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CARROT CHIP DEVELOPMENT AND OTHER
SOURCES OF DIETARY FIBER

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CARROT CHIP DEVELOPMENT AND OTHER SOURCES OF DIETARY FIBER

By

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ABSTRACT

CARROT CHIP DEVELOPMENT AND OTHER SOURCES OF DIETARY FIBER

By

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Carrot chips were prepared from a modified spicy wheat chip formulation, substituting 0 to 40% carrot powder and/or a combination of 12 to 26% carrot powder with 4 to 8% commercial cellulose for wheat flour, to study the feasibility of producing a high vegetable fiber snack.

Incorporation of carrot powder and cellulose into the carrot chip formulation improved color, texture, and flavor quality characteristics. All carrot chips were scored higher than the control wheat chips.

Enzymatic Neutral Detergent Fiber Analysis of more than fifty items indicated that good dietary fiber sources could be obtained from products containing vegetables, fruits, cereals, cereal brans, nuts, plant seeds, and commercial celluloses. Substitution with carrot powder up to 40% and cellulose up to 8% produced carrot chips with 7.43 and 12.58% Enzymatic Neutral Detergent Fiber respectively. All bran, bran buds, Tortilla chips, and Swedish rye crispbread all contained over 30% Enzymatic Neutral Detergent Fiber.

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INTRODUCTION

Whether increasing the amount of dietary fiber in our diet is beneficial is still controversial. Fiber advocates believe that an optimum amount of dietary fiber can prevent gastrointestinal diseases such as constipation (Burkitt et al., 1972), diverticulitis (Painter and Burkitt, 1971), bowel polyps, colonic cancer (Burkitt, 1974), and appendicitis (Burkitt, 1971, Walker et al., 1973). Ischaemic heart disease (Trowell, 1972), obesity (Walker, 1964), and gallstones (Burkitt et al., 1974) are also possibly related to a dietary fiber deficiency.

Dietary fiber functions primarily as bulking and cation-exchanging agents and thereby it promotes bowel function regularity, shortens intestinal transit time, and may prevent gastrointestinal diseases.

Eating a high fiber diet can have some side effects, such as a feeling of being "stuffed" or "bloated" (Harlan, 1977). Since fibers have ionic exchange capacities, large amounts can impair the body's ability to absorb certain important nutrients such as iron, copper, and calcium (Eastwood, 1977). Although much more research is needed before the full role of dietary fiber in human diets is known, low fiber consumption may be related to the higher

incidence of gastrointestinal diseases. Scientists, however, have not yet determined how much fiber one should consume. Currently there is no Recommended Daily Allowance for fiber.

Current studies on the role of dietary fiber reveal that both the source and the amount of dietary fiber have changed during the last century (Friend, 1967). A marked reduction in consumption of cereals has occurred in Western diets during the past century. Along with this reduction, an increased amount of animal products, highly refined cereals, and sweet foods have been consumed (Burkitt, 1973).

To introduce fiber back into the American diet, consumption of such foods as vegetables, cereals, cereal brans, bean hulls, nut skins, plant seeds, seaweeds, plant exudates, commercial cellulose, and synthetic gums will have to increase.

It is also possible to increase the level of dietary fiber in foods commonly consumed but increasing the level of dietary fiber in a food system may have a significant effect on the quality characteristics of a product. Food researchers have increased the amount of dietary fiber in various food products with dietary fibers. Several research papers indicated that various bakery products are feasible fiber carriers, i.e., bread (Tsen, 1975; Lorenz, 1976; Pomeranz et al., 1976; Khan et al., 1976; Prentice and D'Appolonia, 1977; Casey and Lorenz, 1977; and Volpe and

Lehmann, 1977), Cake (Rajchal et al., 1975; Brockmole and Zabik, 1976; Zabik, et al., 1977; Shafer and Zabik, 1978), biscuits (Brys and Zabik, 1976) and sugar-snap cookies (Khan et al., 1976; Casey et al., 1977; and Vratanina, 1978).

The purpose of this research was to evaluate several foods for their dietary fiber content. Cereal grains, vegetables and fruit were thought to have potential as dietary fiber sources, therefore selected commercial cereals and whole grain flatbreads, crackers, cookies and snack foods as well as homemade bakery products were analyzed for dietary fiber. This research also developed a spicy carrot snack food using carrot powder and cellulose to increase the fiber content of a modified oriental spicy wheat chip to provide another choice for consumers should they want to increase their dietary fiber consumption.

REVIEW OF LITERATURE

Nature of Dietary Fiber

Cummings (1976) summarized the different professional viewpoints of fiber. To the cereal chemist, fiber is cellulose. To the animal nutritionist, it is the insoluble matter indigestible by animal enzymes while the human nutritionist considers fiber to be the unavailable carbohydrates and lignin. Trowell (1974) defined dietary fiber as the remnants of the plant cell-walls that are not hydrolyzed by the alimentary enzymes in the human body.

All dietary fibers, except lignin, are complex polysaccharides which behave as structural units in the plant. The major components of the plant cell-walls are cellulose, hemicellulose, lignins, pectin substances, and traces of gums and mucilages; these are present in varying degrees in all plants and natural plant products (Table 1).

Structural Materials of the Plant Cell-Walls

The plant cell-walls are made of a number of discrete layers, and the relative size and composition of these layers change as the cell matures (Reese, 1963). The first stage in the formation of a new cell-wall is the appearance of the cell-plate which is characteristically rich in pectic substances. This extends until it meets the existing

Table 1. Components of dietary fiber[1]

Principal sources in the diet	Description	Classical nomenclature
Structural materials of the plant cell-walls	Structural polysaccharides	Pectic substances Hemicellulose Cellulose
	Non-carbohydrates constituents	Lignin and mineral components
Non-structural materials either found naturally or used as food additives	Polysaccharides from variety of sources	Pectic substances Gums Mucilages Algal polysaccharides Chemically modified polysaccharides

[1]Southgate (1976)

walls and becomes the middle lamella. The secondary cell-wall, also is made up of a number of distinct layers. In these layers the cellulose fibrils lie parallel to one another at an angle to the axis of the cell. The matrix is composed of hemicelluloses; the proportion of cellulose in the secondary cell-wall may be of the order of 20 per cent. In the successive layers of the secondary cell-wall the angle of the fibrils to the axis tends to become less acute (Figure 1).

As the cell matures lignin is deposited in the matrix, the process of lignification starts in the middle lamella and continues toward the inside of the cell. Lignification seems to involve infiltration of the matrix with lignin rather than replacement of the hemicellulose (Figure 2).

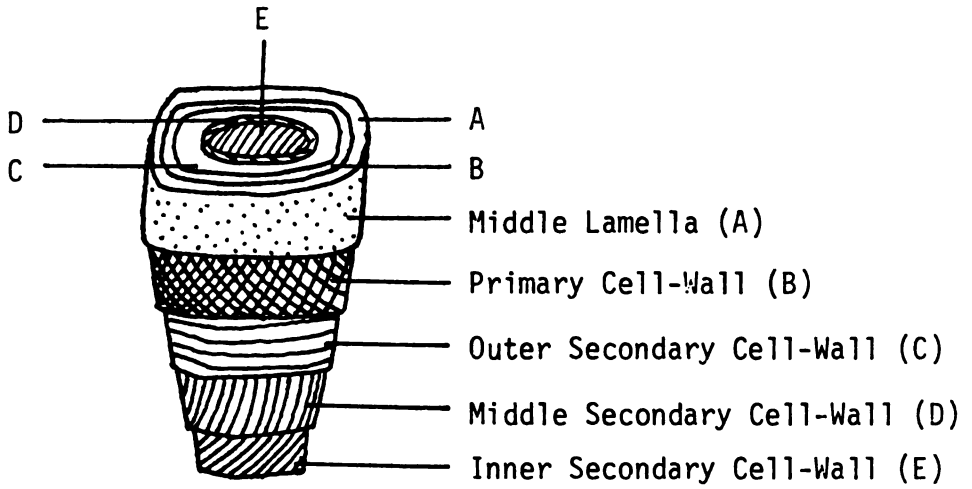


Figure 1. The layers of the cell-walls of cellulose fibers (Reese, 1963).

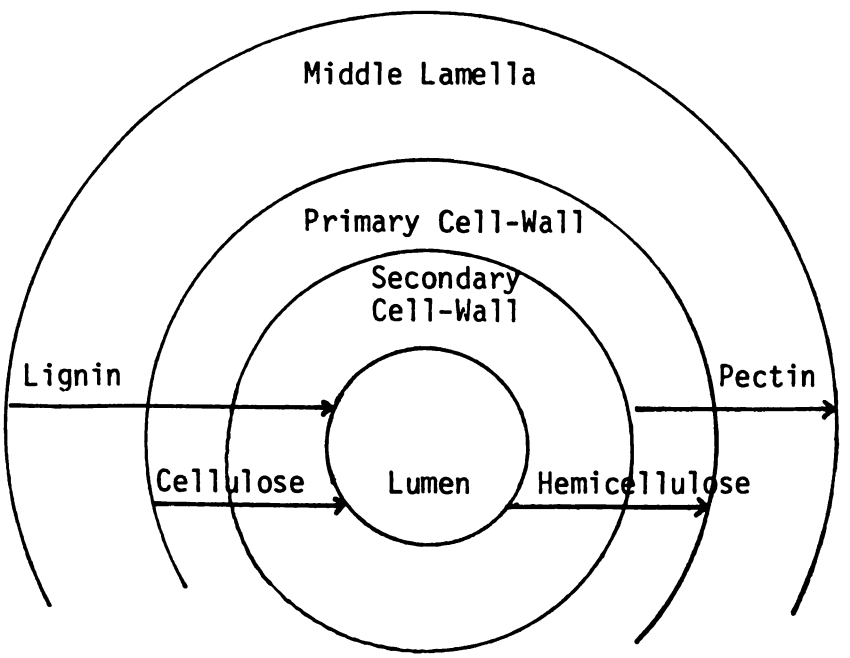


Figure 2. The structure of the plant cell-wall and its major component distribution. Arrow shows the increasing amount of distribution.

Crystalline cellulose is in the highest concentration near the lumen and diminishes toward the primary cell-wall. Hemicellulose predominates in the primary cell-wall and its concentration diminishes toward the lumen, making its distribution pattern opposite to that of cellulose. The rapidly growing young plant tissues have a high concentration of pectic and hemicellulose, whereas the more mature tissues such as stalks, stems, and leaves have a higher lignin and cellulose content (Eastwood, 1974).

Chemistry of the Dietary Fiber

The chemistry of the major components of the plant cell-walls were summarized by Southgate (1976) and are presented in Table 2.

Pectic substances are basically polymers of 1,4-β-D-galacturonic acid. Most of the pectin heteropolysaccharides also contain D-galactose, L-arabinose, D-xylose, L-rhamnose, and L-fucose. The carboxyl groups of D-galacturon acid may be partly esterified by a methyl group. These carboxyl groups also bind with cations such as calcium and magnesium to form insoluble salts. This ion-binding capacity is closely related to its free uronic acid content. Protopectin is the water-insoluble parent pectic substance that occurs in plants and which on restricted hydrolysis yields pectin. Pectic acid is the pectic substance made only from polygalacturonic acid. Pectin is a partly esterified pectic acid (Cummings, 1976).

Table 2. The chemistry of the major components of the plant cell-walls[1]

Classification	Method of isolation	Types of structure	Preferred nomenclature
Pectic substances	Soluble in water in the presence of chelating agent	Galacturonans, arabinans, galactans, arabinogalactans	Part of non-cellulosic, matrix polysaccharide fraction (ideally as specific polysaccharides)
Hemicellulose	Soluble in diluted alkali, precipitated with acid and alcohol	Mixture of heteroglycans, usually rich in xylose and containing other sugars (arabinose, galactose, mannose, and uronic acids	Major part of non-cellulosic matrix, polysaccharide fraction (usually as specific polysaccharides)
Cellulose	Insoluble in alkali but soluble in 72% w/w H_2SO_4	1,4-β-D glucan with trace of other sugar	Cellulosic fraction
Lignin	Insoluble in 72% w/w sulfuric acid and alkali	Aromatic polymers based on phenyl propane units	Lignin

[1]Southgate (1976)

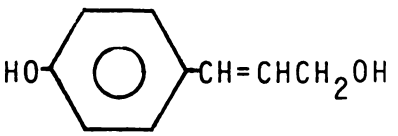
Hemicellulose is made up of long chains of such monosaccharides as xylose, galactose, glucose, mannose, and arabinose (Cummings, 1976). It is soluble in cold dilute alkali, The molecules of hemicellulose, which contain between 150 to 200 sugar units are much smaller than cellulose. They are also more amorphous than cellulose molecules, although some xylans exhibit a crystalline structure. Southgate and Durnin (1970) reported that approximately 85 per cent of hemicellulose undergoes bacterial degradation in the large bowel. The important properties of hemicellulose are its water-holding capacity and ion-binding capacity, and therefore hemicellulose contributes great bulk by swelling in water.

Cellulose is a linear polymer of 1-4 linked β-D-glucopyranose residues (Aspinall, 1970). The materials exist as extremely thin long fibrils which contain a central crystalline region that is pure cellulose, but are surrounded by a coat of mixed polysaccharide chain of xylans and mannans. Cellulose is not hydrolyzed by human alimentary enzymes, and this fine network which is interwoven with hemicellulose and small amounts of partially digestible cellular content, travels to the intestine. Southgate (1975b) assessed that approximately 15 percent of the cellulose present will undergo bacterial degradation in the large bowel.

Lignin is a highly insoluble non-carbohydrate cell-wall material (Neish, 1965). It is an extremely aromatic

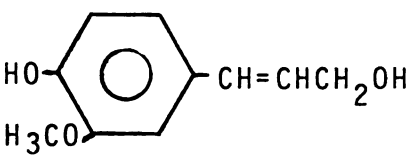
polymer of three different phenylpropane units derived from three alcohols as follows:

4-hydroxyphenylpropane is derived from coumaryl alcohol;



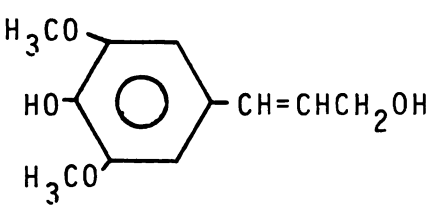
Coumaryl alcohol

guaiacylpropane (4-OH-3-methoxypropane) is from coniferyl alcohol;



Coniferyl alcohol

and 3,5-dimethyl-4-OH-phenylpropane is from sinapyl alcohol.



Sinapyl alcohol

The links between the basic units are complex. Unlike other cell-wall structures, it is a small polymer having a molecular weight of between 1000 to 4500. The basic units of the polymer are joined by carbon-to-carbon bonds, unlike the glycoside and acetal links of the carbohydrates. Lignin's role in the cell-wall is to strengthen the other constituents. In general, wood contains up to 40 to 50 percent lignin in the cell-wall, while wheat cell-walls

contain 23 per cent, cabbage 6 per cent, and apple 25 per cent (Southgate, 1969). Animal nutritionists indicated that lignin impairs the digestibility of other cell-wall polysaccharides and thereby reduces the potential energy available from many common forages used in ruminant nutrition (Van Soest, 1973). Lignin is thought to have bile-salt-binding properties through hydrophobic interactions (Eastwood and Hamilton, 1968).

