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BIOMEDICAL CONSIDERATIONS

OF

OAT DIETARY FIBER AND BETA-GLUCANS

H. DAVID HURT, PH.D.
REBECCA MATHEWS, M.Sc.
STEVEN L. INK, PH.D.

THE QUAKER OATS COMPANY
BARRINGTON, ILLINOIS U.S.A.

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INTRODUCTION

The nutritive value of oats is well documented. Oat products consumed by humans are generally from the entire groat and thus are essentially considered to be whole-grain products. In the normal milling of oats, only the fibrous hull and adhering portions of the oat grain are removed. The bran, the aleurone layers, endosperm, and the germ remain in the fraction consumed as food. The outer cellular layers of the groat are especially rich in protein, fiber, vitamins, and minerals. Therefore, the milling, separation and isolation of oats yields a product high in nutritive value and dietary fiber (Peterson et al, 1975; Gould et al, 1980).

In addition to the general nutritive value, oats has recently received increased attention from the nutrition and medical communities because of its dietary fiber content and associated role in reducing cholesterol levels--a recognized risk factor for coronary heart disease, its affect on sugar levels associated with insulin needs and diabetes, as well as its impact on colon cancer and related disorders. Many of the metabolic and physiological effects of oat products have been attributed to the soluble dietary fiber and particularly the beta-glucan content of oats. This review provides an overview of the physiological effects and potential health implications of oat fiber consumption as well as a brief discussion of the structure and physical properties of oat beta-glucans.

I.   STRUCTURE AND PHYSICAL PROPERTIES OF BETA-GLUCANS

Histochemical studies have shown beta-glucans to be located throughout the oat groat (Fulcher, 1986; Wood et al, 1986). However, beta-glucan levels of typical commercial varieties of oats are more concentrated in the subaleurone/outer endosperm areas of the groat (Henry, 1987). The oat husk contains virtually no soluble fiber and is comprised primarily (99%) of insoluble polymers containing cellulose and considerable amounts of xylans and lignin (Frolick and Nyman, 1988).

The dietary fiber and beta-glucan content of commercial oatmeal and oat bran are outlined in Tables 1a and 1b. The soluble dietary fiber component is primarily comprised of beta-glucans. Beta-glucans are high molecular weight polymers of beta-1, 3 and beta-1, 4 linked D-glucopyranosyl units. The ratio between the number of beta 1, 3 linkages to beta 1, 4 linkages is 1 to 3.2 (Hyldon and O'Mahony, 1979). The resulting irregular configuration makes these molecules partially water soluble. Extraction and purification of the beta-glucan fraction of oats have yielded concentrated forms of oat gum (Wood, 1986). Physical factors such as flour particle size, temperature, pH, and ionic strength have been reported to influence beta-glucan yields and solubility (Wood et al, 1978).

Analysis of 35 commercial oat cultivars indicate a range of 3.1 to 5.9% in total beta-glucan content (Table 2) (Webster, impl. data). This variation is largely due to genetic and environmental differences among the different cultivars. The mean is 4.2%. Variation in beta-glucan content suggests there may be dose related physiological effects. Compared to other cereals, oats and barley have relatively high contents of beta-glucans. One estimate of the beta-glucan content of barley indicates a range of 3.0 to 6.9% (Aman and Graham, 1987).

TABLE 1a*

Total Dietary Fiber in Oatmeal and Oat Bran

	Total Dietary Fiber % Original Dry Weight
Oatmeal	12.1 ± 0.2
Oat Bran	18.6 ± 0.5

TABLE 1b*

Beta-Glucan Content of Soluble and Insoluble Fractions of Dietary Fiber

In Oatmeal and Oat Bran

	% Total Fiber	% Beta-Glucan
Oatmeal		
Soluble	40.5	74
Insoluble	59.5	8
Oat Bran		
Soluble	38.7	74
Insoluble	61.3	19

* Adapted from Shinnick et al, 1988.

