra et al. (1973).

## Fiber Constituents of the Plant Cell

The plant cell is composed of several fibrous compounds that are characterized by their indigestibility in the human gastrointestinal tract. Cellulose, hemicellulose, lignin and pectin are predominately located in the plant cell wall and contribute to its structural integrity. Other indigestible compounds are plant gums, mucilages and algal polysaccharides (Cummings, 1976).

Cellulose is a complex polysaccharide composed of 1,000 or more D-glucose residues held together by  $\beta$ -1,4 linkages. It exists as a long unbranched chain. Groups of chains form slender rods or microfibrils that make up a crystalline latticework and provide the basic structural unity of the cell wall. The multiple hydrogen bonds along the linear chains make it resistant to hydrolysis by enzymes in the human gastrointestinal tract, but a small amount may be broken down by bacterial action in the large intestine (Cummings, 1976).

Hemicellulose also contributes to the structure of the plant cell wall. It is a complex polymer composed of several polysaccharides attached to a nonsugar component, uronic acid. The most frequently found sugars in hemicellulose are xylose and arabinose. They exhibit different degrees of branching, are more amorphous, smaller and slightly more digestible than cellulose (Cummings, 1976).

Pectin is a polymer of D-galacturonic acid units. The presence of methyl groups affects its solubility, but it is generally more digestible in the human gastrointestinal tract than other fibrous compounds (Campbell and Palmer, 1978).

Lignin is one of the noncarbohydrate fractions of the plant cell wall. It is an aromatic polymer composed of phenyl propanoid units which are very resistant to digestion or fermentation. The amount of lignin in the plant cell wall increases with age and reduces the breakdown of cellulose and hemicellulose compounds to which it is covalently bound (Gordon, 1978).

#### Determination of Dietary Fiber in Food

Various experimental methods have been used to measure the different fiber compounds in plant foods. Results of the analyses often determine which definition of dietary fiber will be used by the researcher.

The oldest method to determine the fibrous portion of plant tissues, the Weende method, was discussed by Williams and Olmsted (1935). The dried sample was treated, in order, with hot sulfuric acid, alkali and alcohol. That portion which resisted hydrolysis was then dried and weighed, and became known as crude fiber. It contained small amounts of cellulose, lignin and hemicellulose. Most researchers agree that over 20-50% of the cellulose, 50-90% of the

lignin and 80% of the hemicellulose were lost in the analysis (Van Soest and McQueen, 1973).] In use since the early 1800's, this method was accepted by the Association of Official Analytical Chemists as the preferred method for fiber determination; resulting values have been used in many clinical studies and published in USDA Composition of Food Tables (Agriculture Handbook No. 8, 1975).

Williams and Olmsted (1935) and later, Hellendorn, Noordhoff and Slagman (1975) proposed similar alternatives to crude fiber determination based on enzymatic digestion. Working with the definition that fiber was all indigestible residue which reached the large intestine, they each used a pepsin and pancreatic treatment which would closely simulate human digestive enzyme activity. Resulting values were larger than those for crude fiber. Disadvantages were, however, protein contamination, increased time needed for the determination and inability to measure individual components of the fiber residue (Southgate, Hudson and Englyst, 1978).

Two analytical methods were developed to determine fiber in animal forages. The neutral detergent fiber (NDF) method measured undegraded plant cell wall constituents - cellulose, hemicellulose and lignin - which resulted after a dried sample was refluxed with a solution of sodium lauryl sulfate at pH 7 (Van Soest and Wines, 1967). The acid detergent fiber (ADF) method determined the lignocellu-

lose complex when the dried sample was refluxed in an acid solution of cetyl trimethyl ammonium bromide (Van Soest, 1963b). Nitrogenous compounds were dissolved by the detergents and values were higher than those for crude fiber. These methods were easier and less time-consuming than enzymatic digestions, and values obtained with the detergent and enzymatic methods compared favorably (McConnell and Eastwood, 1974).

Problems with filtration in the NDF method have occurred due to starch contamination (Van Soest and Wines, 1967). To correct for this, Holst (1973) recommended the use of a special filtration apparatus, and Jwuang and Zabik (1979) modified the digestion period with amylase. Because both NDF and ADF methods only measure water insoluble compounds, pectic substances are not included in resulting values (Southgate et al., 1978).

Southgate (1969) developed a comprehensive fractionation of the plant cell wall which provides values for cellulose, lignin and noncellulosic polysaccharides. The method was easy to perform but required five days. It has generally been considered too detailed and impractical for use in clinical studies (Southgate et al., 1978).

Spiller et al. (1978) suggested a new term for dietary fiber, plantix, which would include dietary fiber plus pectin, gums and mucilages. If agreed upon, the use of the term plantix might help avoid the confusion associ-

ated with the definition of dietary fiber. As a new term, however, it must be accepted and used before it can fulfill its purpose.

### Physical Properties of Dietary Fiber

The physical properties of dietary fiber have been discussed by Eastwood and Mitchell (1976). These include water adsorption or water-holding capacity, ion-exchange capacity and adsorption of organic material. Each fibrous component of the plant cell exhibits these properties in different degrees. Water-holding capacity is higher for cellulose and hemicellulose; ion-exchange capacity is stronger for hemicellulose and pectin (Cummings, 1976).

Studies that examine the relationship between the physical properties of dietary fiber and their physiological effect in the human body have shown variable results due to several factors: the proportion of different fibers present in the test material or diet, the method of processing and the interaction of other nutrients (Spiller et al., 1978). For example, foods containing pectin have been shown to decrease cholesterol levels but have no effect on increasing fecal bulk; cellulose will increase fecal bulk but will not affect cholesterol levels (Southgate et al., 1978).

Water adsorption is the ability of dietary fiber to bind water on its surface. The measure of the amount of

water held by a specific amount of fiber prepared under controlled conditions is defined as its water-holding capacity. McConnell et al. (1974), who measured the water-holding capacity of over twenty fruits and vegetables, reported a range of values from 1.47 to 20.0 g of water per g of fiber. Differences were attributed to variations in plant materials, the effect of grinding on particle size and the percent of dry matter. On a wet weight basis, 100 g of bran had the highest water-holding capacity, followed by mangos, carrots, apples and brussels sprouts.

The physiological effect of the ability of dietary fiber to retain water as it passes through the lumen of the intestines is increased fecal weight (Eastwood et al., 1977). At first this was attributed to hemicellulose, which also has a high conversion rate to volatile fatty acids (Williams and Olmsted, 1936), but it is now attributed to both cellulose and hemicellulose (McConnell et al., 1974).

Another property of dietary fiber is its ability to bind divalent cations. McConnell et al. (1974) measured the ion-exchange capacity of a variety of fruits and vegetables and found that most of them acted as strong or medium ion-exchange resins.

The physiological significance of this ion-exchange capacity is reviewed by Spiller et al. (1978). Numerous studies have shown impaired mineral absorption when large

amounts of fiber are present in the diet. Reinhold et al. (1976) reported a significant increase in the fecal excretion of calcium, zinc, magnesium and phosphorous when their subjects switched from white to wholemeal bread. However, this may have been due to the high percentage of calories in the diet that were obtained from the bread, the low consumption of animal protein and the effect of phytates (Spiller et al., 1978). A more recent study has shown a similar effect for copper, zinc and magnesium (Drew, Kies and Fox, 1979). Even with a mixed diet free of phytates, increased fecal excretion of calcium, magnesium and silicon was demonstrated with diets high in fiber (Kelsay, Behall and Prather, 1979).

The third physical property discussed by Eastwood and Mitchell (1976) is the ability of dietary fiber to adsorb organic materials such as bile acids. This ability, found predominately in pectin and guar gum, has been shown to increase fecal bile acid excretion. It has led to numerous claims about the lipid-lowering effect of dietary fiber and its role as a protective agent against heart disease (Spiller et al., 1978).