Non-structural materials either found naturally or used as food additives include plant gums, mucilages, and seaweed extracts. They are usually indigestible in the human alimentary tract. Aspinall (1970) classified gums into the following five groups:

Galactan Group. This includes gum arabic and the exudate gums of a number of other Acacia species. The galactans are a β-galactan linked β(1-3) with side chains of β(1-6) galactopyranosyl chains terminating with glucuronyl residues. These gums undergo autohydrolysis in solution of very weak acid, leading to a loss of arabinose.

Glucuronomannan Group. In the glucuronomannan group the main chain consists of alternate glucopyranosyluronic acid and mannopyronosyl residues, and the side chains are of galactosyl residues linked β(1-6) attached to the main chain by an arabinopyronosyl group. Examples of the plant gums belonging to this group are damson and cherry gums and gum ghatti.

Galacturonorhamnan Group. The gums in this group contain a main chain of D-galacturonic acid and L-rhamnosyl groups. The ratio of these residues varies from gum to gum. Examples include stercularia gum and khaya gum.

Xylan Group. Only a few xylan gums have been studied. Sapote gum and the polysaccharides from the corns and seed cases of Watsonia are structurally related but are more complex than the xylans which have been found as cell-wall components.

Xyloglucan. Xyloglucan is the gel-forming polysaccharide extracted from the seed of tamarind. The interior chain of xyloglucan resembles cellulose but the side chains vary. The detailed structure of this group has not been defined.

Mucilages that are present in many seeds possess water-holding properties and are composed of acidic and neutral fractions. The acidic component contains a main chain of D-galacturonic acid and L-rhamnose. The neutral component includes galactomannans, glucomannans, arabinoxylans, and xyloarabinans. Xyloarabinans are usually closely related to acidic polymers.

Seaweed gums are mainly from algal polysaccharides and include agar, alginate, carrageenan, and furcellaran (Glicksman, 1969). They are dietary fibers and are not hydrolyzed by mammalian digestive enzymes.

Cellulose also occurs in many species of algae. Structural studies on many algal polysaccharides have

confirmed that they are usually linear β-D(1-4) mannans, and β-D(1-4) and (1-3)-linked xylans, respectively. Alginic acid is an important algal polysaccharide used frequently as a food additive. Alginic acid is insoluble in water but readily soluble in aqueous solution of alkalimetal hydroxides and carbonates, and these alginate salts yield viscous solution in water. Alginates that are rich in L-guluronic acid have higher pK values. Those alginates rich in mannuronic have higher calcium affinity in a sodium-calcium ion-exchange reaction (Southgate, 1976).

Both agar and carrageenan are dietary fibers containing the sulfated D- and L-galactans which are extracted from algae with boiling water (Glicksman, 1969). The gel formation of the algal polysaccharides depends on the proportion of 3,6 anhydrogalactose residues. The gel-forming characteristics of both agar and carageenan have been widely used in the food industry; these molecules of relatively high ester sulfate composition being preferred. Carrageenan has the ability to combine with protein to form protein-gel complexes. It is also a good thixotropic material and can be used as a suspending agent in the preparation of chocolate milk. Agar is relatively resistant to bacterial attack and is capable of holding great amounts of water, thereby increasing fecal bulk. Agar has been used as a laxative agent (Shung, 1963).

Furcellaren is made from Furcellaria. It is composed mainly of D-galactose and 3,6-anhydro-D-galactose units and

a half sulfate ester. Furcellaren also has been used as a food additive (Glicksman, 1969).

Synthetic gums commonly used in the food industry are cellulose derivatives. Since cellulose itself occurs in a highly bonded triple strand, alkyl or hydroxyalkyl groups are substituted on each anhydro-glucose unit of the cellulose chain. This results in disorder and causes separation of the cellulose strands so that water or other solvents may enter to solvate the chemically modified cellulose. The substitution groups such as hydroxyethyl, sodium carboxylmethyl, methyl, ethylhydroxyethyl, and hydroxypropyl allow the formation of products with wide range of functional properties (Glicksman, 1969).

Physical Properties of Dietary Fiber

One of the most important properties of the plant dietary fiber is the capacity of the endogenous polysaccharides and other macromolecules to swell when exposed to water.

Water-Holding Capacity

Water-holding capacity may vary with the plant fiber sources due to the differences in the hydrophilic polysaccharide content. The water-holding capacity appears to be greatest in the vascular tissues such as roots, stems and leaves; and is less marked in storage organs as shown in Table 3. Table 4 summarizes the fiber content and water

Table 3. Water-holding capacity of acetone dried food stuffs[1]

Acetone dried food materials	Water-holding capacity (gm water/gm acetone dried powder)
Maize	1.47
Oatmeal	1.82
Potatoes	2.00
Banana	2.90
Broad bean	3.00
Pea	4.10
Cauliflower	4.60
Pear	5.90
Green bean	7.40
Turnip	8.10
Winter cabbage	9.00
Tomato	9.70
Spring cabbage	10.80
Brussels sprouts	11.30
Apple	11.40
Orange	12.10
Onion	12.40
Rhubarb	13.90
Aubergine	14.50
Celery	17.30
Mango	19.20
Cucumber	20.40
Carrot	23.40
Lettuce	23.70

[1]McConnell et al., 1974

Table 4. Water-holding capacities of food fiber[1]

Foods	% fiber in raw materials	Water-holding capacity (gm water/gm fiber)	Capacity of water absorption in 100 gm of raw vegetables (gm water)
Turnip	4.0	9.0	37
Potato	19.5	2.0	41
Rhubarb	4.2	14.4	60
Banana	22.7	2.9	68
Cauliflower	11.6	5.9	68
Tomato	6.6	10.8	71
Broad bean	18.8	4.1	77
Cucumber	3.7	20.9	77
Celery	6.0	16.2	97
Pea	21.6	4.6	99
Lettuce	4.2	23.7	99
Green bean	12.4	8.1	100
Pear	15.3	7.4	113
Orange	9.9	12.4	122
Maize	86.1	1.5	129
Aubergine	7.5	17.3	129
Apple	14.6	12.1	177
Carrot	8.9	23.4	208
Mango	15.3	20.4	312
Bran	89.3	3.0	447

[1]Eastwood and Mitchell, 1976

holding capacity in terms of fiber content as well as fresh weight basis as described by Eastwood and Mitchell (1976). The water-holding capacity based on fiber content ranges from 5 to 6 times (gm water/gm fiber) for bran and up to 35 times (gm water/gm fiber) for lettuse, carrots, and cucumber. However, when water-holding capacity is based on total weight most raw fruits and vegetables including potatoes and turnips have the least ability to absorb water, whereas the mango, carrots and bran are most efficient in absorption of water.

Ion-Exchange Capacity

The acid polysaccharides of fruits and vegetables have a cation-exchange capacity. The divalent metals may be absorbed by dietary fiber to a degree dependant on the presence of unsubstituted uronic acid groupings (Walters et al., 1975). Smidsrod and Haug (1965) indicated that divalent metals such as calcium, have a great effect on gel formation and precipitation properties of sodium alginate. The ion-exchange capacities of vegetable fiber were measured by titration with sodium hydroxide after conversion of the fiber to the acidic form by treatment with excess hydrochloric acid (Hofmann, 1967). Most of the vegetables act as monofunctional weak cation-exchange resins. Maize, oatmeal, banana, cereal bran, and new potatoes act as very weak polyfunctional cation-exchangers; in these, the hydrogen ion dissociates from the uronic acid groups at different

pH levels in the titration curve. McConnell et al. (1974) reported the cation-exchange of acetone-dried food powders. Old potatoes, tomatoes, cucumbers, onions, celery, aubergine, apples, turnips, carrots and spring cabbages all had a high cation exchange capacity (Table 5).

Parrott and Thrall (1978) investigated the physical property differences of 12 commercial fiber sources on their particle size, density, hydrated volume expansion, water-holding capacity, and temperature. They found that each fiber has its own distinct functional properties. In most cases, dry density has a linear relationship to the hydrated density. However, in terms of pH and ionic strength, mono- and divalent cations were highly indifferent. Therefore, the individual fiber responses to processing condition should be taken into consideration when selecting a fiber source.

The Role of Dietary Fiber in Human Nutrition

Studies have indicated that most dietary fiber is indigestible in human alimentary systems. Although dietary fiber contributes little food value, it does play an important physio-chemical role in the human digestive system. Van Soest (1977) reported that dietary fiber undergoes chemical changes through flora fermentation in the colon and releases volatile fatty acids with substantial caloric value. Van Soest suggested that fiber might be considered as a nutrient, despite its indigestibility, since it has beneficial effects on the body similar to those of other

Table 5. Cation-exchange capacity of acetone dried powder[1]

Acetone dried food materials	Cation-exchange capacity mEq/gm acetone dried powder	Degree exchange
Old potato	0.3	strong
Pear	0.6	medium
Pea	0.8	medium
Broad bean	0.9	medium
Cauliflower	1.0	medium
Tomato	1.0	strong
Cucumber	1.1	strong
Brussels sprouts	1.1	medium
Onion	1.3	strong
Green beans	1.4	medium
Winter cabbage	1.5	medium
Celery	1.5	strong
Rhubarb	1.7	medium
Aubergine	1.8	strong
Apple	1.9	strong
Turnip	2.3	strong
Orange	2.4	medium
Carrot	2.4	strong
Spring cabbage	2.4	strong
Lettuce	3.1	medium

[1] McConnell et al., 1974

nutrients

Dietary Fiber and Colon Function

Water soluble dietary fibers such as pectin, mucilages and pentosans (water-soluble hemicellulose) undergo microbial degradation in the colon to produce low molecular weight volatile fatty acids, water, carbon dioxide, and methane (Olmstead and Williams, 1936). These microbial metabolites and the physical presence of other indigestible dietary fibers affect intestinal function. Burkitt et al. (1972) and Cummings (1973) indicated that dietary fiber is essential for normal bowel function by promoting regularity, soft stools, and a rapid transit-time.

Effect on Stool Weight. Food materials composed of high amounts of unavailable carbohydrates have a great water-holding capacity. Also, the various dietary fiber components absorb water to different degrees. The pectic substances and hemicelluloses have a high water-holding capacity. Cellulose absorbs water moderately, while lignin is more hydrophobic, absorbing little water but is significantly active in bile acid absorption at an acid pH. In the colon, pectin absorbs a great amount of water and serves as a cementing material combining all the indigestible lignin, cellulose, hemicellulose, bile acids, and other metabolites. Thus ingesting food materials with mixed dietary fiber components enhances formation of a large amount of soft stool which fills the colon and promotes bowel movement regularity.

Kirwan et al. (1974) and Brodribb and Groves (1978) reported that the particle size of wheat bran affected in vivo laxation by increasing water-holding capacity and stool weight. Brodribb and Groves (1978) reported that there was no significant difference in defecation rate between the two types of bran, but with coarse bran, stool weight was significantly greater than with fine bran. Fine bran increases the pressure within the rectum, therefore coarse rather than fine bran is preferred for prescription (Eastwood, 1977).

Effect on Transit-time. Transit time is the time taken for the passage of food material from the mouth to the anus. Burkitt, et al. (1972) postulated a logarithmic relationship between daily stool weight and transit time; the shorter transit time being related to higher stool weight. When cereal bran was ingested in combination with a normal diet, it not only caused an increase in stool weight but also a decrease in transit-time. This effect has been shown in normal subjects (Burkitt et al. 1972; Brodribb and Groves, 1978) and also in patients with diverticular disease (Mitchell and Eastwood, 1976). However, not all subjects exhibited shortened transit-time when given bran (Harvey et al., 1973). Both banana and guava showed contradictory effects on laxation and constipation. This discrepancy was believed to be related to the degree of maturity of both fruits. The proportion of the various components of dietary fiber in a mixed diet is also an important factor in the determination of stool weight and transit-time.

Dietary Fiber and Gastrointestinal Diseases

Epidemiological studies have indicated that gastrointestinal disorders are related to the low-residue of fiber-depleted diets. In the more developed countires, fiber consumption from cereal sources was greatly reduced by the introduction of new milling techniques and changes in dietary patterns. Consumption of cereals in the form of porridge has also diminished. Cereal fiber intake has probably fallen to one tenth of the pre-1870 figure. Although consumption of fruit and vegetable fiber has increased, these sources apparently have much less effect on bowel physiology than does cereal fiber (Hoppert and Clark, 1945).

Diverticular Disease. Fiber-depleted diets may cause disease directly through the effect of lack of fiber on the bulk and consistency of stools, and the transit-time (Burkitt, 1976). Diverticular disease occurs as a result of hypersegmentation of the colon (Painter et al., 1975). The propulsion of the small, firm stools along the colon will result in increased pressures in the lumen of the bowel. This pressure will cause areas of weakness in the colon to bulge and thus produce small pockets or diverticulae (Burkitt, 1975). Segmentation and consequent pressure generation may be caused by many stimuli including eating habits, mechanical or emotional disturbances and drugs such as morphine (Painter, 1975). A rapid transit-time as provided from a high fiber diet does not produce strain on the

sigmoid and does not favor the development of diverticula.

Colonic Cancer. Prolonged transit-time of the large bowel has been thought to be related to low fiber diets (Eastwood and Mitchell, 1976). The hypothesis of Burkitt et al. (1972) suggested that prolonged transit-time provides more time for bacterial proliferation and thus causes increased microbial degradation of bile acids to potential carcinogens. The degree of microbial degradation is dependent on the nature of the carbohydrates reaching the large bowel. Generally, mature plant fibers such as brans ferment less completely than those of vegetable cell-walls. Lignification of plant material limits the microbial fermentation (Van Soest and Robertson, 1977). Thus vegetable dietary fiber yields more volatile fatty acids via fermentation than those fibers from concentrated cereal grain. The bulking effect of dietary fiber may act to dilute the carcinogen, thereby serving as a protective mechanism in the prevention of colonic cancer.

Constipation. Constipation is a state of inadequate bowel motility. It is caused primarily by an insufficient bulk-forming capacity of the habitual diet (Avery Jones and Godding, 1972). Burkitt (1974) postulated that constipation and fecal stagnation may result in raised intraluminal pressure and prolonged exposure of the lower alimentary mucosa to carcinogenic substances in the feces. Thus, foods which enhance constipation could lead to polyps and cancer.

Appendicitis. Appendicitis may be related to consumption of a low residue diet that increases the viscosity of the feces (Walker, 1976). This causes the formation of fecaliths and excessive segmentation of the appendix which results in obstruction of the appendix lumen. The obstruction can cause the intraluminal pressure to sufficiently devitalize the appendicular mucosa and thus allow bacterial invasion.

Hiatus Hernia. Hiatus hernia is a protrusion of the upper end of the stomach into the thoracic cavity (Burkitt, 1976). Increased intra-abdominal pressures may contribute to the production of hiatus hernia.

Burkitt (1974) emphasized epidemiological and chronological data which associated bowel diseases, venous disorders, and hiatus hernia with obesity, diabetes mellitus, and coronary heart disease. Cleave et al. (1969) reported that removal of fiber from carbohydrate foods apparently leads to over consumption and over absorption of the refined foods.