TABLE 2

Beta-Glucan Content of Oat Cultivars

Cultivar	% Beta-Glucan
Kelly	4.3
Nodaway	4.8
Webster	3.8
Ogle	4.5
Proat	4.6
Otee	5.8
Porter	4.9
Noble	4.3
Dal	4.9
Multiline E-77	4.1
Preston	4.7
Larry	5.9
Lyon	4.0
Lang	4.5
Woodstock	4.6
Oxford	4.3
Ogle T-39	4.2
Ogle T-35	4.0
Kamouraska 1	4.2
Kamouraska 2	4.5
A - 1 Argentina	3.7
Tulancingo	4.5
Paramo	3.9
Tibor #1	3.7
Tibor #2	3.6
Rodney	3.4
Garry	3.6
Coker - 820	3.5
Coker - 227	4.2
Coker - 84	4.2
Donald T.4	3.6
Manic 1	4.0
Manic 2	3.5
Wild Oats	3.1
CR - A Grade	4.0
Old Fashioned Retail	4.4

The effect of viscosity development and solubilization of the beta-glucan due to cooking of rolled oats was investigated (Yiu et al, 1987). Comparison of a rapid cooking method and a gradual cooking method indicate the latter induced more structural disruption of cell walls and an increased release of beta-glucans. Both cooking methods improved the digestibility of the rolled oats, however, increased solubilization of the beta-glucans by gradual cooking may further modify their physiological effects. Gum viscosity in general, has been implicated in mediating several physiological effects such as gastric emptying, intestinal absorption, blood lipid concentrations and postprandial glucose levels (Jenkins et al, 1978; Ink and Hurt, 1987). The effect of cooking on physiological function needs to be further investigated as gradual cooking and rapid cooking methods are both commonly used procedures in preparing oatmeal for consumption.

It has long been believed that soluble dietary fibers in general pass relatively unchanged through the small intestine into the colon where it is fermented (Cummings and Branch, 1986). In the case of soluble oat fiber, this premise had not been demonstrated in humans until recently. Digestion and absorption studies in seven ileostomy patients support the view that human digestive enzymes do not break down the nonstarch polysaccharides (NSP) of oats as the beta-glucans in oats were almost completely recovered after these patients were fed test meals of 100 grams of oats (Englyst and Cummings 1985).

II.   HYPOCHOLESTEROLEMIC EFFECTS

(i)   Animal Studies

As early as 1963 De Groot et al reported that rolled oats incorporated into the diet of rats decreased their serum cholesterol. The hypocholesterolemic effects of oats was greater than that found for all of the other grains tested. Fisher and Griminger (1967) reported that plasma cholesterol levels were significantly reduced in chicks fed whole oats, oat hulls or oat groats. Oat starch and oat oil did not affect cholesterol status. The results of these studies remained unexplained until the health implications of dietary fiber became a significant area of research.

A patent was issued to Hyldon and O'Mahony in 1979 for demonstrating in rats the hypocholesterolemic effects of oat or barley gum in rats. The active cholesterol lowering properties of oat bran was shown to be related to its water soluble gum content. Similar findings were reported by Chen and Anderson (1979). They showed that serum total cholesterol concentrations could be lowered when rats were fed diets supplemented with either 36.5% oat bran, 10% pectin or 10% guar gum. Liver cholesterol concentrations were also reduced. A repeat experiment was conducted with 36.5% oat bran, 10% oat gum or 10% pectin. The oat gum (Chen et al, 1981) yielded more pronounced reductions. Total serum cholesterol concentrations were 40% lower in the oat gum and pectin groups and 24% lower in rats fed oat bran. Increases in HDL-concentrations was highest in the oat gum fed group. The oat gum and pectin groups had significantly lower liver cholesterol concentrations than the oat bran groups.

Other evidence linking the beta-glucan fraction of oat bran to its hypocholesterolemic effect is the demonstration that high beta-glucan containing barley is also effective in lowering serum cholesterol. Prentice et al (1982) showed both oats and barley were effective in reducing plasma and liver cholesterol levels in rats. Fadel et al (1987) recently demonstrated chicks fed a high viscosity barley had lowered serum cholesterol and LDL-cholesterol levels. Addition of beta-glucanase, a beta-glucan degrading enzyme reversed this effect.