## Physiological Functions of Dietary Fiber

Many studies confirm the fact that an adequate dietary fiber intake will regulate bowel function by absorbing water, increasing fecal weight and decreasing transit time through the large intestine (Eastwood et al., 1977). Burkitt and Painter (1971) attributed the low incidence of certain non-infectious diseases such as appendicitis, diverticular disease, hemorrhoids, ischemic heart disease and cancer of the colon to a high consumption of dietary fiber. They hypothesized that the increase in these diseases in the United States and other industrialized countries was due to diets low in dietary fiber. Burkitt et al. (1974) advocated the addition of whole grain breads and bran to the diet as protection against these disorders.

A review of dietary studies on these and other physiological effects of dietary fiber intake was compiled by Kelsay (1978). Different effects were seen depending on the length of the study, the amount of dietary fiber added and the source of the dietary fiber. Bran increased fecal weight more effectively than fruits and vegetables (Cowgill and Sullivan, 1933). When the effect of specific vegetables was studied, carrots (Cummings et al., 1978 and Robertson et al., 1979) and cabbage (Cummings et al., 1978 and Kramer, Kearney and Ingelfinger, 1962) significantly increased fecal bulk.

Spiller et al. (1978) reviewed the role of dietary fiber in cancer of the colon. They suggested that an adequate dietary fiber intake from a variety of foods may protect against cancer by diluting the concentration of potentially carcinogenic products in the colon and by inherently providing a diet lower in fat and cholesterol content.

Spiller et al. (1978) also discussed the relationship of dietary fiber to the etiology of ischemic heart disease. Pectin reduces serum cholesterol and increases steroid excretion better than bran or vegetable fiber. A varied diet containing a mixture of dietary fiber from fruits, vegetables and grains also significantly increases fecal excretion of neutral steroids, bile acids and total fat (Stasse-Walthius et al., 1979). A supplement of raw carrots significantly increases fecal excretion of bile acids and total fat but not neutral steroids (Robertson et al., 1979).

Trowell (1973) hypothesized that a prolonged consumption of a diet low in dietary fiber was conducive to the development of diabetes mellitus. Anderson (1977) reported that a diet high in crude fiber lowered plasma glucose levels in diabetic subjects enabling them to reduce or eliminate oral hypoglycemic agents or insulin as long as the diet was maintained. This effect was attributed to the ability of complex carbohydrates to slowly release glucose

into the blood stream and enhance peripheral sensitivity to insulin (Munoz, Sandstead and Jacob, 1979).

### Effect of Cooking on Dietary Fiber

The structural organization of the living plant cell relates to the various effects of cooking on dietary fiber (Weier and Stocking, 1949). During cooking, moisture and heat disrupt the plant cell and surrounding tissue by destroying cell turgidity and decreasing intercellular adhesion. Loss of turgor occurs when the protein in the cell wall is denatured by heat. This changes the permeability of the cell wall, allowing water and solutes to escape. Limp and flabby, the cell may now rupture leaving the constituents of the plant cell wall exposed to chemical degradation (Weier and Stocking, 1949).

Cooking also changes the pectic substances in the middle lamella. Moisture and heat convert the insoluble protopectin in carrots and parsnips to water-soluble pectin, leading to a decrease in the cementing power of the middle lamella, a loss of cellular adhesion, and a softening of tissues as the cells begin to separate (Simpson and Halliday, 1941).

The extent of cellulose hydrolysis has been debated. Simpson and Halliday (1941) reported cell rupture and a small amount of cellulose hydrolysis in carrots and parsnips. No evidence of this was seen in carrots cooked up

to sixty minutes by Sterling (1955). He later reported that cellulose exhibited limited hydrolysis, hemicellulose was only broken down in alkaline solutions and lignin resisted all chemical action (Sterling, 1963). Polysaccharides bound to lignin also resisted hydrolysis (Isherwood, 1955).

Hellendorn et al. (1975) reported no difference in the crude fiber content of food measured before and after cooking. Van Soest (1965) found that heat in the presence of moisture produced insoluble proteins with lignin-like characteristics. The insoluble proteins, caused by the non-enzymatic browning known as the Maillard reaction, falsely increased ADF and lignin values even though there was no increase in the fiber compounds themselves.

Cooking in boiling water increased the cellulose value in carrots, cabbage, broccoli and okra (Matthee and Appledorf, 1978). Significant increases in NDF and ADF were also indicative of the change in cellulose rather than in hemicellulose or lignin. Neither of these compounds were affected by cooking except in the long cooked broccoli.

McConnell et al. (1974) studied the effect of cooking on the physical properties of dietary fiber. They reported no significant differences in water-holding capacity, although three out of four vegetables exhibited a slight increase in the cooked sample. Only small changes, of a variable nature, occurred in the ion-exchange capacity of

cooked vegetables. Hellendorn (1978) hypothesized that the increased water content of cooked vegetables improved the digestibility of dietary fiber in vivo. Cooking disrupted the cell structure, generated the breakdown of hydrogen bonds and allowed digestive enzymes easier access to fibrous compounds.

### Texture in Food

Texture is defined as a characteristic of food that combines the mechanical and geometrical properties of the food mass with sensory perceptions. Mechanical properties are described by the terms tough, tender, hard, chewy and brittle. Geometrical properties deal with arrangement of the particles: the size and shape of the substance and whether it is coarse, grainy or fibrous. Sensory perceptions are related to mouthfeel and are those feelings other than flavor that produce sensations in the mouth (Corey, 1970).

Texture has been measured objectively with instruments that produce a force over the food mass and cause changes in its size and/or shape. A read-out system records the force in pounds. The greater the force, the tougher the sample (Szczesniak, 1972). Hard et al. (1977) reported the maximum force to shear raw carrots was 967.9 pounds per sample. They tested one constituent of dietary fiber, lignin, and found no correlation between lignin content

and hardness and crispness of raw carrots.

Corey (1970) has described the most commonly used instruments to measure texture: (1) Warner-Bratzler Shearing Device - A single blade is driven through the sample at a constant speed in order to shear or separate it into two or more parts. (2) Kramer Shear Press - Multiple blades are driven through the sample at a constant rate resulting in a combination of shearing and compression. (3) Texturometer - The force needed to penetrate the sample is measured by a device that simulates chewing. The Instron Universal Testing Machine performs a variety of these tests by offering a changeable test cell (Szczesniak, 1972).

Numerous problems with the accuracy of texture measurements have been described in the literature. Finney (1972) reports that texture measurements may change from one point to another within the food mass due to differences in the strength of the middle lamella. The instruments provide several sources of errors that make it difficult to correlate results from other studies. These include differences in the sharpness of blades, variable alignment and warpage (Szczesniak, 1972). The instruments provide one objective measurement of force, although texture is a combination of mechanical properties and human sensations (Szczesniak, 1972). Sensory evaluations will often differ from objective measurements

(Corey, 1970). For accurate texture measurements, sample preparations must be standardized. This includes precisely defining the size and shape of the test sample and uniformly loading it into the test cell (Kramer, 1972).

## MATERIAL AND METHODS

Vegetable Selection

Cauliflower and carrots were used to test the hypothesis that the percent of dietary fiber in vegetables would remain the same whether the vegetable was raw or cooked and that any apparent increase that might occur would be due to changes in the water-absorbing capacity or ash content of the dietary fiber. These vegetables were selected for two reasons: they can easily be divided into samples that are representative of the total structure and they may be served either raw or cooked.