Dietary Fiber and Lipid Metabolism

Eastwood and Boyd (1967) reported that a considerable amount of bile acids bind to unabsorbable materials in the small intestine. Lignin particularly tended to be more hydrophobic in nature and actively bound bile salts at an acid pH. Story and Kritchevsky (1976) suggested that fiber inhibited cholesterol absorption by binding bile salts;

such absorption would increase bile acid excretion, and cause an increase in bile acid synthesis in order to replace the lost bile salts. Both events would drain cholesterol pools.

Birkner and Kern (1974) studied in vitro absorption of bile salts to food residues, finding significant binding of sodium glycocholate and sodium chenodeoxycholate to hemicelluloses from apple, celery, lettuce, potato, and string bean. Wheat fiber did not lower the plasma cholesterol in hamsters and human beings (Truswell and Key, 1975). Nevertheless, rolled oats and whole ground oats were found to lower plasma cholesterol in experimental animals (Fischer and Griminger, 1967). These researchers also reported that citrus pectin and other gums have a significant effect on the reduction of plasma cholesterol in man. Truswell and Key (1975) found that methoxy pectin had a great effect on lowering cholesterol levels in the rat, especially when dietary fat was low. Leveille and Sauberlich (1966) suggested that the mechanism of the action of pectin was to inhibit cholesterol absorption and increase fecal bile acid excretion. Cellulose has not been found to lower plasma cholesterol in human experiments unless very large amounts of cellulose were fed (Prather, 1964; Eastwood et al., 1973). Forsythe et al. (1976) reported that fiber did not decrease serum cholesterol in rats, when compared to fiber-free group. The uronic acid content of rice also reduced cholesterol levels in plasma (Truswell, 1976).

Side Effects of Dietary Fiber

Fiber intake increases the fecal loss of certain important nutrients (Eastwood, 1977). Cereal bran as well as vegetables and fruit fiber have cation-exchange capacities which may increase the excretion of both mono- and di-valent cations such as sodium, potassium, calcium, and magnesium, in normal subjects. Fiber ingestion causes fecal loss of lipids and nitrogen (Southgate, 1973) and leads to a slight energy loss.

Suggestions for Recommended Daily Allowance of Fiber

Spiller (1977) assumed that an intestinal transit time less than three days would not cause colonic intraluminal stress. Therefore, he suggested a daily allowance of any fiber component of combination yielding a transit time of no longer than three days. Based on correlation between fecal weight and transit time, this allowance can be converted to the amount of fiber which produces at least 150 gm of fecal weight per day. This suggestion must be adjusted for individual body weight, sex, age, and type of fiber ingested.

Analyses of Dietary Fiber

Recent studies have emphasized the nutritional function of the dietary fibers of plant origin. This has initiated a series of modifications in the methodology of fiber content determinations.

There are five methods that have been developed and used to determine fiber content. All five methods are based on the extraction of a uniformly air-dried sample to remove excess lipid. The fat free or low fat (less than 2 per cent by weight) sample is then extracted successively with various reagents to remove all digestible constituents. These methods use different reagents to obtain varying degrees of accuracy in fiber content determinations.

Crude Fiber Analysis (CFA), the oldest method and an Official Method of Analysis of the Association of Official Analytical Chemists (AOAC), determines primarily the residue left after a sequential hot digestion with 1.25% sulfuric acid and 1.25% sodium hydroxide solutions (AOAC, 1975). The Crude Fiber (CF) method determines approximately 50 to 90% of the celluloses, 20% of the hemicelluloses, and 10 to 40% of the lignins, based on the total weight of a sample (Schaller, 1977). Therefore Crude Fiber Analysis underestimates the total dietary fiber content value.

Acid Detergent Fiber Analysis (ADFA) was developed by Van Soest (1963) and has been accepted as an Official Method for feed by the AOAC. He reasoned that the addition of a detergent, cetyltrimethylammonium bromide to the acid extraction, could minimize the nitrogenous materials which were present in the residue of the crude fiber. Therefore, the Acid Detergent method gives a more accurate measure of the cellulose and lignin components than that of the Crude Fiber method.

Buffered Acid Detergent Fiber Analysis (BADFA) was developed by Baker (1977). It is a modified Acid Detergent method using a hydrochloric acid-potassium chloride buffer solution as a solvent for the detergent. Baker claimed that the HCl-KCl buffer solution is less corrosive than sulfuric acid and its pH is within that of the human stomach digestive medium, so it can be used to simulate the action of human digestive processes. He analyzed the fiber in cereal samples by the CFA, ADFA, and BADFA methods. The result was that the BADFA had the highest recovery of cellulose and lignins; in addition most starches and proteins were removed.

Neutral Detergent Fiber Analysis (NDFA) was developed by Van Soest (1963) using a neutral detergent, sodium lauryl sulfare, to measure the total cell-wall constituents in vegetable food stuffs. This method simulates the action of the human gastrointestinal digestive system. The final residue includes all the cellulose, water insoluble hemicellulose, lignins, traces of pectins, gums, mucilages, cutins, and starches. However, the NDFA method is difficult to filter and to remove starch and protein, especially in samples of high starch content. NDFA underestimates the total dietary fiber since the hot water soluble carbohydrates, such as pectins, gums, mucilages, and pentosans (water soluble hemicellulose), are lost in the filtrate.

In the Enzymatic Neutral Detergent Fiber Analysis (ENDFA), Van Soest and McQueen (1973) suggested that the addition of alpha-amylase and proteolytic enzymes, prior to

the neutral detergent extraction, aids in obtaining a more complete digestion of starch and protein in the sample, so that one can overcome the difficulties of filtering and foaming during extraction. A suitable lipid extraction, prior to the enzymatic hydrolysis, will also largely resolve these problems. ENDFA is more accurate for samples with high starch and protein content, but it still underestimates the total dietary fiber content.

Sources of Dietary Fiber

Fiber values obtained from NDF method approximate those of dietary fiber, but very few samples have been analyzed by this method. Spiller and Fassett-Cornelius (1976) compared NDF data, true fiber, and crude fiber of limited number of fruits, vegetables, grains (Table 6) and cereal products (Table 7) (Spiller and Amen, 1975).

Several other Crude Fiber and Neutral Detergent Fiber Analyses of bakery materials from natural grains and cereal brans are shown in Table 8 and 9 (French, 1977) and Table 10 (Shafer and Zabik, 1978).

Southgate (1976) compared the total dietary fiber and specific composition of the dietary fiber component of selected vegetables (Table 11) and wheat products (Table 12). His data indicates that the total dietary fiber in both vegetables and fruits is relatively low on a fresh basis, although it represents a substantial proportion of the solids in some of these foods. The lignin values for most

Table 6. Approximate dietary fiber content of some common food stuffs (gm/100 gm dry matter)[1]

Food	NDF %	Total pectin (TP) %	True fiber (TF) %	Crude fiber (CF) %	Approximate error (CF/TF) %
Apple	12	17	29	9	69
Cabbage	14	5	19	8	59
Carrots	9	9	18	6	79
Lettuce	17	4	21	12	43
Whole corn	13	negligible	12	3	77
Whole oats	31	negligible	31	13	58
Wheat bran	45	negligible	45	11	76
Rice bran	24	negligible	24	13	46

[1] Spiller and Fassett-Cornelius (1976)

Table 7. Comparison of neutral detergent fiber and crude fiber value in selected foods[1]

Foodstuff	Dry Matter (%)	Neutral Detergent (%)	Crude Fiber (%)
White pan bread, enriched	64.2	3.3	1.7
Whole wheat bran	64.4	14.9	5.1
Kelloggs All Bran	97.3	34.0	9.2
Kelloggs Special K	96.2	7.4	1.1
Kelloggs Corn Flakes	96.3	7.9	1.4
Nabisco Shredded Wheat	95.5	22.4	3.6
Ralston Purina Wheat Chex	96.4	17.6	3.5
General Mills Cheerios	94.0	8.8	2.7
General Mills Wheaties	95.0	13.8	3.0

[1] Spiller and Amen (1975)

Table 8. Comparative fiber data from crude fiber and neutral detergent fiber analyses[1]

Foodstuff	Neutral Detergent Fiber (%)	Crude fiber (%)
Wheat bran	34.8	7.4
Linseed meal	20.2	7.2
Soy hull	63.1	36.0
Rice bran	21.3	7.0
Soy concentrate flour	7.2	3.1
Corn germ meal	43.9	11.2
Corn bran	61.7	14.6

[1]French, 1977

Table 9. Proximate analyses of various agricultural products[1]

Foodstuff	Protein (%)	Fat (%)	Ash (%)	Crude Fiber (%)	Other carbo-hydrates (%)
Wheat bran	17.2	4.3	6.0	9.6	62.9
Wheat shorts	19.5	5.4	5.5	8.4	61.6
Wheat middlings	17.8	4.0	6.5	10.2	61.5
Wheat germ	27.9	8.3	5.6	4.3	53.9
Wheat germ, defatted	30.4	0.8	5.9	4.5	58.4
Bran from bulgur operations	16.3	5.8	3.6	10.9	63.4
Corn hull	6.9	1.7	1.3	14.4	75.5
Corn germ (dry milling)	16.4	21.4	11.9	8.3	42.0
Corn germ expeller cake	19.0	6.2	7.3	6.0	61.5
Corn gluten feed	20.0	2.9	3.9	7.9	64.9
Corn germ (wet milling)	13.0	37.4	1.1	7.8	40.7
Corn germ (wet milling defatted)	25.2	3.4	2.2	12.0	57.2
Barley sprouts	28.8	1.7	5.6	14.8	49.1
Barley screenings	11.5	2.8	16.7	13.1	55.9
Barley dust	19.3	2.3	13.6	17.7	49.1
Milo hulls	8.7	2.9	6.8	17.9	63.7
Soybean hulls	10.4	1.6	4.4	41.1	42.5
Linseed meals	39.0	4.6	8.8	7.5	40.1

[1] Frehch, 1977

Table 10. Proximate analyses of cereal brans[1]

Type	Moisture (%)	Protein (%)	Ether Extractable lipid (%)	Ash (%)	Neutral Detergent (%)
Corn	4.0	6.0	1.1	0.3	63.96
Soy	5.5	13.3	3.5	4.6	56.68
Oat	6.9	28.2	5.8	6.0	19.12
Commercial wheat	7.8	14.5	5.0	5.6	39.63
Soft white wheat:					
Ionia	6.7	14.2	4.5	5.6	38.22
Yorkstar	6.6	13.2	4.7	5.5	37.41
Soft red wheat:					
Oasis	7.4	15.5	4.9	5.4	38.46
Arthur	5.8	15.6	5.4	5.8	40.45
Hard red wheat:					
Comanchee	8.8	13.6	3.5	5.3	44.88
Shawnee	8.6	13.9	3.9	5.9	36.79

[1] Shafer and Zabik, 1978

Table 11. Total composition of dietary fiber in some fruits and vegetables[1]

Food	Total Dietary Fiber (g/100 g)		Composition of the Dietary Fiber (%)			Composition of the Non-Cellulosic Fraction (%)		
	On Fresh basis	On Dry weight basis	Non-Cellulosic Polysaccharides	Cellulose	Lignin	Hexoses	Pentoses	Uronic Acids
Cabbage (cooked)	2.83	32.6	37	63	Tr	16	55	28
Carrots (cooked)	3.70	28.6	60	40	Tr	20	35	45
Peas (frozen, raw)	7.75	47.6	69	27	2	48	22	30
Tomato (raw)	1.40	21.9	47	32	21	14	42	44
Apple flesh only	1.42	9.16	66	33	1	20	35	40
Banana	1.75	5.97	64	21	15	54	19	27
Pear flesh only	2.44	14.7	54	28	19	20	46	35
Plum raw flesh + skin	1.52	9.56	65	15	19	28	46	25
Strawberry raw	2.12	19.1	46	16	38	22	33	45

[1]Southgate, 1976

Table 12. The total dietary fiber and its composition in some wheat products[1]

	Total Dietary Fiber (g/100 g)[2]	Composition of the Dietary Fiber (%)			Composition of the non-cellulosic Polysaccharides		
		Non-Cellulosic Polysaccharides	Cellulose	Lignin	Hexoses	Pentoses	Uronic Acids
White Flour (72%)	3.45	80	19	1	80	11	9
Brown Flour (90-95%)	8.70	72	18	10	44	45	11
Wholemeal Flour	11.00	72	20	8	39	48	13
Bran	48.00	74	18	7	19	69	12

[1] Southgate, 1976

[2] On a dry matter basis

vegetables are very low. Fruits containing lignified seeds and cells such as strawberry and pear are high in lignin value. The noncellulosic polysaccharides in vegetables and fruits are usually rich in uronic acids and pentoses. Whole wheat and rye have relatively higher percentages of fiber than their representative refined flours. Total dietary fiber increases as the extraction rate of the flour is increased. Bran which contains very small amounts of endosperm represents the maximum fiber value. The lignin value of the flour also increases from low to high as the percentage extracted increases (Table 8).

Various fiber sources can be identified from current tables of food composition which list crude fiber data. This crude fiber data tabulated in Table 13 and 14 can serve as a guide to foods high in dietary fiber until an accurate quantification of dietary fiber content in foods has been clarified by the scientists. Several types of commercially purified fibers are now available (Lang and Briggs, 1976).

Avicel-Rc is a white hygroscopic powder containing 92% Microcrystalline cellulose and 8% sodium carboxymethylcellulose. It has been used in formulating varieties of low-caloric products, such as honey-flavored doughnuts, peanut butter dried mix, bran muffins, layer cakes, fibrous breakfast food, chocolate pudding, sauce, salad dressings and candy. Solka-Floc is a purified cellulose which contains 99.5% fiber (89% cellulose, 10% hemicellulose, 0.3%

Table 13. Crude fiber and calorie content of cereals, roots, tubes and seeds[1]

	Crude Fiber (%)	Calories (Kcal/100 gm)
Barley, whole dehulled	2.0	363
Barley, pearled	0.8	351
Whole maize	2.0	363
Maize meal, 96% extraction	1.5	362
Maize meal, 60% extraction	0.7	354
Corn flour	0.2	352
Whole millet	3.0	336
Millet meals	2.4	332
Oat meals	0.9	350
Brown rice	2.0	360
White skinned rice	0.7	354
Polished rice	0.25	352
Rye meal, 80 to 90% extraction	1.5	350
Whole sorghum	2.0	355
Whole wheat meal - 100% extraction	1.6 - 2.1	344
Whole wheat meal - 85% extraction	0.4 - 0.9	346
Whole wheat meal - 70% extraction	0.2	350
Wheat bran	10.5 - 13.5	300
Cassava, fresh	1.0	153
Cassava flour	1.5	342
Irish potatoes	0.4	75
Sweet potatoes	1.0	114
Sago flour	trace	352
Plantain	0.3	128
Banana	0.3	128
Fresh yam	0.5	104
Sugarcane stem	2.1	50
Chick pea	2.8	368
Fenugreek	7.2	335
Dry ground nuts	3.0	579
Horse gram	5.3	338
Kidney bean	4.0	339
Lathyrus pea	15.0	293
Lentil	4.0	339
Lima bean	5.0	326
Mung bean	4.5	329
Pea, mature	4.5	337
Pea, immature	1.0	70
Pigeon pea	7.0	328
Soybean mature	4.5	382
Soybean, immature	1.9	139
Oil seeds, nuts, most varieties	2.5	400-700
Sesame seeds	12.3	166

[1] Burkitt and Trowell, 1975

Table 14. Crude fiber and calorie content of vegetables, fruits and seaweeds[1]

Foodstuffs	Crude Fiber (%)	Calories (Kcal/100 gm)
Most vegetables[2]	0.5-1.5	30-50
Most fruits[2]	0.5-1.5	50-150
Dried dates[2]	2.4	303
Dried figs[2]	11.0	269
Orange peel, raw	3.7	92
Orange peel, dry	13.7	307
Lime rind	3.2	71
Kumquat fruit	1.5	48
Guava	5.6	69
Jackfruit, immature	2.8	53
Jujube (Chinese dates), dried	2.9	281
Jamaica-cherry	2.0	87
Grape	3.5	69
Indian gooseberry	2.4	58
Fresh fig	1.5	59
Dried fig	7.2	278
Crabapple	1.7	89
Cranberry	1.4	46
Calabao	1.5	35
Apricot, dried	4.1	245
Sweet potatoes	1.6	42
Sesbania raw leaf	3.9	45
Agar, dried	2.7	83.5
Laver (porphya)	4.7	44.5
Seagirdle (Laminaria), dried	6.7	54.2
Eisenia bicyclis, dried	9.8	60.2
Heterochordaria abietina, dried	5.5	45.8
Hijikia fusiformis, dried	13.0	42.8
Prasiola japonica, dried	4.8	43.9
Undaria pinnatified, dried	3.6	51.4
Ulva lactuca, dried	4.6	46.7

[1] Leung et al., 1972

[2] Burkitt and Trowell, 1975

lignin, and 0.1% ash). Several food grades of Solka-Floc have been produced and have been used successfully in meat products, pasta products and snack foods (McCormick, 1976).