(ii)   Human Studies

The cholesterol lowering properties of rolled oats observed with laboratory fed rats, prompted DeGroot and his coworkers (1963) to conduct similar studies in hypercholesterolemic men. They were able to reduce serum cholesterol levels by (11%) in these men when they ate 140 g of rolled oats as bread each day for three weeks.

Subsequent studies over the past two decades have repeatedly demonstrated the lipid lowering effects of oat consumption in humans (Table 3). The degree to which serum cholesterol is lowered may be influenced by a host of variables such as the initial cholesterol status of subjects, the total fat and cholesterol content of the diet, and the amount and nature of the oat product (i.e. oatmeal versus rolled oats versus oat bran, versus oat fiber) that is incorporated into the diet. Generally greater decreases in serum cholesterol are achieved by subjects that have an elevated serum cholesterol level.

Studies in which relatively low daily doses of oat fiber were consumed (e.g. 43 g oatmeal, 0.6 g/kg BW oat bran) by individuals with normal to low serum cholesterol levels consuming self-selected or high cholesterol diets have resulted in lesser changes in serum cholesterol (Gromley et al, 1978; Kretsch et al, 1979). The decrease in cholesterol is shown to correlate well (r = .867) with the oat bran dose. (Gold and Davidson, 1988). Gold and Davidson (1988) approximate this relationship to be: percentage decrease in cholesterol = 0.156 X (gram oat bran/day) + 1.0.

Decreased total serum cholesterol and more specifically LDL-cholesterol concentrations have been associated with a lower risk of coronary heart disease (CHD). Higher HDL-cholesterol concentrations are associated with a reduction in the risk of CHD. Most clinical studies with oat products have demonstrated lowered LDL-cholesterol levels and increased or no change in HDL-cholesterol levels. Kirby and co-workers (1981) demonstrated a significant decrease in serum cholesterol (13%) and LDL-cholesterol (14%) after hypercholesterolemic subjects consumed 100 grams of oat bran for two weeks in a hospitalized setting. To determine whether these results were applicable in a free living situation, eight men were followed for a period of 24 to 99 weeks (Anderson et al 1984b). These men were instructed to consume a low cholesterol diet that included oat bran and beans in their daily diets. After 99 weeks, serum cholesterol had maintained a 22% reduction, LDL-cholesterol a 29% reduction, and HDL-cholesterol an increase of 9%.

The hypocholesterolemic effects of fat modified diets have been well documented. The ability of oat products to enhance the blood lipid lowering effects of a low fat diet has been studied by several investigators. Turnbull and Leeds (1987) observed an 8% drop in the serum cholesterol levels of 17 hypercholesterolemic individuals consuming a diet containing no more than 35% calories from fat, for a period of one month. Subjects were than randomized to one of two treatment groups for another month, in which they were instructed to continue eating the low fat diet supplemented with either 150 g of rolled oats or 137 g of wheat. Oat supplementation further reduced serum cholesterol levels by 5%, whereas wheat supplementation did not produce further significant reductions below that which resulted from the fat-modified diet alone.

Van Horn et al (1986) demonstrated similar added effects of oatmeal or oat bran on cholesterol levels of free-living normolipidemic individuals consuming the type of low fat/low cholesterol diet advocated by the American Heart Association (AHA).