Sample Preparation

## Cauliflower

The cauliflower purchased was Marion Snowball White, R-Proved (grown at Shane Farms, Mt. Vernon, Washington and harvested at eighty-five days). Twenty heads of cauliflower were trimmed of outer leaves, washed and cut into approximately equal quarters. The quarter to be used for the raw NDF determination was cored, ground in the blender and mixed well. A representative sample of 14 to 16 g was measured and set aside. The quarter, including the core, to be used as the cooked sample was placed in a one quart aluminum saucepan with 60 ml of distilled water. It was cooked

three minutes to boiling on high heat and then covered and cooked four more minutes on medium heat. After cooking, it was removed from the heat and drained after five minutes. The temperature curve was recorded from the core during cooking. After cooling the core was removed from the quarter. One flowerette weighing between 20.0 and 21.5 g and of fairly uniform size was removed for the texture reading. The remaining portion was ground in the blender. A representative sample of 14 to 16 g was measured for the NDF determination. Samples for the NDF determination were treated with liquid nitrogen and blended to obtain samples of uniformly fine particle size.

### Carrots

Twenty carrots were selected from a twenty-five pound bag of jumbo carrots grown in Bakersfield, California. Each carrot was washed, peeled and cut lengthwise into two approximately equal halves that were weighed. Each half was then cut into three sections 5 cm long, and the radius of each section was measured at the narrowest end. The smallest section from one half was set aside for the NDF determination of the raw carrot. Three sections from the other half were placed in a one quart aluminum saucepan with 60 ml of distilled water. They were cooked three minutes to boiling on high heat and then covered and cooked five minutes more on medium heat. After cooking, they were

removed from the heat and drained after five minutes. Of the three pieces that were cooked, one section, having a radius between 1.6 and 1.9 cm, was used to record the temperature changes in the cooking vegetable. Another section with a radius of 1.4 to 1.5 cm was chosen for the texture reading. The smallest section, which matched the section in the raw carrot, was used for the NDF determination. Both of the sections to be used for NDF were cut into smaller pieces, treated with liquid nitrogen and ground in the blender to obtain samples of uniformly fine particle size.

### Laboratory Analyses

#### Temperature Reading

The temperature curve for the cooked vegetables was recorded on the Leeds and Northrup Multipoint Speedomax Recorder, Portland, Oregon. Chart speed was 12 in/hr: time between each point was 1.5 seconds.

#### Moisture Content

Raw and cooked samples were dried at 60°C in a vacuum oven to a constant weight. Weight loss divided by the weight of the sample times one hundred gave the percent moisture.

## Neutral Detergent Fiber

Dietary fiber was measured by the neutral detergent method of Van Soest and Wines (1967). To facilitate filtration of the refluxed sample, the sample size was limited to 0.50 to 0.54 g and refluxing time was staggered in fifteen minute intervals so that each sample could be filtered hot. No suction was applied when the sample was first poured into the filter crucible. Very low suction was then applied and gradually increased as needed to maintain a steady flow.

## Water-absorbing Capacity

The weighed NDF residue was combined in a test tube with 6 ml distilled water and incubated at 20°C for 24 hours as suggested by McConnell et al. (1974). After soaking, the resulting mass was drained through Vanlab filter paper, no. 74, for ten minutes. The tube was rinsed with 1 ml distilled water. The mass was scrapped from the filter paper and immediately weighed. The difference in weight between the NDF residue and the mass was the amount of water absorbed by the dietary fiber. The difference between water-holding capacity determined by McConnell et al. (1974) and water-absorbing capacity determined in this study was that the water-absorbing capacity test used the acetone-dried NDF residue without centrifugation.

The test was done for half of the twenty samples from each vegetable. The NDF residues of two samples were combined to provide a sufficiently large volume.

#### Ash Content

The remaining half of the NDF residues from each vegetable were used to determine the ash content. Residues were ashed at 600°C overnight, removed from the oven, cooled in a desiccator and weighed.

#### Texture Reading

The force necessary to shear the cooked samples was recorded with a Kramer cell attachment on the Universal Testing Instrument, Model 1132, Instron Corporation, Canton, Massachusetts. Chart speed was 12 in/min; cross-head speed was 20 in/min. The range was set at 10.

#### Statistical Analysis

The data were statistically analyzed using the Statistical Package for the Social Sciences, Version 8. The computer analysis was done by a statistician at Oregon State University. Paired t-tests and correlation coefficients were done (Steel and Torrie, 1980). Any p-value less than 0.05% was accepted as significant.

## RESULTS

Temperature

Mean value for the highest internal temperature reached in the cooking process was  $90.9 \pm 2.2$  (S.D.) $^{\circ}\text{C}$  for cauliflower and  $90.3 \pm 2.6^{\circ}\text{C}$  for carrots. Figures 1 and 2 present three representative heating curves for cauliflower and carrots, respectively.

Moisture Content

The moisture content of the raw cauliflower samples was the same as that of the cooked vegetables whereas it was slightly higher in the cooked carrots than in their raw counterparts. The mean moisture content of the raw and cooked cauliflower was  $91.9 \pm 0.7\%$  and  $91.9 \pm 0.5\%$ , respectively; that of the raw and cooked carrots was  $86.6 \pm 1.3\%$  and  $87.5 \pm 1.3\%$ , respectively.

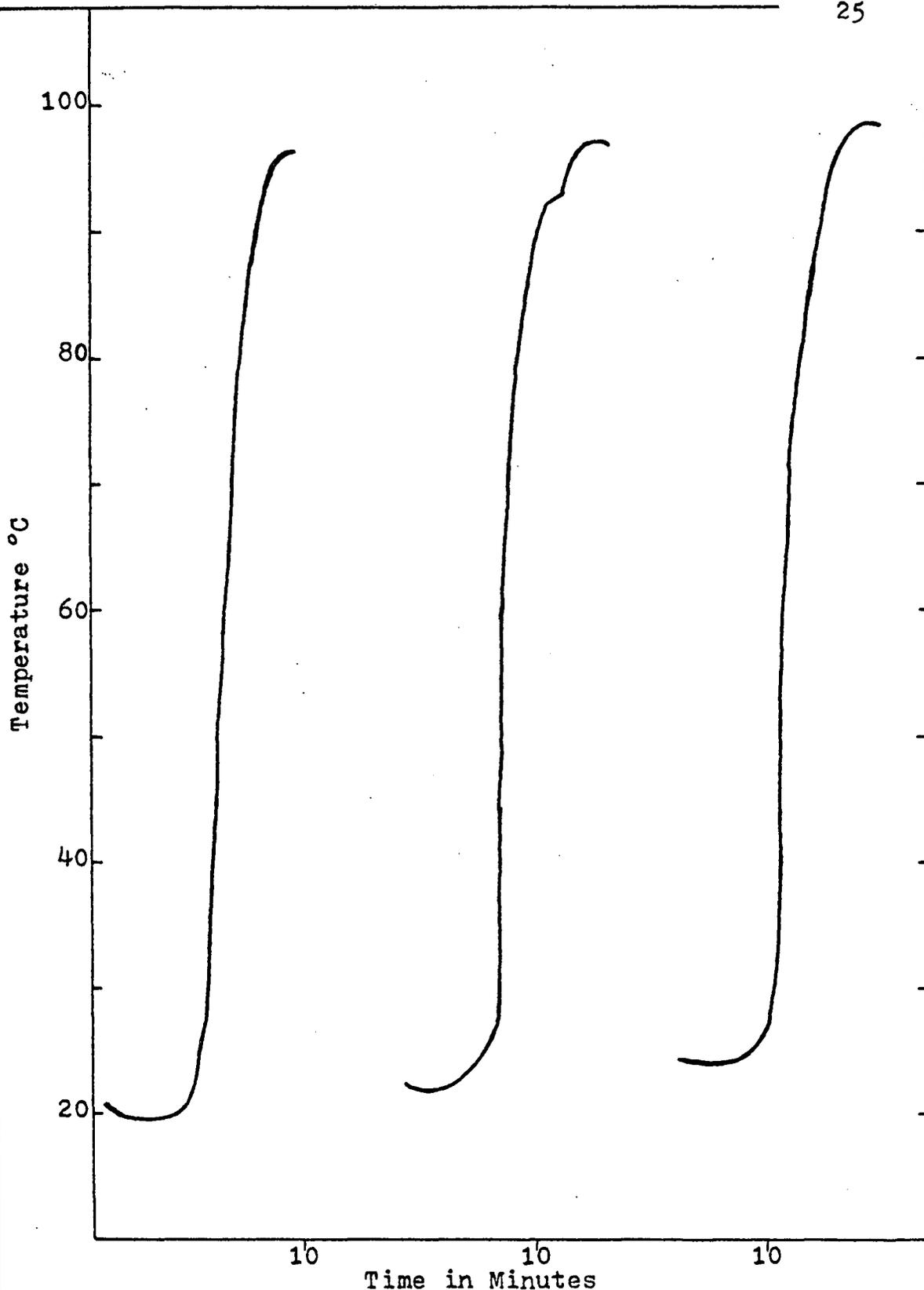


Figure 1. Representative heating curves for three cauliflower samples showing uniformity of the cooking process.