Nutrifibers are the product made from soybean hull, containing 40% fiber. Protex is a high protein, defatted rice bran and contains 6 - 8% crude fiber. By-products of both soybean and wheat millings have been suggested in the formation of expanded snack foods with excellent physical characteristics (Breen et al., 1977).

Use of Dietary Fiber in Food Systems

Both alpha-celluloses and cereal brans have been recommended as good sources of dietary fiber for their functional bulking properties in food and nutrition. Microcrystalline cellulose has been used as a partial substitute for wheat flours in the production of muffins, cookies (Lee et al., 1968), cakes and biscuits (Brys and Zabik, 1976) and mashed potatoes (Lee et al., 1968) for use in low calorie diets. Zabik et al. (1977) reported on substitutions with 8 kinds of celluloses (Solka-Floc BW-200, Avicel PH-101, Prototype sample #170-2, Prototype sample #174-2, Prototype #170-2, plus CMC, Prototype sample #174-2 plus CMC, Prototype sample #174-2 (85%) coated with 15% NF grade citric pectin, and 70% Prototype sample #174-2 coated with 30% NF grade citric pectin for 30% of the cake flour in high ratio layer cakes. The results indicated that all cakes were of good quality with few significant differences

occurring among the objective and sensory data. However, cakes containing pectin-coated cellulose had compact, gummy, soggy and dough-like textures and were slightly gray in interior color.

Rajchel et al. (1975) reported that up to 16% wheat bran and 12% middlings could be successfully used in place of flour and incorporated into chocolate, banana, nut and spice cakes. Brockmole and Zabik (1976) also indicated that replacement of flour with 16% wheat bran and 12% middlings in white layer cakes was acceptable. They found that the particle size of the bran used in these cakes could affect the quality characteristics. Springsteen et al. (1977) indicated that the fineness of grind was important for successful incorporation of bran into cakes and found that substitution of 30% of the cake flour with a finely ground bran produced acceptable cakes. The behavior of wheat brans and other cereal brans in white layer cakes was compared by substituting three types of wheat brans (hard red, hard white, and soft red), corn bran, soy hulls and oat bran for 30% of the cake flour (Shafer ana Zabik, 1978). Successful results were obtained in the layer cake systems at the level of 30% substitution of wheat and corn brans. Though cake batters containing non-wheat brans had higher batter viscosities, the resulting cakes were less tender than the cakes made with wheat bran. In addition, cakes with oat and soy bran had less pleasant flavor and were not acceptable to taste panelists. These researchers indicated

that cakes could be successful carriers of dietary fiber in food systems.

Since the cellulose and hemicellulose levels in millet are high, millet is another source of dietary fiber. It is mostly consumed locally in Northern China, India, Africa and Southern Russia (Casey and Lorenz, 1977). Leavened breads cannot be made from 100% millet, since it does not contain gluten-forming proteins (Badi et al., 1976). The use of millet flours leads to rather compact pan breads with dense texture (De Ruiter, 1972). Therefore millets must be baked into flat breads, as is done in Eastern Europe and Africa. In the Western world millet flour has been substituted in bread, cookie, and biscuit formulations for part of the wheat flour. This results in a different and distinct flavor in these baked products. However millet flour alone does not produce acceptable cookies. Addition of soybean lecithin for millet flours at the 0.6% level greatly improved top grain and cookie spread. The quality of these cookies, however, was not that of cookies made solely with wheat flour. Biscuits formulated with millet flour and 10% wheat flour were given acceptable consumer responses in Nigeria (Casey and Lorenz, 1977).

Vratanina (1978) reported that highly acceptable cookies could be formulated by incorporating red and white wheat brans up to the 30% level in sugar snap cookies, and up to 50% in oatmeal cookies. A 30% substitution of flour with wheat bran in sugar snap cookies did not significantly

affect the top grain but did reduce the spread factor. Bran darkened the color and yielded more tender, less crisp cookies. Khan et al. (1976) incorporated coconut residue in sugar cookies at 5, 10, 15 and 20% levels. An excessive amount of water was required to mix an optimum sugar cookie dough when more than 10% coconut residue was incorporated. Cookies made with 20% coconut lowered the spread factor, but the aroma, taste and texture were acceptable. The crude fiber content increased from 0.14% in the control cookies to 2.02% for the 20% substituted cookies.

Of all cereal foods, bread is the most popular (Scade, 1951). Many varieties of bread are made from whole grain meals and whole grain brans. Bakery scientists have reported that breads can be a feasible carrier of dietary fiber. Whole wheat flour and from 5 to 16% wheat bran can be satisfactorily substituted for white flour in bread and muffins (Pyler, 1973). Defatted corn-germ flour which contains 15.9% dietary fiber has been partially substituted for flour in bread. Acceptable corn-germ bread having a specific volume of more than 6.00 cc/gm could be prepared from wheat flour replaced with 12% of corn-germ flour (Tsen, 1975). Tsen reported that by using a stronger wheat flour (13.6% protein and 0.53% ash), an acceptable bread could be produced with 18% corn-germ flour.

Coconut residue is a fiber-rich by-product (16% crude fiber) obtained from the aqueous processing of fresh coconut. Replacement up to 10% of wheat flour with coconut

residue in white pan bread yielded an acceptable product (Khan et al., 1976). This coconut bread contained approximately 7.5% crude fiber.

Lorenz (1976) reported that replacing up to 15% of wheat flour with brans from triticale and rye increased farinograph absorption and decreased mixing time and mixing tolerances. Amylograph studies of blends of wheat flour and triticale bran showed that these were less viscous probably because of a high alpha-amylase activity in the bran sample. Fine bran caused greater changes in viscosity than coarse bran samples. Good quality breads were baked with the fine bran samples, up to replacement levels of 15%. There was no decrease in bread volume. Proof time of breads with 10 and 15% bran were shorter than those of control breads. Loaves baked with 10 and 15% fine bran samples were softer than the control loaves after 6 days of storage. The importance of bran particle size in determining bread baking characteristics was apparent.

Pomeranz et al. (1976) used wheat bran, all malt spent grains, and malt-grits spent grains to replace wheat flour at levels of 0, 3, 5, 7, 10 and 15% to produce high fiber breads. They found that all three fibrous materials increased water absorption. The increase was largest for the malt-grits replacement and smallest for wheat bran. The loaf volume decreased and the crumb grains were impaired with increasing fiber replacement levels. The decreased bread loaf volume was due to dilution of gluten protein

from the substitution of various fibrous materials. As a result, the bread made from white wheat bran-enriched was superior in loaf volume, crumb grain and crumb color to the bread in which the brewer's spent grains and all malt-corn grits were added.

Prentice and D'Appolonia (1977) made high fiber bread containing brewer's spent grain (BSG) at 5, 10, and 15% levels of substitution. Consumer panels accepted favorably the bread made with the BSG for flour at 5 and 10% levels of replacement. Crude fiber and acid-detergent fiber were approximately double in flour with 10% BSG substitution.

Volpe and Lehmann (1977) used 10% alpha-cellulose blend (88.6% alpha-cellulose and 11.4% Vital wheat gluten) to replace wheat flour in 70/30 sponge-dough method. As a result, bread which contained cellulose had a lower loaf volume than either the unbromated or bromated control breads. The over-all quality of the bread containing cellulose was lower than the control bread for most of the characteristics evaluated. The addition of fiber to the bread had a slight darkening effect on the crumb. The fiber bread required more force for compression at the end of seven days, but the amount was not significantly higher than the control bread. The use of alpha-cellulose in white pan bread was found to be feasible. Over-all quality of the bread was affected by the addition of fiber, but the products were acceptable.

Formation of Snack Chip Structure

The basic dough processing technique of extruded starch-based snacks is similar to the dough formation of any baked product. Cereal flours can be used to control both the rheology of the fabricated system and a variety of textural functions such as mouth feel and consistency of foods. Coarseness or smoothness in the fabricated structure can be modified by granulation of the cereal flour. Products formulated with cereal starches may range in texture from light, fragile, highly puffed open cell structures to a dense, crisp product with very close cell structures. These snacks are normally processed by extrusion or a similar process, and followed by baking or deep-fat frying (Feldberg, 1969).

In general, snack chips are prepared by mixing dry ingredients and liquid to form a dough with a moisture content from 25 to 45%. The dough is kneaded until it becomes pliable and forms a thin sheet. Pieces are cut from the thin dough sheet using a rotary cutter or dicer of the extruder and are deep-fat fried to a final moisture content of 0.2 to 5.0% (Campbell and Liedman, 1976).

Wheat flour is the best source for the development of a dough with good extensibility and elasticity. The protein and starch components of wheat flour contribute to the main structure of the dough and to the finished products. Addition of tuber materials such as cassava and yam increases water absorption and modifies dough structure because of the

dilution effect on gluten (Ciacco and D'Appolonia, 1977). The dilution of wheat flour with casava has been found detrimental to the wheat protein quality. The addition or replacement of the part of the flour with non-gluten materials such as fiber, bran, and commercial cellulose shortened the gluten strength and impaired the quality characteristics of the baked products. The extensibility of dough decreased as starch or non-gluten materials increased (Heaps and Coppock, 1968). In contrast to baked products, snack chips possess a dense, crisp and close cell structure. To obtain satisfactory handling characteristics, snack chip dough should have enough cohesiveness and extensibility to stick together as a sheet, but not be so much elasticity that it resists extension. Therefore, some dilution of wheat gluten to reduce the elasticity is beneficial.

Mixing of the snack chip ingredients yields an apparently homogenous mass (Bushuk, 1966). At the beginning of the mixing process, a mass or wet lump with little cohesiveness is formed. Gradually the cohesiveness increases, and the dough develops elastic properties and begins to pull away from the mixing bowl. Continued mixing makes the dough smoother and its appearance drier (dough development). The function of mixing is at least twofold: even distribution of the ingredients, and development of gluten structure. These changes are accompanied by hydration of the ingredients, which is facilitated by blending. Hydration of protein is a condition for gluten development. This development is

based on the formation of a network of protein molecules with occasional cross-links.

The rheological properties of dough are primarily determined by its continuous phase, the swollen protein. This continuous phase contains the gluten proteins which form thin extensible and compressible films. The snack chip dough must be sufficiently rigid to form a thin sheet that can withstand rolling yet still remain a continuous mass, so that large surface blisters will not be formed during frying (Robbins, 1976).

The viscous and elastic properties of dough are primarily due to the properties of its continuous or gluten phase. The rheological properties of such a network greatly depend on the number and strength of the cross-links between the protein molecules (Heaps et al., 1967).

The insolubility of the gluten proteins is due to their intermolecular hydrogen bonds (Redman and Ewart, 1967). The viscous flow is a result of thio-disulfide interchange reaction in the protein network. Thio-disulfide interchange during mixing causes the formation of a protein network in dough, in which protein molecules originating from different flour particles are cross-linked one with another. In this way they form a continuous and coherent phase. The observation that the interchange reaction is most rapid in wheat flour dough, slower in doughs from rye, and still slower in dough from other cereals may offer an explanation for the differences in gas retention between these doughs (Redman

and Ewart, 1967).

In general, there is a correlation between the resistance to mixing and between dough development times as determined with various recording mixers. In the same way there is a correlation between the resistance to deformation and between the extensibilities of the curve provided by various load-extension meter. Dilution of gluten will result in low resistance to mixing and a short time dough development.

When a dough is formed, water is taken up by the flour constituents in proportion to their capacity. Bushuk (1966) indicated that about 46% of water in dough is associated with starch, 31% with gluten, and 23% with pentosans. Wheat flour contains approximately 2% pentosans; they form a soft-gel upon hydration and contribute significantly to dough consistency. Since pentosan molecules cannot penetrate the starch granules, they form an intimate association with the gluten in which are embedded the starch granules in a dough system. Bechtel et al. (1971) indicated that pentosans from wheat flour could readily disperse in water, forming highly viscous solutions. D'Appolonia and Kim (1976) reported that water insoluble pentosans interact with gluten to increase the resistance of dough to extension thus decreasing its extensibility. It has been postulated that pentosans and glycoproteins are present as transitional compounds, which play a part in the physical association and chemical bonding between carbohydrates and proteins. Patil et al.

(1975) found that the hydrogen bonding capacity of water-soluble pentosan molecules intensified the association between carbohydrate and protein constituents in the dough formation. It is not known if water-insoluble pentosans play a similar role. The water-insoluble fraction of the wheat endosperm cell walls are arabinoxylans, which are held within the cell wall structure by ester linkages between adjacent arabinoxylans and other cell wall polysaccharides.

During the deep-fat frying process, starch components of the wheat flour upon gelatinization absorb a great amount of the available moisture from the hydrated gluten and pentosans. They thus become thermoplastic and develop a distinct structure (Smith, 1976). According to Sandstedt (1961) starch functions to dilute the gluten, to provide a surface for union of gluten, and to become flexible during gelatinization and provide a structure permeable to gas so that baked breads do not collapse on cooling. In snack chips, gelatinized starch also lends a brittle texture to the finished product.

Shortening is also an important ingredient in snack dough formation. It functions as a lubricant and shortening agent. The selection of the type of shortening is important for textural properties.

Other ingredients, selected for functional characteristics include leavening agents such as sodium-aluminum sulfate (SAS) baking powder to give a crumb texture to the

chips. SAS baking powder produces carbon dioxide to modify the quality of the chip and results in an optimum amount of friability, density, and crispness.

As materials are substituted for wheat flour, water must be added proportionately to the level of the water-holding capacity of the material substituted. The total moisture content of the dough may vary somewhat depending on the particular starchy food material being used, but it will range from 25 to 45% by weight (Robbins, 1976). The desirable moisture level is about 40%.