TABLE 3

HUMAN STUDIES INVOLVING OAT FIBER INTAKE

Reference	Subjects (Chol. Status)	Test Duration	Diet	Fiber Source Amount/Day	Results
1) deGroot et al (1963 Lancet 2, 303	21 males 30-50 yrs. (High-normal)	3 week	Self-selected	140 g rolled oats in bread	Serum cholesterol decreased significantly (11%) when rolled oats were added to the diet.
2) Luyken et al. (1978 Voeding, 26, 229.	76 males 19 women 20-16 yr. (High-normal)	4 or 8 wk	Self-selected.	50 g oatmeal in bread	The use of oatmeal bread for 8 wks was accompanied by a significant drop in the cholesterol level of about 6%.
3) Gormley, et al. (1978) Ir. J. Fd. Sci. Technol. 2, 85.	58 males 10 females 30-50 yr. (Normal)	6 wk	Self-selected	43 g oatmeal	Serum cholesterol and HDL-chol. levels were not reduced compared to cornflakes.
4) Kretsch et al. (1979) Am. J. Clin. Nutr. 32, 1492.	6 males 23-40 yr. Normal	15 days	Controlled	oat bran or toasted oat bran (0.6 g/kg BW)	No significant differences in serum cholesterol and triglyceride levels were found.
5) Gould et al. (1980) In: "Cereals for Food and Beverages." G.E. Inglett & L. Munck, Ed. Academic Press, NY p. 447	12 males 2 women 32-53 yr. (Normal)	4 wk	Self-selected	1½ oz. Instant (oats)	No significant change in the mean serum levels was observed, though a significant depression was found in four subjects over age 40.
6) Kirby et al. (1981) Am. J. Clin. Nutr. 34, 2061.	8 males 35-62 yr (high)	10 days	Controlled	100 g oat bran as cereals & muffins	Significant decreases in serum total cholesterol (13%) and LDL-cholesterol (14%) were found. HDL-cholesterol remained changed.
7) Judd & Truswell (1981) Am. J. Clin. Nutr. 34, 2061	6 males 4 women 27-37 yr (Normal)	3 wk	Controlled	125 g rolled oats	Mean reduction of 8% was not significant although 7 of 10 subjects showed reduction in plasma total cholesterol.
8) Anderson et al. (1984a) Am. J. Nutr. 34, 2061.	20 males 34-66 yr. (High)	3 wk	Controlled	100 g oat bran or dried beans	Both fiber sources decreased serum cholesterol levels (19%) and LDL-cholesterol (23%) significantly over the test period.
9) Anderson et al (1984b) J. Can. Diet. Assn. 45:140-149	20 males 34-66 yr. (High)	24-99 wks	Fat Modified	41 g oat bran and 145 g beans	After 24 wks serum cholesterol was decreased by 26% and LDL-cholesterol by 24%. After 99 wks serum cholesterol was decreased by 22%, LDL-chol. by 29%, and HDL-chol. increased by 9%.
10) Van Horn et al. (1986) J. Am. Diet. Assoc. 86:5, 759-64	208 incl controls 30-65 yrs. (Normal)	12 wks.	Fat Modified	35-39 g oatmeal or oat bran	Total cholesterol dropped 8% with fat modified diet and oatmeal product; 5% with fat modified diet alone.
11) Turnbull & Leeds (1987) Am. J. Clin. Nutr. & Gastroenterology, Vol. 2	9 men 8 women (high)	12 wks	Fat Modified	rolled oats 150 g	Total cholesterol dropped 13% with fat modified diet and oats; 8% with fat modified diet alone.
12) Gold et al (1988) Western J. Medicine 148:99-307	72 inc. controls (Normal to low)	4 wks	Self-selected	34 g oat bran	Total Cholesterol dropped 5.3%, LDL-cholesterol 8.7%, and no change in HDL-cholesterol.
13) Van Horn et al (1988) J. Preventive Med. 17:3	236 incl. controls (Normal)	12 wks	Fat Modified	56 g oatmeal	Total cholesterol dropped 8.3% with fat modified diet plus oats; 6.6% with fat modified diet alone. Subgroup with >198 mg/dl baseline dropped 10% with fat modified diet plus oats, 6.6% with fat modified diet.

After six weeks of dietary fat modification, total serum cholesterol levels dropped 5-6%. The inclusion of 35-39 g of oat products per day for another six weeks resulted in a further 3% drop in cholesterol levels. Van Horn et al (1988) confirmed the reproductibility of their findings with a similar study of 236 healthy volunteers with normal cholesterol status. Supplementation with about 2 oz./day of oatmeal to the AHA diet resulted in a total serum cholesterol decrease of 8.3%, whereas the AHA diet alone had resulted in a decrease of 6.6%. A subgroup of individuals in this cohort with initial cholesterol levels $\geq$ 198 mg/dl experienced a 10% decrease in total serum cholesterol with oat supplementation and 6.6% decrease with the AHA diet alone.