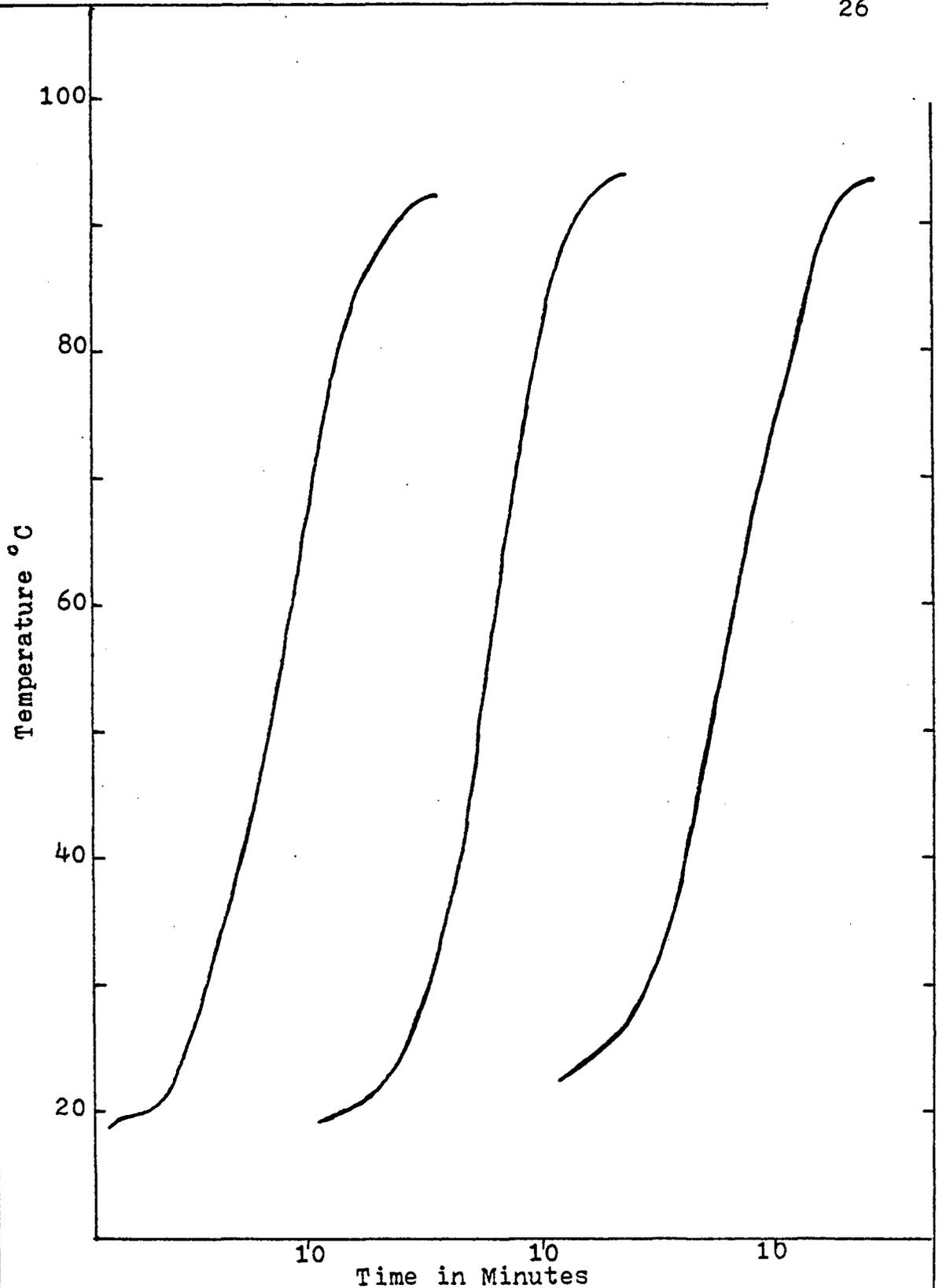


Figure 2. Representative heating curves for three carrot samples showing uniformity of the cooking process.

### Neutral Detergent Fiber

Figure 3 presents the effect of cooking on NDF in cauliflower and carrots. NDF was significantly lower ( $p < 0.05$ , paired t-test) in cooked cauliflower.\* The mean NDF, which was  $19.13 \pm 2.30$  g/100 g dry weight for the raw samples, decreased to  $17.22 \pm 2.18$  g/100 g dry weight for the cooked vegetables. Expressed in terms of 100 g of wet weight, the mean NDF in the raw and cooked samples was  $1.53 \pm 0.23$  g and  $1.38 \pm 0.21$  g, respectively ( $p < 0.05$ , paired t-test). Cooking significantly increased the NDF in carrots ( $p < 0.05$ , paired t-test). Mean NDF was  $9.47 \pm 0.98$  g/100 g dry weight for the raw sample and rose to  $10.54 \pm 0.94$  g/100 g dry weight in the cooked sample. In terms of 100 g wet weight, the mean NDF was  $1.27 \pm 0.14$  g and  $1.31 \pm 0.17$  g for raw and cooked carrots, respectively ( $p > 0.05$ , paired t-test).

The weight of the vegetables selected for the NDF determination varied greatly. The mean weight per one half head of cauliflower was 302 g, ranging between 179 and 438 g; that for carrots was 114 g, ranging from 66 to 151 g. No relationship was found between the weight of the vegetable and NDF content of either vegetable.

\* Three of the twenty cooked samples were excluded due to the occurrence of nonenzymatic browning during the drying process which caused elevated values. The NDF values for the cooked samples 1, 13 and 15, which were eliminated from the mean, were 26.3, 27.8 and 28.0 g/100 g dry weight, respectively.