There are some differences in the basic expanded product, principally in texture and eating qualities (Nadison, 1969). The type of extruder and process used to produce the basic product can alter snack chip characteristics. Basic formulations may vary somewhat, depending upon whether the product is produced by hot or cold extrusion, and whether the resulting extruded product is baked or fried.

Corn, rice, potatoes, modified food starches, wheat flour, soy protein, and even high fiber-high protein materials have been used in producing expanded snack products. All of these impart unique flavors and properties to the finished product.

The addition of seasonings makes the product unique and acceptable to the snack consumer. The method of introducing seasoning into the spicy products is done by dusting or spraying the seasoning over the finished snack after frying or baking (Nadison, 1969). Dusting or spraying is

advantageous because it allows for the application of a large variety of seasonings. Also the seasoning are not exposed to extremely high temperatures, which minimizes the escape of volatile aroma components. Seasoning and flavor should be applied at low levels, with just enough used to impart the desired flavor. This allows the product to be seasoned and prevents an undesirable build-up of flavor.

EXPERIMENTAL PROCEDURE

This research was initiated to determine whether the dietary fiber constituents of dehydrated carrot powder and solka floc BW-200 could be satisfactorily substituted for bread flour in a chip type snack food formulation, and to determine the dietary fiber content of various types of commercial baked products and snack foods. Additional tests were carried out to determine the dietary fiber contents of traditional home-made whole grain and fruit-type breads.

Food Material and Chemical Procurement

Common lots of salts, sugars, shortening, baking powders, bread flours, white sesame seeds, Parmesan cheese, garlic salt, and corn oil were purchased from the Michigan State University Food Stores. Sugar free egg powder was donated by Seymour Foods Company, Kansas. Fresh carrots were donated by Dr. Jerry N. Cash, Assistant Professor in the Food Science and Human Nutrition Department at Michigan State University. Ground cellulose sold under the trade name of solka-floc BW-200 was obtained from Berlin Brown Company. Rye flour, yellow corn meal, whole wheat flour, all purpose flour, wheat germ, dry apricots, dry figs, raisins, apples, bananas, breakfast cereals, bar cookies,

oat cookies, walnuts, dry active yeast, caraway seeds, whole wheat bread, pumpernickle, schwazbrot, and stollen were purchased from Meijers Thrifty Acres. Ardex-700F defatted soy flour was donated by Archer Daniels Midland Company, Illinois. Wheat brans were donated by the soft Wheat Quality Laboratory of the Ohio Agricultural Research Development Center, Wooster, Ohio. Flat crisp whole grain breads were purchased from the Grande Gourmet retail store.

Sodium lauryl sulfate, disodium hydrogen phosphate, and 2-ethoxyethanol were purchased from Fischer Scientific Company. Disodium ethylene-diaminetetraacetate (EDTA) and sodium borate decahydrate were purchased from Michigan State University General Stores. Alpha-amylase (type VI-A) obtained from hog pancrease was purchased from Sigma Chemicals.

Carrot Chip Formulation

A Chinese sweet wheat chip formulation (Table 15) was modified to prepare eight spicy carrot chips and a controlled plain wheat chip. Five replications of each variable were evaluated objectively and subjectively. The flour component of the control wheat chip was substituted with 10%, 20%, 30%, 40% of the dehydrated carrot powder, respectively. In addition, 4% and 8% ground cellulose were used in place of part of the dehydrated carrot powder at both the 20% and 30% levels (Table 16). Preliminary experiment were conducted to determine the optimum water and

Table 15. Formulation for Chinese Sweet Wheat Chips[1]

Ingredients	% weight/100% flour	
Bread flour	50.0	>100.0
All purpose flour	50.0	
Fresh eggs	20.0	
Soy-bean curd (90% moisture)	40.0	
Sesame seeds	7.0	
Sugar	30.0	
Shortening	3.0	
Salt	1.0	
Baking powder	0.5	

[1] Anon

Table 16. Formulation of control wheat chip and eight spicy carrot chip variables

Ingredients	Level of bread flour substituted with carrot powder and ground cellulose								
	0%[1]	10%	20%	30%	40%	12-8%	16-4%	22-8%	26-4%
Bread flour[2]	100.0	90.0	80.0	70.0	60.0	80.0	80.0	70.0	70.0
Carrot powder		10.0	20.0	30.0	40.0	12.0	16.0	22.0	26.0
Solka floc, BW-200						8.0	4.0	8.0	4.0
Egg Powder	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Parmesan cheese	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Sesame seeds	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Shortening	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Garlic salt	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
SAS baking powder	1.0	1.0	1.5	1.7	1.7	1.5	1.5	1.7	1.7
Water	60.0	70.0	80.0	85.0	90.0	80.0	80.0	85.0	85.0

[1]Control

[2]Formulation expressed as percantage of the 100 grams of flour used in control

baking powder level for each variable.

Preparation of Dehydrated Carrot Powder

Thirty kilograms of fresh carrots were washed, peeled, trimmed and shaved into strips. The strips were collected in a container which contained 1% salt water. The carrot strips were drained in a plastic basket, before being dipped in a 0.3% sodium bisulfite solution for 3 minutes. Sulfite treated carrot strips were drained and dried at room temperature for 30 minutes. The carrot strips were then dehydrated in an air-blast oven, Proctor & Schwartz, model K12395, at 205^{o}F (96^{o}C) for the first 30 minutes, after which the oven temperature was reduced to 175^{o}F (66^{o}C) and drying continued for two additional hours. The oven temterature finally was reduced to 150^{o}F (64.4^{o}C), and the carrot strips dried for another two hours. The moisture content of the dehydrated carrot strips was 4.5%. The dehydrated carrots were ground into a fine powder using a Udy Cyclone Sample Mill, model MS. Four and a half pounds of carrot powder were obtained and packed in several half-pound polyethylene bags, then wrapped with tin foil and stored in a dark cabinet at room temperature (21^{o}C) in order to prevent carotenoid and xanthophyll degradation by sun light and ultraviolet light.

Carrot Chip Preparation

All the preweighed dry ingredients except egg powder and Parmesan cheese were mixed and sifted. Water, egg

powder, and Parmesan cheese were placed in the bowl of a Kitchen Aid mixer, model K5-A. These ingredients were beaten with a wire whip attachment at medium speed (142 rpm) for 5 minutes until homogenized. The sifted dry ingredients were added to the cheese mixture and mixed with a dough hook at low speed (60 rpm) for 3 minutes. The shortening was added and beaten at medium speed for 7 minutes until the dough was just developed. The dough was conditioned at room temperature (21^{o}C) in a tightly covered container to prevent moisture loss for 2 hours. Each dough was divided into five equal parts and rolled into approximately 0.08 cm thin sheets with a wooden rolling pin. Four sheets were cut into 4-cm diamond-shaped pieces (Figure 3); the fifth sheet into 4-cm square-shaped pieces (Figure 4). These pieces were deep-fat fried in a General Electric Hotpoint deep fat frier, model HK3 at 365^{o}F (185^{o}C) for 15 seconds and finished drying at 250^{o}F (121^{o}C) in a 12 1-lb. loaf size National Reed Type Test Baking Oven for 10 minutes. After cooling at room temperature (21^{o}C), these diamond-shaped chips were packed in several polyethylene bags, sealed, and stored at room temperature (21^{o}C) and 60% relative humidity. The diamond-shaped carrot chips were used for sensory evaluations. The square-shaped carrot chips were pressed into flat pieces within 5 seconds after deep-fat frying and before they finished drying. These square-shaped carrot chips were packed and sealed in the

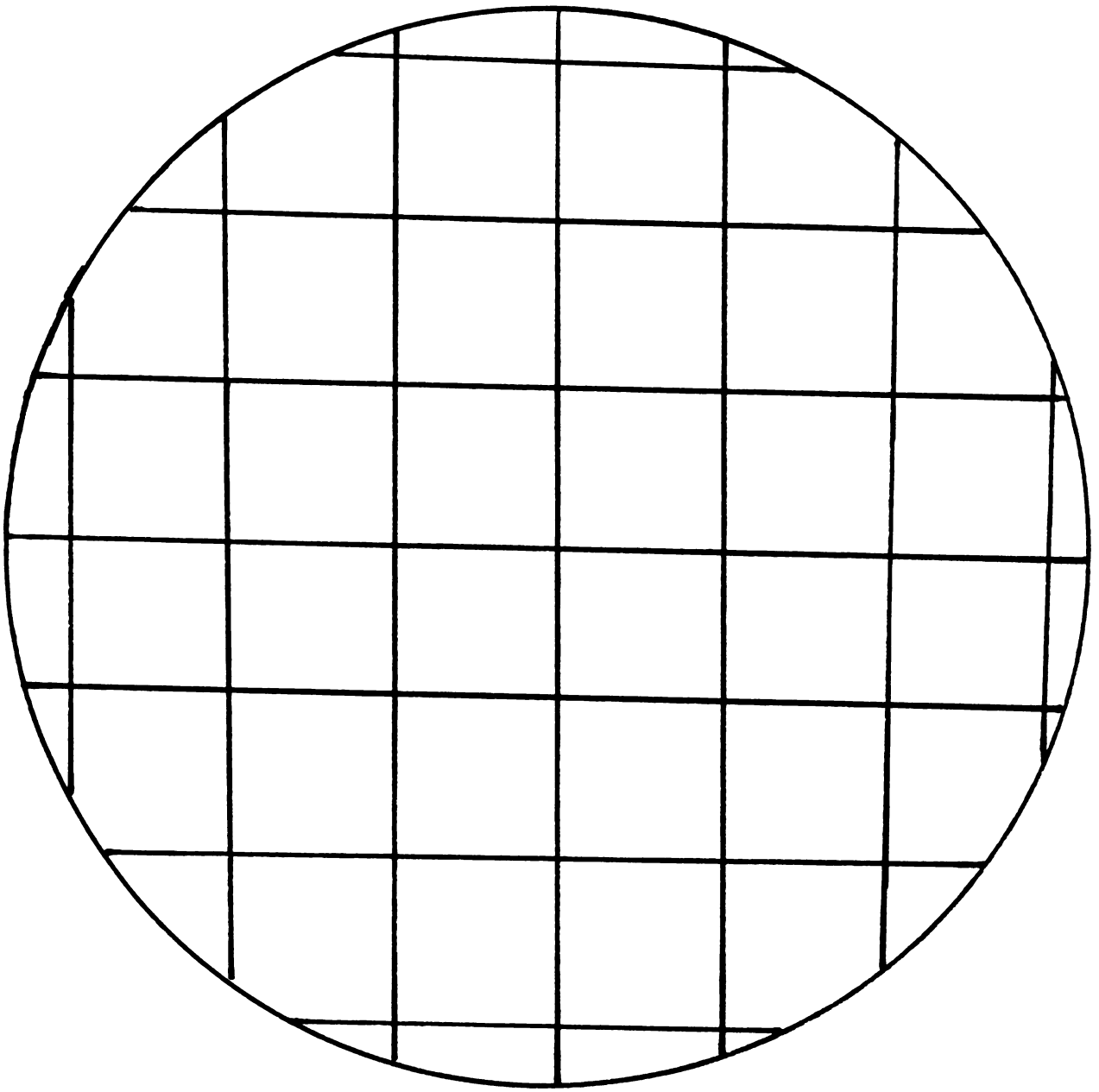


Figure 3. Cutting diagram for square-shaped raw carrot chip dough

same way as the diamond-shaped ones, except that they were stored in a desiccator at room temperature (21°C). These chips were used for color and Allo-Kramer shear press tests.

Objective Measurement

Objective measurements were used to determine the quality characteristics of the carrot chips. These included moisture content, color, and crispness (or breaking strength).

Moisture. Moisture determination was done on both the raw dough and the finished product by drying 2.000 ± 0.0001 gm of samples at 100°C under a vacuum of 27-in of Hg in a Hotpack vacuum oven, model 633 for 8 hours (AOAC, 1975). The dried samples were reweighed after cooling in a desiccator. The percentage moisture was calculated according to the following formula:

$$\% \text{ Moisture} = \frac{\text{Weight of Moisture Loss (gm)}}{\text{Weight of Original Sample (gm)}} \times 100$$

Color. The surface color of the carrot chips was measured using a Hunter Color Difference Meter, model D25. After standardizing with a yellow tile (L = 83.0, aL = -3.5, bL = 26.5), the measurements were taken. Two reading were taken on each piece of carrot chip and averaged to give individual averages for L, aL, and bL values.

Crispness. Crispness of the carrot chips was determined using the standard shear-compression 10-blade cell of

the Allo-Kramer Shear Press, model SP12. The Allo-Kramer Shear Press (model E2EZ) is equipped with an electronic recorder. The carrot chips were weighed to the nearest 0.01 gm before being placed in the bottom of the standard shear-compression cell. A 3000 pound proving ring with a range 5 was selected for each measurement except for the 40% variable in which case a range of 10 was used. The cell assembly was cleaned with a brush between each measurement. The crispness value expressed as a pound force per gram of sample was determined by a single measurement calculated according to the formula,

$$\text{Crispness} = \frac{\text{Reading} \times \text{Ring} \times \text{Range (lb force)}}{\text{Sample weight (gm)} \times 100 \times 100} \quad \text{or}$$

$$\text{Crispness} = \frac{\text{Factor} \times \text{Peak High (lb force)}}{\text{Sample weight (gm)}}$$

where the factor of the 3000 pound ring was adjusted permanently for this machine to be 3.0 for range 10 and 1.5 for range 5.

Subjective Evaluations

Two training sessions were held prior to taste panel evaluation to familiarize the panel members with the score card. Twelve panel members were selected out of twenty to be included in the final panel group based on their ability to discriminate and their willingness to serve. A sample score card appears in the Appendix.

The sensory evaluations included: (1) Appearance (color, bristles), (2) Flavor (saltiness, greasiness, detectable flavor, and over-all flavor), (3) Texture (friability, crispness, and mouthfeel), and (4) General acceptability using a descriptive scale. Each characteristic had a continuous scale with descriptive terms placed adjacent to the bar. Each taste panelist marked the bar by the descriptive term best describing the product. These were converted to numerical values by assigning the highest score with the most desirable descriptive term.

Home-Made Whole Grain and Fruit Type Breads

Ten variables of whole grain breads and fruit-nut breads were prepared by formulations and procedures selected from American Cookbooks. These are shown in Tables 17 to 25. Three replications of each variable were made for determining the Enzymatic Neutral Detergent Fiber content. Thirty loaves of bread in total were baked randomly within two weeks. After each baking, breads were cooled to room temperature, wrapped with polyethylene sheets and stored in the freezer at -20^{o}C for later dietary fiber determination.

Home-Made Bread Preparation

Material Preparation. Ten types of bread were prepared, five were chemically leavened quick bread and five were yeast raised bread. The quick breads included fig-bran bread (Table 17), banana-bran bread (Table 18), bran bread

Table 17. Formula for fig-bran bread[1]

Ingredients	% based on flour components		Weight (gm)
Whole wheat bran	37.0		24.0
All purpose flour	40.0	> 100.0	26.0
Yellow corn meal	23.0		15.0
Dark brown sugar	53.0		34.5
Full fat milk	127.0		82.5
Shortening	60.0		39.0
Dried figs, chopped	77.0		50.0
Baking powder, SAS	3.0		2.0
Fresh eggs	50.0		32.5
Baking soda	2.0		1.3

[1]Rombauer, 1942

Oven temperature: 375°F. Product size: 8 x 4" loaf.
Baking time: 35 minutes.

Table 18. Formula for banana-bran bread[1]

Ingredients	% based on flour components		Weight (gm)
Whole wheat bran	9.0		8.7
Whole wheat flour	32.0	> 100.0	30.5
All purpose flour	59.0		57.4
Dark brown sugar	45.0		39.0
Shortening	23.0		20.0
Walnut, chopped	18.0		15.7
Dried apricot, chopped	31.0		27.0
Baking powder	1.5		1.3
Baking soda	0.8		0.7
Salt	1.0		0.9
Fresh eggs	27.0		23.5
Vanilla	1.0		0.9

[1]Rombauer, 1942

Oven temperature: 375°F. Product size: 8 x 4" loaf.
Baking time: 35 minutes.

Table 19. Formula for bran bread with molasses[1]

Ingredients	% based on flour components		Weight (gm)
Whole wheat bran	13.0	> 100.0	11.0
Whole wheat flour	87.0		75.0
Dark brown sugar[2]	42.0		36.0
Full fat milk, sour[3]	139.0		119.0
Raisins	47.0		40.4
Baking powder, SAS	2.0		1.7
Baking soda	1.0		0.9
Salt	2.0		1.7
Fresh egg	16.0		13.8

[1]Rombauer, 1942

[2]If molasses was used, one part of molasses would be equal to one and a half parts of dark brown sugar.

[3]One cup of full fat milk and one teaspoon of vinegar were mixed to make sour milk.

Oven temperature: 375°F. Product size: 8 x 4" loaf.
Baking time: 40 minutes.

Table 20. Formula for zucchini[1] (or carrot[2]) bread

Ingredients	% based on flour components	Weight (gm)
All purpose flour	100.0	63.7
Fresh eggs	43.0	27.0
Dark brown sugar	122.0	76.9
Grated zucchini (or carrot)	107.0	67.4
Shortening	69.0	43.5
Chopped walnuts	36.0	22.7
Baking powder, SAS	2.3	1.4
Salt	1.7	1.1
Vanilla (for zucchini bread)	3.0	1.9
Cinnamon (for carrot bread)	5.0	3.2
Baking soda	1.2	0.8

[1]Behan, 1976

[2]Kent, 1976

Oven temperature: 350°F. Product size: 8 x 4" loaf.
Baking time: 45 minutes.

Table 21. Formula for rye bread[1]

Ingredients	% based on flour components		Weight (gm)
Whole wheat flour	40.0	> 100.0	57.0
Rye flour	60.0		70.5
Dark brown sugar	19.0		22.5
Salt	2.0		2.3
Shortening	2.0		2.3
Dry active yeast	3.2		3.5
Luke-warm water (38°C)	85.0		100.0
Caraway seed	1.0		1.2
Grated orange skin	5.0		6.0
Fine chopped apricot	40.0		47.0

[1]Rombauer, 1942

Oven temperature: 425°F. Product size: 8 x 4" loaf.
Baking time: 35 minutes.

Table 22. Formula for raisin-nut rolled oat bread[1]

Ingredients	% based on flour components		Weight (gm)
Whole wheat flour	75.0	> 100.0	59.0
Oat meal	25.0		20.0
Full fat milk	143.0		113.0
Molasses	13.9		11.0
Yeast	2.3		1.8
Raisin, chopped	45.6		36.0
Salt	1.9		1.5
Water	71.5		56.5
Nut, chopped	38.0		30.0

[1]Rombauer, 1942

Oven temperature: 400°F. Product size: 8 x 4" loaf.
Baking time: 35 minutes.

Table 23. Formula for rolled oat nut bread[1]

Ingredients	% based on flour components		Weight (gm)
Whole wheat flour	75.0	> 100	59.0
Oat meal	25.0		20.0
Full fat milk	143.0		113.0
Molasses	13.9		11.0
Yeast, active dried	2.3		1.8
Water	71.5		56.5
Walnuts, chopped	38.0		30.0
Salt	1.9		1.5

[1]Rombauer, 1942

Oven temperature: 375°F. Product size: 8 x 4" loaf.
Baking time: 45 minutes.

Table 24. Formula for apple bread[1]

Ingredients	% based on flour components	Weight (gm)
Bread flour	100.0	106.0
Shortening	11.0	11.6
Active dry yeast	1.3	1.4
Salt	1.1	1.2
Water	20.5	21.7
Apple, McIntosh[2]	148.7	157.6

[1]DeBoth, 1929

[2]Freshly peeled and cored

Oven temperature: 410°F. Product size: 8 x 4" loaf.
Baking time: 25 minutes.

Table 25. Formula for raisin bread[1]

Ingredients	% based on flour components	Weight (gm)
Bread flour	100.0	100.0
Sugar	4.0	4.0
Active dry yeast	3.0	3.0
Salt	1.0	1.0
Shortening	4.0	4.0
Water	80.0	80.0
Raisin	80.0	80.0

[1]Bennion, 1967
Oven temperature: 392°F. Product size: 8 x 4" loaf.
Baking time: 25 minutes.

with molasses (Table 19), zucchini nut bread (Table 20), and carrot nut bread (Table 20). The yeast raised breads were rye bread (Table 21), raisin-nut rolled oat bread (Table 22), rolled-oat nut bread (Table 23), apple bread (Table 24) and raisin bread (Table 25). The ingredients were prepared as follows: fresh bananas were chopped and mashed, walnuts and dried fruits were chopped into finely uniform particles, and raisins were soaked in warm water (36°C) for 30 minutes, after which they were drained dry and then chopped. All the dry ingredients were preweighed to the nearest 0.1 gm. The materials for each variable were packed in individual plastic bags, and stored in a freezer at -20°C. The individual packages were thawed at room temperature for 30 minutes before mixing the dough.

Methods and Procedures. A straight dough method was used to mix the yeast raised breads and a conventional method was applied to quick breads.

Straight dough method: A desirable amount of active dry yeast was allowed to rehydrate in luke-warm water (yeast:water = 1:5) at ca 38°C for 5 to 10 minutes just before mixing the dough. Then the yeast water, sugar, salt, eggs, milk, and any semi-liquid materials such as oat-milk mixture, banana puree, or apple stew, etc. were placed in a bowl of a Kitchen Aid mixer, model K5-A, and beaten at low speed (60 rpm) with a wire ship attachment for 2 minutes. The sifted flour, bran or corn meal was then added to the mixture and mixed with a dough hook at low speed for 3 minutes. The shortening was added and beaten at medium speed (142 rpm) for about 2 minutes, after which the finely chopped dried fruits and nuts were added and beaten at low speed for 2 minutes or until all the ingredients were well mixed. The dough was then placed in a 8 x 4" well greased loaf pan and allowed to ferment at 29°C and relative humidity of 75% for 30 minutes. Proofing was continued for another 30 minutes at 38°C and 85% relative humidity. Finally the raised dough was baked at the specific temperature.

Quick bread method: The shortening and sugar were placed in a mixing bowl of a Kitchen Aid mixer and beaten using the paddle attachment at medium speed for 3 minutes until creamy. The fresh eggs were added and mixing was continued at medium speed for another 2 minutes. The grated zucchini or carrot was then added and mixed for one minute at low speed. All the sifted dry ingredients were added

and mixed well with other ingredients. The batter was placed in a 8 x 4" loaf pan and baked at 350° to 375°F for half an hour or until done. All breads were baked in a 12 1-lb loaf size National Reel Type Test Baking Oven.

Dietary Fiber Sources in Commercial Baked Products

The commercial products selected for enzymatic Neutral Detergent Fiber analysis are grouped into 5 categories; (1) Whole grain fresh breads, (2) Breakfast cereals. (3) Cookies and snacks, (4) European whole grain crisp flat breads, and (5) Other food materials. These products are tabulated in Table 26.

Determination of Enzymatic Neutral Detergent Fiber

This method is based on the method of Van Soest (1973). Food samples were extracted with a hot neutral solution of the detergent sodium lauryl sulfate. The pH of the extraction medium was 7.0 ± 0.1. The detergent solubilizes lipids and protein, EDTA removes minerals. and heat gelatinizes the starches; so that proteins, starches, minerals, and other hot water soluble materials can be separated from the fiber residues through filtration at hot stages.

Solution Preparation

Neutral Detergent Solution. The following chemicals and amounts were used to prepare the neutral detergent solutions:

Table 26. Commercial grain-based products of dietary fiber source

Source (trade name)	Distributor or manufacturer	Ingredients contributing dietary fiber
Whole grain breads:		
Pumpernickle	May-bud, Purity Cheese Co. dist.	Wheat flour, rye flour.
Schwazbrot	May-bud, Purity Cheese Co. dist.	Dark rye flour, soy flour.
Stollen	West Germany, Grande Gourmet.	Wheat flour, raisins, canned lemon and orange peels, apricot kernels.
Wheat bread	Awrey Heart	Whole wheat flour.
Italian Rye Bread	Shafer's Bakery	Wheat flour, rye meal.
Breakfast cereals:		
Country Morning	Kellogg	Rolled oat, raisins, rice, untoasted coconut, dates, almonds.
Frosted Mini-Wheat	Kellogg	Whole wheat.
All Bran	Kellogg	Wheat bran.
Bran Buds	Kellogg	Wheat bran.
Wheat Chex	Ralston Purina	Whole wheat.
Raisin Bran Flakes	Kellogg	Wheat bran, wheat flour, raisins.
Total	General Mills	Whole wheat.
Raisin Bran Flakes	Food Club, Topco Ass.	Raisin, wheat bran.
Cap'n Crunch's Crunch Berries	Quaker Oats	Corn flour, oat flour.
C.W. Post Family Style Cereals	General Foods	Malted barley, whole wheat.
Grape-nut Cereal	General Foods	Oats, rice.
Natural Valley Granola Cinnamon & Raisin Cereal	General Mills	Rolled oats, raisins, sesame seeds.
Natural Cereal	Nature Valley	Whole wheat, raisins, crushed nuts.
Cookies and snacks:		
Fig Bar	Alger Candy Co.	Figs, coconut, date, almond.
Old Fashioned Oat Meal Cookies	Keebler	Rolled oat, wheat flour.
Nature Valley Granola Bar With Coconut	General Mills	Oat meal, sesame seeds, coconut.

Table 26 (cont'd.)

Sesame Bran Sticks	Flavor Tree	Sesame seeds, bran, wheat flour.
Sesame Buds	Flavor Tree	Sesame seeds, wheat flour.
Corn Chips	Seyfert	Corn.
Doritos Tortilla Chips	Planters	Corn, tomato pulps.
Potato Chips	Spartan Store	Potato.
Wheat Square Cracker	Kroger	Whole wheat flour, rye flour.
Triscuit	Nabisco Inc.	Whole wheat.
Honey Sorghum	Food Club, Topco Inc.	Whole wheat flour.
Hearty Wheat Snack	Keebler	Whole wheat flour.
Whole Grain Natural Rice	Japan, Health Food store	Brown rice.
European whole grain		
Crisp Bread With Linseed	Jans, West Germany	Whole rye, linseeds.
Siljan Swedish Rye Crispbread	Siljan, Sweden	Whole rye flour.
Crispbread With Sesame	Wasa, Sweden	Whole rye flour, sesame.
Rogga	Bahlsen, West Germany	Whole rye flour.
King's Crisp Bread	Vaasa Mill, Finland	Whole meal rye flour.
Ideal Flat Bread	Norwegian	Whole grain wheat, rye, and barley, caraway seeds.
Mor Flatbread	Jakob Haugstad, A.S.	Whole grain rye and wheat flour.
Other Food Materials:		
Jiffy Bran Muffin Mix	Jiffy	Wheat bran, wheat flour, dates.

Distilled water, freshly distilled	1.00 liter
Sodium lauryl sulfate (USP)	30.00 gm
Disodium ethylene diaminetetraacetate (EDTA), dihydrate crystal, reagent grade	18.61 gm
Sodium borate decahydrate ($Na_2B_4O_7 \cdot 10 H_2O$), reagent grade	6.81 gm
Disodium hydrogen phosphate (Na_2HPO_4) anhydrous, reagent grade	4.56 gm
2-ethoxyethanol (ethylene glycol monoethyl ether), purified grade	10.00 ml

Sodium lauryl sulfate was dissolved in 500 ml of distilled water in a 1500 ml beaker, after which 2-ethoxymethanol was added to the sodium lauryl sulfate solution, and the mixture continuously mixed with a magnetic stirrer until the solution was clear. The combination of EDTA and $Na_2B_4O_7 \cdot 10 H_2O$ was completely dissolved with 100 ml distilled water contained in a 250 ml Erlenmeyer flask with the aid of heat. Disodium hydrogen phosphate was also dissolved in distilled water with the aid of slow heat. These two solutions were then added to the sodium lauryl sulfate solution, mixed well and the final volume adjusted to one liter by adding distilled water. The pH of the neutral detergent solution was adjusted to 7.0 ± 0.1 with concentrated hydrochloric acid or sodium hydroxide solution when necessary. Since this solution changes gradually with exposure to sunlight, it was stored in an amber bottle.

Enzyme solution. The enzyme solution was prepared just prior to use by dissolving 1.0 gm bacterial crude alpha-amylase (Type VI-A) in a 250 ml volumetric flask with the

neutral detergent solution.

Extraction Procedure

Carrot chips, commercial bakery products, and home-made whole grain, fruit, and vegetable breads were used as the samples for analyses of Enzymatic Neutral Detergent Fiber content.

Samples of 0.5 to 1.0 of air-dry, well ground material (20 to 30 mesh, 1 mm) were measured to the nearest 0.0001 gm and transferred quantitatively to a beaker of refluxing apparatus. Forty ml of neutral detergent solution at room temperature was added to the beaker and the mixture was heated to boiling in 5 to 10 minutes. Foaming was monitored, and the heat reduced when necessary. After heating for 15 minutes, the mixture was cooled to 50^{o}C, after which 40 ml of enzyme solution was added, and the starch digestion allowed to continue at room temperature for 30 minutes. The mixture was then refluxed for one hour, and was watched for foaming; the heat was reduced if foaming occurred. A Gooch Crucible was used to filter the neutral detergent extracts under low volume. The reflux beaker was washed with a small amount of boiling water, and this water was transferred to the same crucible. Additional boiling water was used to wash the extract and this was filtered with as low a vacuum as needed. These steps were repeated until use of the vacuum pulled no more foam from the crucible. Acetone was then added to remove all the lipid that remained with

the residue, after which the residue was again filtered with a vacuum as needed. Finally the residue was dried by placing the crucible in a vacuum oven at 100°C for 8 to 16 hours. After weighing, the dry residue was ashed in a muffle oven at 525°C for 8 to 12 hours. The percentage ENDF of a material was calculated as:

$$\% \text{ ENDF} = \frac{\text{(Wt. of crucible plus dried ENDF - wt. of crucible plus ash) gm}}{\text{Original sample weight (gm)}} \times 100$$

Analyses of Data

The objective data, sensory evaluation and ENDF data from the carrot chips were analyzed for variance. Duncan's Multiple Range Test (1957) was then used to pinpoint significant differences among variables revealed by the analysis of variances.