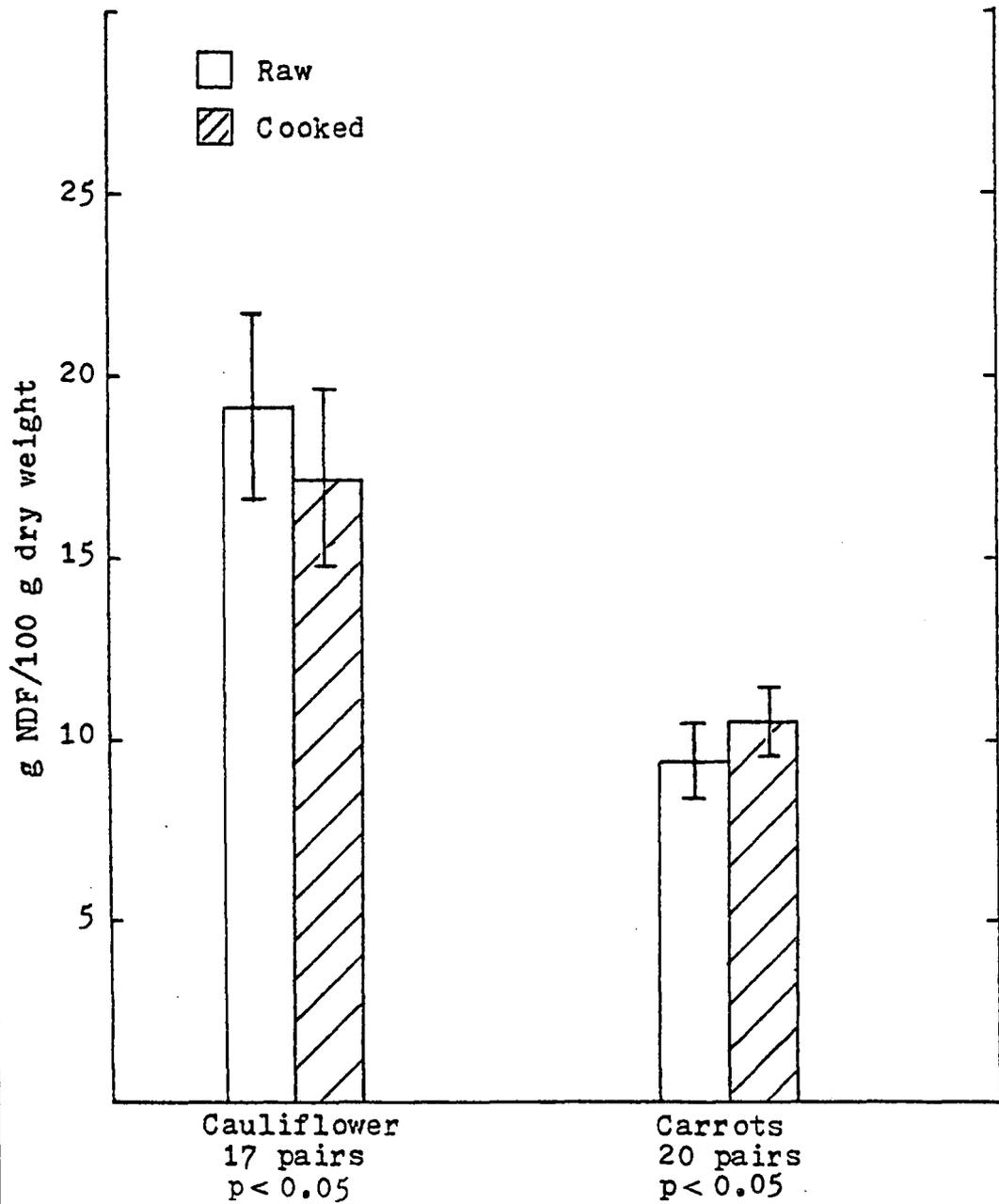


Figure 3. Histograms representing the amount of neutral detergent fiber in raw and cooked samples of cauliflower and carrots. Vertical lines indicate S.D.

### Water-absorbing Capacity

The effect of cooking on the water-absorbing capacity of NDF residue from cauliflower and carrots is depicted in Figure 4. For raw and cooked cauliflower, the mean water-absorbing capacity, in g water/g NDF, was  $17.2 \pm 5.1$  and  $19.1 \pm 4.2$ , respectively. Although individual variation was high, this increase was significant at  $p < 0.05$ , paired t-test. The mean water-absorbing capacity for carrots decreased from  $25.3 \pm 2.4$  to  $21.9 \pm 4.5$  g water/g NDF, but the difference was not statistically significant.

### Ash Content

The ash content of ten raw and ten cooked NDF residues was compared in both cauliflower and carrots. Raw NDF residues consistently produced no ash in either vegetable. A small amount of ash was measured in five cooked residues and three cooked residues of cauliflower and carrots, respectively. Cooking increased the mean ash content of the cauliflower NDF residue from zero to  $0.0012 \pm 0.002$  g/sample but it was not significant ( $p > 0.05$ , paired t-test). The increase in the ash content of carrot NDF residues was significant ( $p < 0.05$ , paired t-test). Mean ash content in grams/sample for raw and cooked carrots was zero and  $0.0004$ , respectively.

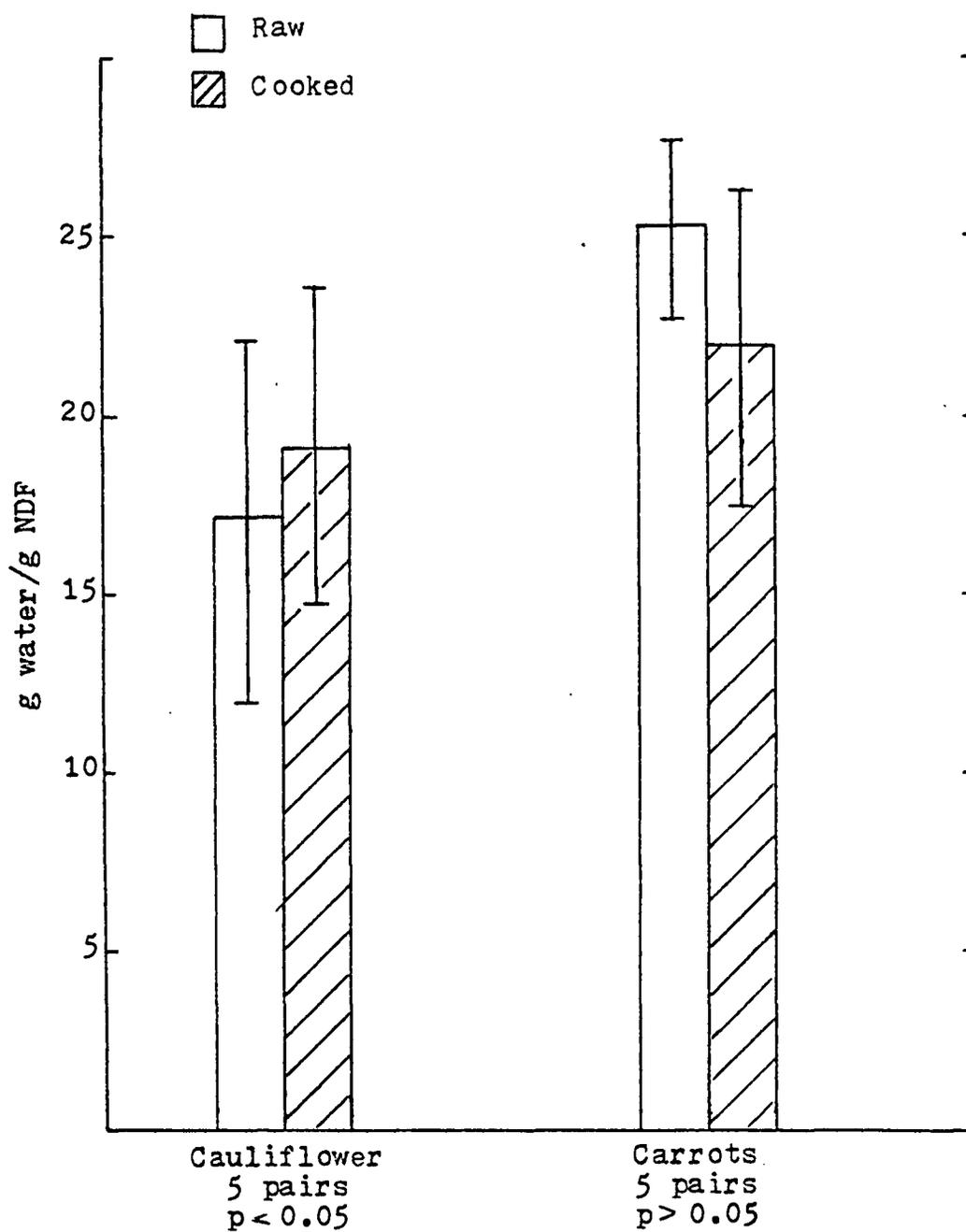


Figure 4. Histograms representing water-absorbing capacity in raw and cooked samples of cauliflower and carrots. Vertical lines indicate S.D.