RESULTS AND DISCUSSION

This study was designed to determine the effects of the replacement of 0 to 40% carrot powder in combination with 4 to 8% commercial cellulose for wheat bread flour on the quality characteristics of carrot chips. Additional Enzymatic Neutral Detergent Fiber Analyses were carried out to determine the dietary fiber content of each carrot chip variable and some selected commercially baked cereal products and traditional home-made whole grain breads in order to assess potential sources of dietary fiber for American consumption. Discussions of the experimental results were based on the numerical data obtained from subjective and objective determinations. Tables 27 to 28 present the means and standard deviations as well as a summary of the analyses of variance.

Carrot Chips

The Chinese wheat chip is primarily flour and can be easily prepared in the laboratory with the use of extrusion equipment commonly used in commercial snack food production. Also several studies had indicated fiber could be substituted for flour in baked products. Carrots were chosen as a high vegetable fiber source while commercial cellulose was used to increase the fiber content.

Moisture

Means and standard deviations of percentage moisture in the raw dough and finished chips are presented in Table 27. Eastwood and Mitchell (1976) reported that 100 gm of raw carrot is able to hold 208 gm of water. Parrott and Thrall (1978) reported that 79 to 232 mg of solka floc can hold

Table 27. Means and standard deviations[1] for moisture determination of carrot chips

Level of Substitution		Moisture	
Carrot powder	Solka-floc BW-200	Raw dough[2]	Fried carrot chips
%	%	%	%
0	0	36.67 ± 0.02	3.41 ± 0.06
10	0	38.70 ± 0.01	3.44 ± 0.12
20	0	43.33 ± 0.02	3.45 ± 0.13
30	0	43.76 ± 0.02	3.43 ± 0.14
40	0	44.79 ± 0.02	3.40 ± 0.08
12	8	42.17 ± 0.02	3.39 ± 0.06
16	4	41.92 ± 0.01	3.41 ± 0.07
22	8	43.64 ± 0.02	3.42 ± 0.02
26	4	43.68 ± 0.03	3.46 ± 0.05

[1]Based on five replications

[2]Significant difference at 1% level of probability

1 ml of water. Therefore, as the level of carrot powder and cellulose was increased in the carrot chip formulation, the amount of water required to produce a consistent dough also had to be increased. The percentage moisture values in the raw dough revealed the expected significant differences ($p < 0.01$) among variables (Table 28), but no significant differences in moisture content were found in the finished carrot chips. This was probably because the very thin dough

Table 28. Analyses of variance for objective evaluations of carrot chips prepared with substitutions of carrot powder and/or cellulose

Sources	Degree of Freedom	Mean Square					
		Moisture		Color			Shear Press
		Raw Dough	Carrot Chips	L	aL	bL	
Total	44	6.53	0.01	2.41	7.67	16.11	75.52
Variables	8	35.91**	0.0013	10.05**	40.01**	87.58**	370.53**
Within	32	0.003	0.02	0.78	0.51	0.25	10.16

**Significant difference at 1% level of probability

sheet provided a large surface area that facilitated evaporation of water molecules during deep-fat frying.

Color

Means and standard deviations for the L, aL, bL, and visual color values are presented in Table 29; and a summary of analyses of variance for these data are presented in Table 28 and 30. Duncan's multiple range test revealed that significant differences ($p < 0.01$) were present in both objective and subjective determinations among variables. As the level of carrot powder increased the L or lightness value decreased, except that the chip substituted with 26% carrot powder and 4% cellulose had slightly higher L value than those substituted with 12 to 40% carrot powder. The aL or redness and bL or yellowness value increased as the level of substitution increased. As the level of cellulose substitution increased the aL or redness value decreased slightly, but L (lightness) and bL (yellowness) did not show any significant differences among the variables. All the carrot chips had a very pleasant yellow-orange color except that with 40% carrot powder substitute which was scored significantly lower. It may be that with this high level of substitution the finish-drying procedure needs to be modified to reduce surface browning. The carotenoid component of carrots was responsible for the predominant carrot chip color. The natural orange yellow color of egg powder and Parmesan cheese also contributed to the color characteristics.

Table 29. Means and standard deviation[1] for both subjective and objective color[2] values of carrot chips

Level of Substitution		Hunter Color Difference Values			Visual[3] Color (6)
Carrot powder %	Solka-floc BW-200 %	L	aL	bL	
0	0	65.45 ± 0.42^{d}	-1.96 ± 0.52^{e}	19.22 ± 0.33^{f}	5.37 ± 0.28^{ab}
10	0	69.40 ± 1.44^{a}	-0.48 ± 0.97^{e}	28.52 ± 0.89^{ed}	5.35 ± 0.09^{ab}
20	0	66.97 ± 1.28^{b}	1.85 ± 0.46^{e}	30.90 ± 0.21^{d}	5.36 ± 0.13^{ab}
30	0	66.49 ± 0.87^{b}	3.92 ± 0.72^{c}	32.43 ± 0.21^{b}	5.37 ± 0.20^{ab}
40	0	64.21 ± 0.77^{e}	7.17 ± 0.27^{a}	33.59 ± 0.25^{a}	3.80 ± 0.30^{c}
12	8	66.65 ± 1.12^{bc}	2.36 ± 0.56^{de}	28.74 ± 0.51^{ed}	5.72 ± 0.19^{a}
16	4	65.77 ± 0.81^{b}	3.43 ± 0.73^{cd}	29.03 ± 0.53^{a}	5.50 ± 0.21^{ab}
22	8	65.66 ± 0.55^{b}	4.53 ± 0.31^{bc}	31.18 ± 0.23^{c}	5.23 ± 0.27^{b}
26	4	66.83 ± 0.37^{bc}	5.31 ± 0.81^{b}	31.13 ± 0.57^{c}	5.27 ± 0.27^{b}

[1]Based on five replications

[2]L = Lightness -aL = Greenness aL = Redness bL = Yellowness

[3]Total possible point listed in parenthesis under the descriptive term

a...f = Average superscripted by the same letter are not significantly different at the 5% level of probability (Duncan, 1957).

Table 30. Analyses of variance for subjective evaluation of carrot chips prepared with substitutions of carrot powder and/or cellulose

Sources	Degree of Freedom	Mean Square					
		Color	Flavor	Texture			General Acceptability
				Crispness	Friability	Mouthfeel	
Total	44	0.32	0.19	0.11	0.06	0.25	0.15
Variables	8	1.54**	0.53**	0.17*	0.08	8.84**	0.39**
Within	32	0.06	0.11	0.07	0.04	1.62	0.09

**Significant difference at 1% level of probability
* Significant difference at 5% level of probability

Another factor contributing to the overall color of the carrot chips was the Maillard reaction. Fresh carrots contain approximately 4 to 6% total sugar, mainly sucrose and glucose. High protein materials were also present in the chips, causing the Maillard reaction between the reducing sugar and amino groups during the frying and baking process.

Crispness, Friability and Shear Press

Means and standard deviations for crispness, friability, and shear press values are presented in Table 31. The shear press is a physical device which was used to measure the crispness and friability of carrot chips. The analyses of variance for shear press values revealed highly significant differences ($p < 0.01$) among variables (Table 28), while analyses of variance for crispness and friability (Table 30) revealed slightly significant differences at the 5% level of probability. The friability values decreased only slightly as the level of carrot powder substitution increased. However, crispness actually increased slightly as the carrot powder substitution increased. The reason for the differences were not greater in crispness and friability among the variables could be because the level of baking powder was also increased as the level of carrot powder increased. They may have altered the dense cell structure of the carrot chips to produce a lighter texture. Shear press values indicated that the pounds of force needed to break a gram of sample increased as the level of

Table 31. Means and standard deviations[1] for texture and shear press value of carrot chips

Level of Substitution		Texture[2]		
Carrot powder %	Solka-floc BW-200 %	Crispness (6)	Friability (5)	Shear press lb force/gm
0	0	4.53 ± 0.18^{ab}	3.77 ± 0.14^{a}	20.68 ± 2.80^{d}
10	0	4.75 ± 0.52^{a}	3.62 ± 0.15^{ab}	22.69 ± 2.13^{cd}
20	0	4.67 ± 0.25^{a}	3.40 ± 0.16^{b}	30.79 ± 3.20^{b}
30	0	4.63 ± 0.36^{ab}	3.38 ± 0.27^{b}	41.08 ± 5.25^{a}
40	0	4.90 ± 0.42^{a}	3.50 ± 0.27^{ab}	44.62 ± 5.00^{a}
12	8	4.27 ± 0.27^{b}	3.47 ± 0.30^{b}	27.14 ± 1.08^{bc}
16	4	4.60 ± 0.23^{ab}	3.53 ± 0.23^{ab}	24.36 ± 1.75^{cd}
22	8	4.73 ± 0.18^{a}	3.42 ± 0.34^{b}	26.30 ± 2.28^{c}
26	4	4.78 ± 0.21^{a}	3.36 ± 0.08^{b}	21.31 ± 2.23^{d}

[1] Based on five replications

[2] Total possible point listed in parenthesis under the descriptive term

a...e = Average superscripted by the same letter are not significantly different at the 5% level of probability (Duncan, 1957)

carrot powder and cellulose increased. This was probably a result of the dilution of the gluten-forming proteins which are responsible for dough extensibility and starch which contributes thermoplastic properties by the increased amount of carrot powder and cellulose. Addition of 10% egg powder and 10% Parmesan cheese into the carrot chip formulation caused further dilution of the main structural components of the carrot chip. The dilution effect could result in a chip with a denser cell structure. Therefore, more rigid chips were obtained. Fewer small bristles were also found in these rigid chips.

Mouthfeel and Flavor

Means and standard deviations for flavor and mouthfeel are presented on Table 32. Analyses of variance showed significant differences for both flavor and mouthfeel scores (Table 30). The panelists indicated that the flavor scores of all the substituted carrot powder chips were higher than the control. However, as the level of carrot powder increased from 10 to 40% the flavor scores decreased slightly, nevertheless even at the 40% level the chips were preferred by the panelists over the control. The chips with carrot powder plus cellulose were considered more acceptable in flavor by the panelists than the chips with a comparable level of only carrot powder substitution. Cellulose slightly modified the distinct carrot flavor in a way more desirable to the panelists. The distinct taste of the carrot chips

Table 32. Means and standard deviations[1] for flavor and mouthfeel of carrot chips

Level of Substitution					
Carrot powder %	Solka-floc BW-200 %	Flavor[2] (8)		Mouth-feel[2] (5)	
0	0	5.63	0.34[c]	3.75	0.17[a]
10	0	6.33	0.35[ab]	3.83	0.19[a]
20	0	6.28	0.48[ab]	3.70	0.25[a]
30	0	6.18	0.41[ab]	3.63	0.33[a]
40	0	6.05	0.38[b]	3.32	0.39[b]
12	8	6.03	0.40[b]	3.63	0.24[a]
16	4	6.30	0.07[ab]	3.83	0.14[a]
22	8	6.40	0.26[ab]	3.93	0.18[a]
26	4	6.50	0.27[a]	3.90	0.20[a]

[1] Based on five replications

[2] Total possible point listed in parenthesis under the sensory characteristics

[ab] Average superscripted by the same letter are not significantly different at the 5% level of probability (Duncan, 1957).

results from a combination of the following flavors: (1) the natural flavor from the carrot powder; (2) a nut-like flavor of pyrazine a compound which resulted from the Maillard reaction between carbonyl and α-amino groups of the carrot chip components; (3) flavors from added ingredients, such as garlic, sesame, egg powder, and Parmesan cheese, which not only add specific flavors, but appeared to complement the carrot taste.

General Acceptability

Means and standard deviations for general acceptability values are presented in Table 33. The analyses of variance of these data indicated significant differences among the variables (Table 30). Chips formulated with carrot powder received higher scores than the control chips. Combining cellulose with carrot powder produced chips with the highest acceptability scores. All the chips possessed good eating quality and acceptability. Since the carrot chips were a newly developed snack food, time was required for the taste panelists to adapt to the unique flavor of carrots. The sensory scores revealed that very diverse acceptability was obtained from the first two sections of panelists. Among 20 of the panelists, only 2 marked "like very much"; 6 marked "like slightly"; 4 marked "neither dislike nor like"; and 2 marked "dislike very much". The degree of acceptability increased markedly after the third session. Perhaps the higher scores resulted as the panelists became accustomed to the carrot flavor or less prejudiced toward eating

Table 33. Means and standard deviations[1] for general acceptability of carrot chips

Level of Substitution		General Acceptability[2]
Carrot powder	Solka-floc BW-200	
%	%	(9)
0	0	6.60 ± 0.41[f]
10	0	7.20 ± 0.33[c]
20	0	6.97 ± 0.30[de]
30	0	7.17 ± 0.36[c]
40	0	6.93 ± 0.31[e]
12	8	7.10 ± 0.26[d]
16	4	7.32 ± 0.32[b]
22	8	7.47 ± 0.24[a]
26	4	7.50 ± 0.21[a]

[1]Based on five replications

[2]Total possible point listed in parenthesis under the descriptive term

a...f Average superscripted by the same letter are not significantly different at 1% level of probability (Duncan, 1957)

carrots as a snack chip. The level of substitution with carrot powder up to 40% produced a chip with good eating qualities and a high acceptability. The dilution effect of cellulose on the quality characteristics of carrot chips revealed a higher acceptability of color, texture, mouth-feel, and flavor than those chips without cellulose. However, preference for carrot flavor intensity varied with different individuals. The snack food manufacturer could use various levels of carrot powder in chip formulations to produce a versatile carrot chip by modern extrusion techniques.

Enzymatic Neutral Detergent Fiber (ENDF) Values

Means and standard deviations for ENDF values of carrot chips are presented in Table 34. Analysis of variance indicated that highly significant differences ($p < 0.01$) for ENDF values occurred among variables (Table 35). ENDF content values increased as the level of carrot powder and cellulose substitutions increased. The percentage of ENDF was greater in samples with cellulose substitutions than in those with only carrot powder replacement. This was because fiber concentration in commercial cellulose was much greater than in carrot powder. Southgate (1976) reported that dry carrots contain 28.6% dietary fiber, while commercial cellulose contains almost 99% pure fiber. Sesame seeds have 14.36% ENDF and bread flour 2.09% ENDF. Sesame seeds contributed a constant amount of ENDF since the percentage weight of sesame seeds was the same for each variable. Therefore

Table 34. Means and standard deviations[1] for Enzymatic Neutral Detergent Fiber (ENDF) Analyses of carrot chips

Level of Substitution		ENDF	gm ENDF per oz of carrot chips
Carrot powder	Solka-floc BW-200		
%	%	%	
0	0	3.13 ± 0.05	0.89
10	0	4.20 ± 0.04	1.20
20	0	5.27 ± 0.05	1.50
30	0	6.34 ± 0.04	1.81
40	0	7.43 ± 0.04	2.12
12	8	11.44 ± 0.03	3.26
16	4	9.08 ± 0.02	2.59
22	8	12.57 ± 0.05	3.57
26	4	9.47 ± 0.05	2.70

[1] Based on five replications. All means are significantly different at 1% level of probability

Table 35. Analysis of variance for Neutral Detergent Fiber (ENDF) values of carrot chips prepared with carrot powder and/or cellulose

Source	Degree of Freedom	Mean Square of ENDF
Total	44	9.52
Variables	8	52.37**
Within	32	0.0006

**Significant difference at 1% level of probability

the total percentages of ENDF values for each variable were altered as the level of bread flour substitution with carrot powder and cellulose changed.

Very little research has been reported on the composition of carrots, particularly in terms of the carbohydrate constituents of carrots. Southgate (1976) reported that dry carrots contain 28.6% dietary fiber which includes 11.44% cellulose, 6.01% pentoses, 7.72% uronic acid, and 3.43% hexoses. Spiller and Amen (1976) reported that carrots contain 9% NDF and 9% pectin. Thus, carrots contain 18% true fiber and 50% of that true fiber is lost during NDF extraction. The ENDF analyses value of carrot powder in this study was 12.88%. If 50% of water-soluble dietary fiber is lost during ENDF extraction as have been reported by Spiller et al. (1976), it can be concluded that in actuality the carrot powder could contain 25.76% dietary fiber. Each 10 gm of carrot powder could contribute as much as 2.5 gm of dietary fiber. Thus, the percentage of dietary fiber in the carrot chips ranged from 5.7 to 12.6% dietary fiber for levels of carrot powder substitution from 10 to 40% and 11.1 to 15.2% for carrot powder and cellulose combination replacement. Therefore, the real dietary fiber value for carrot chips in each variable could be 33% higher than the reported ENDF value.

Dietary Fiber Available From Commercial and Home-made Foods

Means and standard deviations for ENDF value obtained from ENDF analyses of some commercially baked products and cereals as well as selected home-made, whole grains breads which were prepared for this study, are tabulated in Tables 36 and 37. These data indicated that products made from brans and crushed whole grains contributed substantially higher amounts of dietary fiber. The ENDF percentages in cereals, corn chips, crackers, and European flat breads were significantly higher than in breads. While fruit-nut breads had moderate ENDF values, vegetable breads such as zucchini and carrot bread had low ENDF values. Among chips, Tortilla chips had the highest ENDF values, corn and potato chips had lower values and carrot chips had the lowest values.

The fact that carrots had lower ENDF values than those of Tortilla chips, corn chips, and potato chips are due to the following reasons: (1) Tortilla chips are made from whole corn and tomato pulps. Whole corn kernels contain 2.1 to 2.3% crude fiber and 10% hemicellulose but contain no pectic substances (Inglett, 1970), while dry tomatoes contain 4.41% lignin, 6.72% cellulose, 4.15% pentoses, and 4.34% uronic acid (Southgate, 1976). Therefore, corn and tomato pulp together contribute at least 19% of ENDF, with less lost during ENDF extraction since corn does not contain water-soluble pectins; (2) Corn chips are made

Table 36. Means and standard deviations for Enzymatic Neutral Detergent Fiber Content in cereals and whole grain breads

Food Items	% ENDF	gm ENDF per serving (1 oz)
Cereals:		
Kellogg's All Bran	34.06 ± 0.44	9.71
Kellogg's Bran Buds	33.84 ± 0.04	9.64
Kellogg's Raisin Bran Flakes	14.72 ± 0.15	4.20
Ralston's Wheat Chex	13.85 ± 0.13	3.95
Kellogg's Frosted Mini-Wheats	13.55 ± 0.19	3.86
General Mill's Wheaties	10.57 ± 0.55	3.01
Food Club Raisin Bran Flakes	8.80 ± 0.11	2.51
Grape-Nut Cereal	7.54 ± 0.45	2.15
Kellogg's Country Morning	6.34 ± 0.30	1.81
Nature Valley's Nature Cereals	5.87 ± 0.43	1.67
Total, General Mills	5.81 ± 0.19	1.66
Nature Valley Granola Cinnamon and Raisin Cereal	5.63 ± 0.25	1.60
C.W. Post Family Style Cereal	4.56 ± 0.28	1.30
Cap'n Crunch Crunchy Berries	3.84 ± 0.18	1.09
Whole grain bread:		
Rye Bran Bread	13.72 ± 0.46	3.91
Schwazbrot	13.50 ± 0.02	3.85
Pumpernickle	11.33 ± 0.36	3.25
Fig Bran Bread	9.99 ± 0.09	2.85
Stollen	7.84 ± 0.11	2.23
Awrey Heart Health Wheat Bread	7.66 ± 0.20	2.18
Apple Bread	6.32 ± 0.06	1.80
Bran Bread	6.08 ± 0.19	1.73
Rolled Oat-Nut Bread	6.06 ± 0.10	1.73
Oat Raisin Bread	5.54 ± 0.13	1.58
Banana Bran Bread	5.49 ± 0.33	1.56
Italian Rye Bread	5.21 ± 0.04	1.48
Raisin Bread, 80%	4.48 ± 0.13	1.28
Carrot Nut Bread	3.44 ± 0.22	0.98
Zucchini Bread	2.02 ± 0.05	0.58

Table 37. Means and standard deviations for Enzymatic Neutral Detergent Fiber Content in crackers, European flat breads, cookies, snacks and other food stuffs

Food Items	% ENDF	gm ENDF per serving (1 oz)
Crackers and European flat bread:		
Siljan Swedish Rye Crispbread	36.27 ± 0.31	10.34
Idea Flat Bread, Norwegian	28.23 ± 0.28	8.05
Rogga	25.40 ± 0.36	7.24
King's Crisp Bread	25.21 ± 0.22	7.24
Crisp Bread with Linseed	22.44 ± 0.09	6.40
Mors Flatbread	17.77 ± 0.15	5.05
Crisp Bread with Sesame	16.44 ± 0.26	4.69
Triscuit Whole Wheat	14.67 ± 0.42	4.11
Hol Grain Natural Rice	5.97 ± 0.18	1.70
Wheat Square Crackers	5.41 ± 0.41	1.54
Honey Sorghum	4.76 ± 0.29	1.36
Hearty Wheat Snack Cracker	3.67 ± 0.38	1.05
Cookies and snacks:		
Doritos Tortilla Chips	32.44 ± 0.46	9.25
Sesame and Bran Sticks	16.10 ± 0.12	4.59
Corn Chips	14.11 ± 0.04	4.02
Potato Chips	12.64 ± 0.28	3.60
Sesame Buds	10.85 ± 0.12	3.08
Nature Vallye Granola Bars with Coconut	8.09 ± 0.10	2.31
Old Fashioned Oatmeal Cookies	5.43 ± 0.16	1.55
Fig Bar	4.25 ± 0.16	1.21
Other food stuffs:		
Red Wheat Bran	40.81 ± 0.12	
White Wheat Bran	39.77 ± 0.14	
Wheat Germ	24.26 ± 0.14	
White Sesame Seeds	14.36 ± 0.10	
Carrot Powder	12.88 ± 0.05	
Jiffy Bran Muffin Mix	9.67 ± 0.08	
Defatted Soy Flour	7.31 ± 0.10	
Rolled Oat	5.63 ± 0.28	
Bread Flour, General Mills	2.09 ± 0.04	

primarily from corn and contain at least 12% ENDF in a dry matter base; (3) Potato chips are entirely made from potatoes in which some starches have been removed before deep-fat frying. According to Southgate (1976) potatoes contain 6.24% lignin, 7.02% cellulose, and 6.24% hemicellulose based on dry weight; (4) Carrots contain 11.44% cellulose and 17.16% noncellulosic dietary fiber (mainly 7.72% uronic acid, 6.01% pentoses, and 3.43% hexoses). Most of the non-cellulosic dietary fiber components are soluble in water, and therefore, at least 50% of dietary fiber in carrots is lost during ENDF extraction due to the composition; (5) Carrot chips are made from 5 to 18% carrot powder, 4% sesame seeds, 26 to 43% wheat flour, and 2 to 4% cellulose. Carrot chips, therefore, contain porportionally less water-insoluble fiber components than other chips. Therefore, carrot chips contain less ENDF than other chips. However the water-soluble constituents; pectin, uronic acids, pentoses, and hexoses, found in carrots are considered excellent bulking and ion-exchange agents making carrot chips feasible carriers of vegetable dietary fiber.

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the effects of substituting varying levels of carrot powder for bread flour on the physical and sensory quality characteristics of carrot chips. Cellulose was used to modify the intense carrot flavor, color and texture of the carrot chips containing the higher levels of carrot powder substitution. Enzymatic Neutral Detergent Fiber Analyses were carried out for the carrot chips as well as other cereal and grain products to determine their dietary fiber contributions. It is hoped that this research will provide more definitive information on sources of dietary fiber.

Carrot chips were prepared from wheat bread flour using a modified wheat chip formulation with increasing substitution levels of carrot powder. Substitution levels included 10, 20, 30, and 40% carrot powder; 12 and 22% carrot powders blended with 8% cellulose; and 16 and 26% carrot powders blended with 4% of cellulose, respectively.

Fresh carrots were dehydrated and dried in an air-blast oven, the dry carrots were then ground with a cyclone mill to the same particle size as the bread flour to facilitate rehydration and to provide consistent dough sheeting.

Both subjective and objective methods were used to evaluate the quality characteristics of the carrot chips.

The subjective evaluation included (1) appearance (color and bristles), (2) flavor, (3) texture (mouthfeel, crispness and friability), and (4) general acceptability. The objective evaluations included moisture, crispness using the Allo-Kramer shear press, and color using the Hunter Color Difference meter. Chemical analyses of the dietary fiber content of carrot chips, and other cereal products, were used to determine foods rich in fiber content.

Objective measurement of the quality characteristics of the carrot chips indicated that the moisture level of the raw dough increased as the levels of carrot powder and cellulose substitution increased due to additional water in the formulation, the different levels of substitution did not affect the final moisture content of the carrot chips. The natural orange yellow color of carotenoids in the carrots resulted in chips that were slightly darker with higher redness and yellowness values. Test panelists, however, scored those chips similarly.

Carrot powder substitution made chips slightly crisper and a little less friable. As the level of carrot powder increased, more force per gram was required to shear the carrot chips. Corrot substitution reduced the gluten available extensibility of the dough. Nevertheless, the chips produced had acceptable crispness and friability scores and were felt to be suitable for packaging without excessive breakage.

Carrot powder and cellulose substitution improved the flavor and general acceptability scores of the chips while mouthfeel was unaffected except for the variable with 40% carrot powder substitution. The carrot chips were well-liked by the panel. Using cellulose along with the carrot powder produced the most acceptable chips. Addition of sesame seeds to the chips not only provided nut-like flavor but also contributed a substantial amount of dietary fiber.

Increasing the substitution levels of carrot and cellulose resulted in increased ENDF values of carrot chips. Increasing ENDF did not impair the eating quality of carrot chips. On the contrary, replacement levels up to 40% carrot powder and 8% cellulose in the chip formulation produced good quality and acceptable carrot chips. Moreover, carrot chips prepared from the blended carrot powder and cellulose had the best quality characteristics among variables evaluated.

Substitution of carrot powder alone provided from 1.2 gm of ENDF per ounce at the 10% level to 2.12 gm ENDF at the 40% substitution level. The combination of 12% carrot powder and 8% cellulose contributed 3.26 gm ENDF per ounce, and the largest amount of fiber per ounce in the various chips was found in the 22% carrot powder and 8% cellulose chips which contained 3.57 gm per ounce serving.

Smith (1974) reported that the total snack market in the United States has passed the $5 billion figure per annum and responsible estimates indicate this will reach

$8 billion in annual sales by 1980. Snack can be specially formulated as high protein, high energy, or high dietary fiber foods. Carrot chips contained approximately 7.7 to 11.5% protein, 30% fat, and 4.2 to 12.6% ENDF.

Thirteen cereals evaluated for their dietary fiber composition ranged from 3.8 to 34.1% ENDF. Six of these cereals had over 10% ENDF and would contribute from 3 to 9 gm dietary fiber per one ounce serving. The fourteen whole grain and vegetable quick breads analyzed were found to contain 2.0 to 13.7% ENDF. These breads could contribute from 0.6 to 3.9 gm of dietary fiber per one ounce serving. Eight cookies and snack foods contained 4.3 to 32.4% ENDF and would contribute from 1.2 to 9.3 gm dietary fiber per serving. Twelve types of crackers and European flat breads contained 3.7 to 36.3% ENDF with contributions of 1.1 to 10.3 gm dietary fiber per serving. Of the foods analyzed, All Bran, Bran Buds, Doritos Tortilla Chips and Siljan Swedish Rye Crispbread contained over 30% ENDF while several other European flatbreads analyzed had 20% ENDF.

In conclusion, several commercial and homemade products have been found to contain substantial amounts of dietary fiber. In addition, a carrot chip has been formulated which is of good quality and is a significant source of dietary fiber. If dietary fiber becomes a recommended nutrient, the more sources available for selection of this nutrient, the more likely people with diverse food habits will meet their requirement.

PROPOSALS FOR FUTURE STUDIES

1. A study of the effect of combinations of roasted bran flakes, coconut residues, dry fruits, and nuts in snack bar product formulation should be undertaken.
2. An investigation such as substituting carrot powder and cellulose in frozen egg-roll skins and other pastry products is recommended since carrots are stable at low temperatures.
3. Fortification of cereals, candy bars, popcorns, and poprices with seaweed films (Ze-Tsi) or dry vegetables is recommended. These seaweed films are rich in cellulose, hemicellulose, gums and mucilages.
4. Higher levels of carrot powder and cellulose substitutions should be studied. Increasing the levels of carrot powder up to 50% with a maximum of 12% cellulose might produce chips of good quality with higher dietary fiber values. The dense structural characteristic can be solved by adding slightly higher levels of a leavening agent and/or selected emulsifiers to improve the dough consistency.
5. Techniques for preventing the oxidation of carotene in carrot substituted products need to be developed.
6. More efficient methods of dietary fiber analyses on the combined daily diets should be developed.

APPENDIX

CARROT CHIP SCORE SHEET

Please check the word which best describes how you feel about these products - just check with "+" for each product.

Appearance

Characteristics | Product Number

Color

6	entirely golden				
5	entirely golden brown				
4	golden brown with slightly edge burned				
3	bristle burned				
2	dark brown				
1	over burned				

Shape

5	like very much				
4	like moderately				
3	like slightly				
2	neither like nor dislike				
1	dislike				

Bristle

4	many bristles evenly distributed				
3	few bristles evenly distributed				
2	few bristles unevenly distributed				
1	no bristle				

Texture

Characteristics | Product Number

Friable

5	extremely				
4	very easy				
3	slightly				
2	moderately				
1	hard				

Crispy

6	extremely				
5	very				
4	moderately				
3	slightly				
2	not				
1	soggy				

Mouthfeel

5	very pleasant				
4	pleasant				
3	neither tough nor gritty				
2	slightly tough and gritty				
1	tough, gritty, dry				

Flavor

Characteristics		Product Number			
Salti-ness	6 extremely				
	5 very much				
	4 moderately				
	3 slightly				
	2 bland				
	1 tasteless				
Greasi-ness	5 just fine				
	4 slightly				
	3 moderately				
	2 very much				
	1 extremely				
Over all flavor	8 like extremely				
	7 like very much				
	6 like moderately				
	5 like slightly				
	4 neither like nor dislike				
	3 dislike slightly				
	2 dislike very much				
	1 dislike extremely				
Detectable flavor or aroma - Please describe the detectable flavor as much as you can					

General Acceptance

		Product Number			
9	 like extremely				
8	 like very much				
7	 like moderately				
6	 like slightly				
5	 neither like nor dislike				
4	 dislike slightly				
3	 dislike moderately				
2	 dislike very much				
1	dislike extremely				
Suggestions - Gratefully Welcome!					

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