## Texture

Figures 5 and 6 present the texture measurement for four cooked cauliflower and carrot samples, respectively. Due to great variation among the samples, there was no significant relationship between texture and NDF in either cooked cauliflower or carrots. Texture in pounds of pressure needed to shear cauliflower samples ranged from 76.0 to above 200.0; mean value was  $133.5 \pm 40.0$  lbs. The range for carrots was 50.0 to 200.0 + lbs.; the mean was  $134.8 \pm 52.8$  lbs. In Figure 6, the first and smaller peak on three of the four samples of carrots measures the pressure necessary to shear through the outer core and the larger peak measures the inner core.

## Correlations

The results of correlation analyses performed in the present study are given in Table 1. NDF in the raw vegetable and water-absorbing capacity and ash content in the cooked vegetable were significantly correlated with NDF in cooked cauliflower. Water-absorbing capacity in the raw cauliflower correlated significantly with water-absorbing capacity in cooked cauliflower. For carrots, NDF in the raw sample correlated significantly with NDF in cooked samples. A correlation between the force necessary to shear the cooked carrots with the weight of the sample

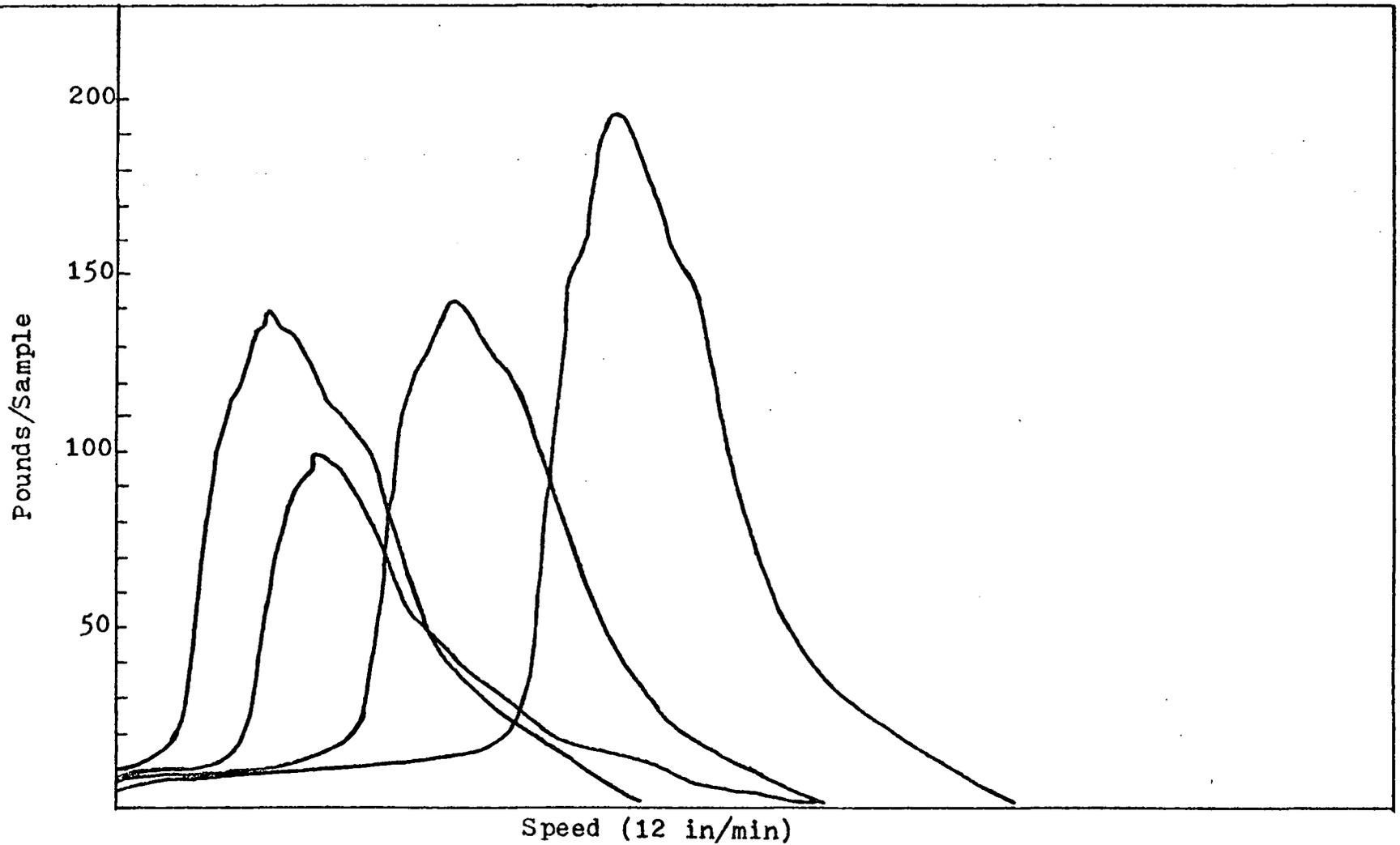


Figure 5. Variable shear force of four cooked cauliflower samples.

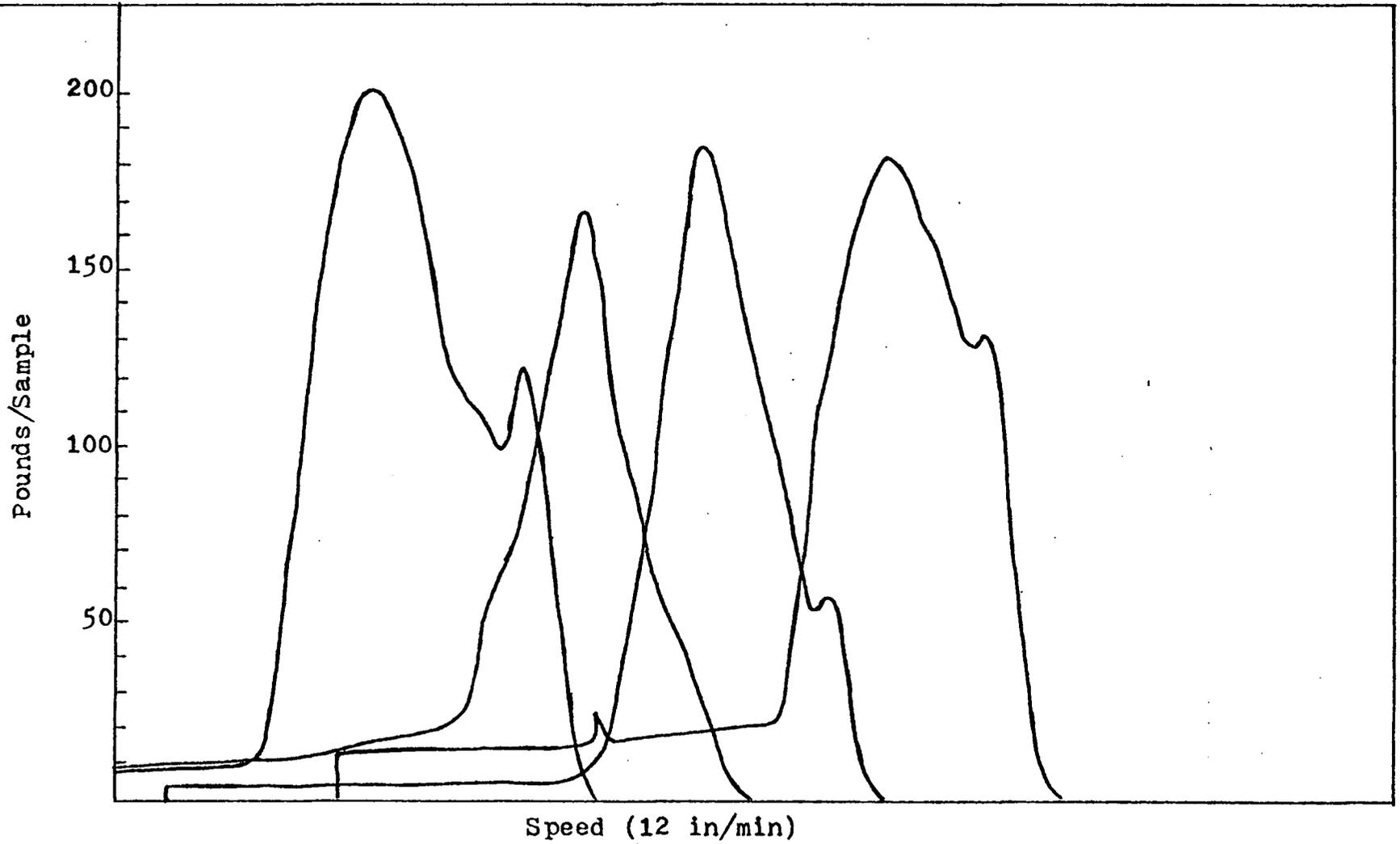


Figure 6. Variable shear force of four cooked carrot samples.

was sought but this relationship was not statistically significant ( $p > 0.05$ ). Neither vegetable exhibited a positive correlation between the moisture content and the NDF content or the water-absorbing capacity.

Figure 7 depicts the relationship between NDF (raw) and NDF (cooked) for both cauliflower and carrots.

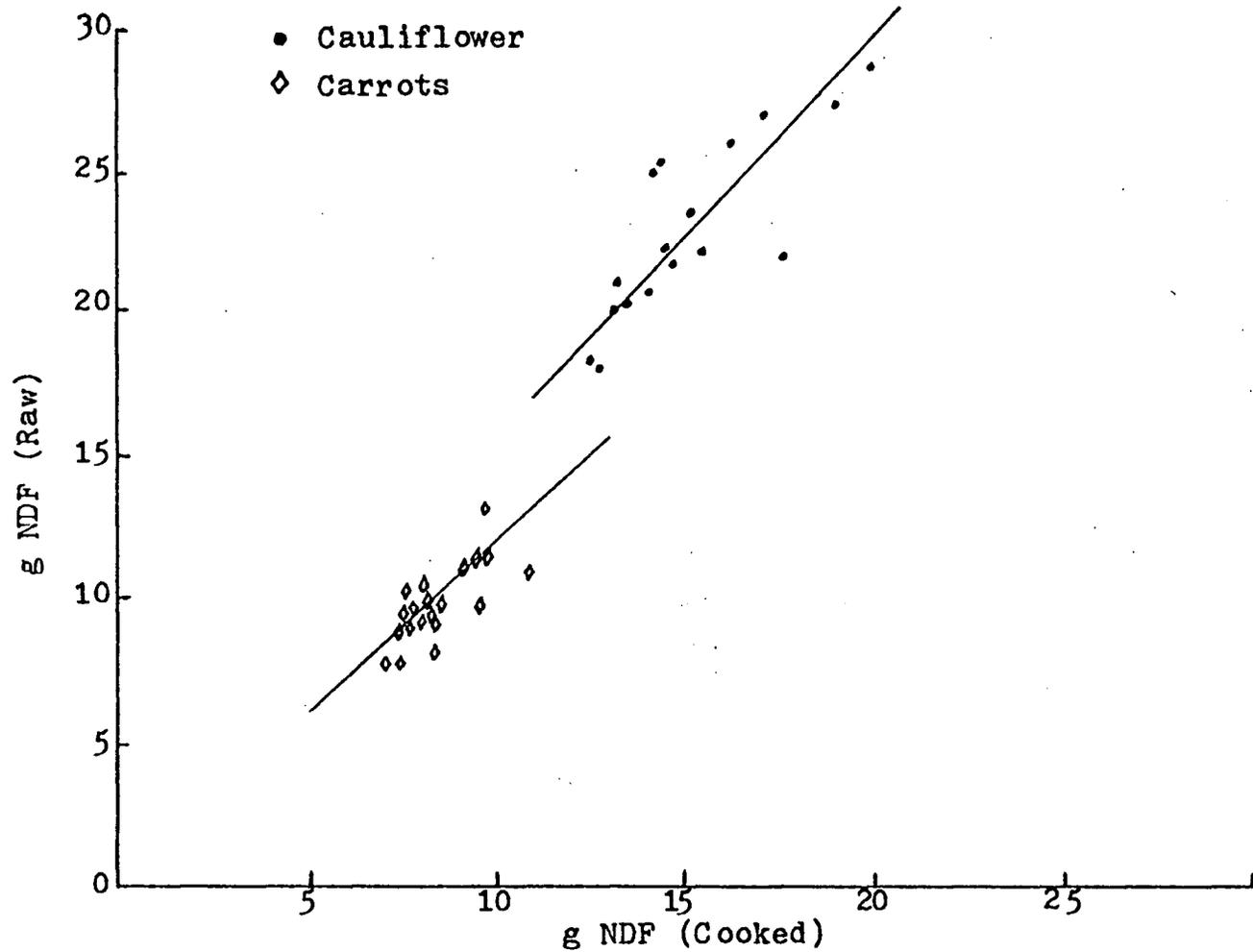


Figure 7. Scattergram depicting the relationship between NDF (Raw) and NDF (Cooked) in cauliflower and carrots.

Table 1. Results of correlation analysis.

| Variable                                     | Correlation coefficient | p-value |
|--|-------------------------|---------|
| I. Cauliflower                               |                         |         |
| NDF(R) <sup>1</sup> vs. NDF(C) <sup>2</sup>  | 0.7977                  | 0.001   |
| Ash content(C) vs. NDF(C)                    | 0.7324                  | 0.016   |
| Water-absorbing(C) vs. NDF(C)                | 0.9006                  | 0.037   |
| Water-absorbing(R) vs.<br>water-absorbing(C) | 0.9633                  | 0.008   |
| Pounds pressure vs. NDF(C)                   | 0.1570                  | 0.592   |
| %Moisture(R) vs. NDF(R)                      | 0.1030                  | 0.694   |
| %Moisture(C) vs. NDF(C)                      | 0.0090                  | 0.973   |
| %Moisture(R) vs.<br>water-absorbing(R)       | 0.2432                  | 0.694   |
| %Moisture(C) vs.<br>water-absorbing(C)       | 0.2813                  | 0.648   |
| II. Carrots                                  |                         |         |
| NDF(R) vs. NDF(C)                            | 0.6949                  | 0.001   |
| Pounds pressure vs. weight                   | 0.6515                  | 0.057   |
| Pounds pressure vs. NDF(C)                   | 0.1013                  | 0.795   |
| %Moisture(R) vs. NDF(R)                      | 0.4428                  | 0.051   |
| %Moisture(C) vs. NDF(C)                      | 0.1132                  | 0.636   |
| %Moisture(R) vs.<br>water-absorbing(R)       | 0.0596                  | 0.925   |
| %Moisture(C) vs.<br>water-absorbing(C)       | 0.2808                  | 0.648   |

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<sup>1</sup> (R) denotes raw

<sup>2</sup> (C) denotes cooked

## DISCUSSION

The results of this study show that cooking consistently caused a slight change in the NDF content of cauliflower and carrots. NDF decreased in cooked cauliflower ( $p < 0.05$ ) and increased in cooked carrots ( $p < 0.05$ ). While the hypothesis stated that the percent of NDF would remain the same in raw and cooked samples, the fact that one vegetable decreased in NDF and the other increased after cooking suggests that the effect of cooking on dietary fiber is a complex phenomenon that can not be investigated easily.

Mean NDF value in raw cauliflower,  $19.13 \pm 2.3$  g/100 g dry weight, is close to the value reported by Van Soest and Robertson (1977) of 15.1 g/100 g dry weight. According to Van Soest and Robertson (1977), this amount of NDF in cauliflower is composed of 9.7 g cellulose, 4.3 g hemicellulose and 1.1 g lignin.

In the present study, cooking at a uniform time and temperature consistently reduced the NDF measured in cauliflower. It did not increase the moisture content of the cooked samples. Although a 1.8% increase in the moisture content of cooked cauliflower is listed in Agriculture Handbook No. 8 (1975), the failure to attain this in the present study may be due to variations in the cauliflower and difficulties in accurately determining

the moisture content (Joslyn, 1970). When tests were performed on the resulting NDF residues, the water-absorbing capacity of the cooked residues was significantly higher ( $p < 0.05$ ) than that in the raw residues. These data may not be meaningful, however, due to the small number of samples (5), the wide range of values that were obtained, the small sample size of the NDF residues and the crudeness of the method.

The relationship of water-absorbing capacity and moisture content to changes in NDF in cauliflower is unclear. The ability of dietary fiber to hold water is primarily attributed to the cellulose and hemicellulose portions (McConnell et al., 1974), which according to Van Soest and Robertson (1977) make up 92.7% of the dietary fiber in cauliflower. Although in vivo studies suggest that this water-absorbing capacity increases fecal bulk (Eastwood et al., 1977), it may not necessarily contribute to increased NDF measurements in vegetables during the cooking process. Instead, the slight decrease in NDF in cooked cauliflower observed in the present study may support the theory of Simpson and Halliday (1941) who reported a breakdown in the cell wall and limited cellulose hydrolysis in cooked carrots and parsnips. This would also be consistent with the theory of Hellendorn (1978) that the water absorbed by cooked vegetables is responsible for the breakdown of hydrogen bonds in their fibrous compounds

and their consequent solubilization. Therefore, it is reasonable to suggest that cooking effected the dietary fiber in cauliflower by promoting its breakdown into soluble compounds. Future experiments may be able to clarify this by measuring the solid contents of the drained cooking water.

Due to severe nonezymatic browning in three cooked samples, the data presented for cauliflower were based on seventeen instead of twenty pairs. During the drying process, the reaction of an amino group and a carbonyl group in the cauliflower formed insoluble proteins, called Maillard compounds, that respond like lignin in the NDF determination and cause elevated NDF values (Van Soest, 1965). These values were eliminated in order to reduce errors in the statistical analysis. In future experiments it may be helpful to note the intensity of the browning reaction in all the samples and compare them to the NDF values.

The results for carrots also indicate that the effect of cooking on dietary fiber is obscure. Cooking in boiling water increased the NDF measured in carrots from  $9.47 \pm 0.98$  to  $10.54 \pm 0.94$  g/100 g dry weight. It also increased the moisture content from 86.6 to 87.5%. At the same time, the water-absorbing capacity of the NDF residues decreased in the cooked samples. Again, these data must be questioned for the same reasons as mentioned above.

Van Soest and Robertson (1977) report that raw carrots contained 9.2 g NDF/100 g dry weight, composed of 6.6 g cellulose, 1.2 g hemicellulose and 1.4 g lignin. Compared to cauliflower, carrots have less cellulose and hemicellulose (84.7% compared to 92.7%) and more lignin (15.3% compared to 7.3%). The data suggests that the NDF in cooked carrots may have taken in less water, enabling the glycosidic bonds to withstand hydrolysis and the fibrous compounds to remain intact. Future studies to investigate the effect of cooking on NDF in vegetables may want to use samples with widely different proportions of cellulose, hemicellulose and lignin.

It is unclear why the NDF measurement increased in cooked carrots unless it was a consequence of increased adsorption of inorganic material to the fibrous compounds. Even though EDTA was used in the NDF method to bind inorganic ions, measurable ash was obtained in 40% of the NDF residues from the cooked vegetables.

Few researchers have studied the differences between dietary fiber in raw and cooked vegetables. Our data for carrots are similar to the results of Matthee and Appledorf (1978) who found that NDF in carrots, cabbage, broccoli and okra increased with cooking. They did not study cauliflower or investigate water-absorbing capacity or ash content of their vegetables. They concluded that the increase was due to measuring cellulose which had been released

from broken cell walls. This supports Simpson and Halliday (1941) who saw cell rupture but contrasts with Hellendorn (1978) who hypothesized that cell rupture leads to cellulose solubilization and a decrease in its measurement.

McConnell et al. (1974) studied water-holding capacity and reported no significant differences in several vegetables that were either raw or cooked. The differences observed in the present study may be due to the fact that water-absorbing capacity was done on the NDF residue without centrifugation whereas McConnell tested the whole vegetable.

McConnell et al. (1974) also studied the ion-exchange capacity of several vegetables. The capacity for carrots was twice that of cauliflower: 2.4 mequiv/g acetone dried powder compared to 1.0 mequiv/g acetone dried powder. In the present study, the NDF residue was ashed; and although ash was only found in part of the samples, the presence of inorganic matter was significantly higher for carrots but not for cauliflower.

Texture and its relationship to dietary fiber in vegetables has not been examined in previous studies. The present investigation was limited by several factors: first, no data could be collected for raw vegetables because the Instron could not measure forces high enough to shear them; second, due to the natural variation among vegetables, it was difficult to choose samples of the same

size and weight; and third, the destructive nature of the test prevented the use of the same sample for both texture and NDF measurements. In order to reduce these variables, the size and weight of the cauliflower samples were defined as precisely as possible and the carrot samples for both NDF and texture measurements were always taken from the same portion of the carrot.

The results of the texture measurement revealed great individual variation among samples and no positive correlation between texture, as measured by shear force, and NDF in cooked cauliflower and carrots. This supports the concept that food is a complex structural material whose texture is not easily defined or measured (Finney, 1972). It also indicates that textural qualities, such as hardness or toughness, do not necessarily predict the fibrous structure of the vegetable, as measured by NDF.

It was interesting to observe the shear force readings for carrots. A majority of the curves showed two peaks (Figure 6). The first and smaller peak appeared to measure the force necessary to shear through the outer rim. The second and larger peak measured the inner core and indicated that it was tougher than the outer rim. Future research might incorporate sensory evaluations into the experimental design in order to relate sensory perception, texture and degrees of cooking.

No previous investigations have been done to compare the physiological effects of raw and cooked vegetables. The findings suggest that cooking will affect the physical properties of NDF in an undetermined manner and that the quantity of NDF may be slightly increased or decreased depending on the vegetable. On a wet weight basis, the NDF in cauliflower decreased from 1.53 to 1.38 g/100 g ( $p < 0.05$ ); that in carrots increased from 1.27 to 1.31 g/100 g ( $p > 0.05$ ). Compared to bran, (Southgate et al., 1976), the actual quantity of NDF in carrots and cauliflower is small and the changes due to cooking are slight.

Future experiments in which the subjects alternately consume dietary fiber in raw and cooked forms will help clarify this point on physiological properties. At this time, however, it is reasonable to suggest that both raw and cooked vegetables will produce similar physiological effects and the changes due to cooking are not of nutritional importance.

## CONCLUSION

The present study was undertaken to investigate the effect of cooking on the NDF content of cauliflower and carrots. For each replication the vegetable was divided in half to serve as its own control. One half was used raw and the other half was cooked in a uniform amount of distilled water for a specified amount of time. Consistent internal temperatures of the cooked samples verified a uniform cooking process. Moisture and NDF were determined for both raw and cooked samples. A texture reading, determined by shear force, was also done on the cooked sample. Resulting NDF residues from the raw and cooked samples were used to compare water-absorbing capacity and ash content.

The effect of cooking was not consistent in cauliflower and carrots. The NDF decreased in cooked cauliflower and increased in cooked carrots. The water-absorbing capacity of the raw and cooked NDF residues were compared in both vegetables, but the crudeness of the method made it difficult to produce consistent results. A comparison of the ash content in raw and cooked NDF residues was also hindered because ash was only present in some of the samples. Therefore, it is impossible to determine the reasons for the changes in the NDF content.

The results of the study suggest that cooking will

only cause slight decreases or increases in the fiber content of vegetables and that differences may depend on the vegetables' physical structure and composition.

In terms of the physiological effects of dietary fiber, these changes may not be nutritionally important.

Definite conclusions must await future investigations.

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