Reductions in serum cholesterol levels by the ingestion of oat bran or oat fiber have been reported among young normocholesterolemic individuals even while consuming the usual Western diet (i.e. 40% calories from fat). Gold and Davison (1988) observed a drop in total serum cholesterol of 5.3%, a drop in LDL-cholesterol of 8.7%, and no change in HDL-cholesterol when a group of young, healthy medical students ingested 34 g of oat bran daily in the form of oat bran muffins for four weeks. More concentrated formulations of oat fiber have demonstrated even further reductions in total serum cholesterol among young individuals with normal to low cholesterol status. Vorster et al (1986) observed a reduction of 15-20% in total cholesterol values of young physiology students when daily dietary fiber intake was increased from 22 g to 32 g. Dietary fiber intake was increased by the consumption of 15 fiber tablets that supplied 9.75 g of oat fiber. Body weight changes during the three week experimental period were insignificant.

Evidence that oat fiber may be a useful dietary adjunct in treating hypercholesterolemia is increasing. The public health significance of dietary induced reductions in serum cholesterol can be quantified since recent data indicate that every 1% fall in the level of serum cholesterol leads to as much as 2% fall in the incidence of first major coronary events (LRCP, 1984). The advantages of using oat products include its low cost of intervention and availability (Kinosian et al, 1988).

(iii) Beta-Glucan Concentration and Processing

Diets containing 10% oat gum beta-glucan content in rats was shown to be more effective in lowering serum cholesterol than diets containing 35% oat bran (Chen et al, 1981). The effects of processing and soluble fiber intake on the hypocholesterolemic properties of oat fiber was assessed by Shinnick et al (1988). Rats were fed high cholesterol diets containing 2-6% dietary fiber as cellulose, oatmeal, oat bran, high fiber oat flour or one of flour processed high fiber oat flours for three weeks. The soluble beta-glucan content of oatmeal and oat bran was 28-30% of the total dietary fiber and 29-43% of the total dietary fiber in high fiber oat flours.

All of the diets containing oat fiber products demonstrated a 30-35% decrease in plasma cholesterol concentration with no alteration in food intake or growth. As little as 4% dietary fiber derived from processed oat flour significantly reduced serum cholesterol concentrations. Processing increased the soluble fiber fraction and the amount of total beta-glucans in the high fiber oat flour, as well as demonstrated a trend towards producing a greater hypocholesterolemic effect.

The increased benefits of processed oat fiber was also reflected in lipoprotein changes. Ney et al (1988) reported the lipoprotein profile of rats fed these same diets containing 1% cholesterol and 0.2% cholic acid and 6% dietary fiber from oat bran, high-fiber oat flour, or a processed oat fiber product for 20 days. All oat fibers reduced total lipoprotein cholesterol by 25-45%, VLDL and LDL cholesterol by 40-60% and increased

HDL cholesterol by 25-40%. The processed oat fiber product which contained a higher proportion of soluble fiber reduced lipoprotein cholesterol levels significantly more than oat bran or high oat flour. Lipoprotein cholesterol concentrations in animals fed the processed oat product were no different from controls not fed the high cholesterol diet. Alteration in the lipoprotein fraction has been suggested to represent the most significant factor in reducing the risk of atherosclerosis. All of the oat products tested demonstrated this effect, but the enhanced effect of processed oat fiber seems to confirm the hypothesis that soluble fiber is the component of oat fiber responsible for the hypocholesterolemic properties observed in experimental animals and man. Processing of oats may decrease the dose of oat fiber needed to produce significant cholesterol lowering effects in man. This finding may be of significance in the dietary management of free-living hypercholesterolemic individuals.

Beta-glucans isolated from oats, barley, wheat and sorghum incorporated independently into 7% of pan white breads, produced similar serum-liver-and HDL-cholesterol effects in rats (Klopfenstein and Hoseney, 1987). Feed efficiencies of the wheat and barley glucan breads were not different from that of the control bread, whereas efficiencies of 7% and 13% oat-glucan breads were lower than that of the control. Therefore, beta-glucans from different cereals apparently have different physiological affects in relation to nutrient absorption interference.

(iv) Mechanism of Action

The biochemical or physiological basis for oat fiber induced changes in cholesterol metabolism is not clearly understood. A variety of mechanisms have been proposed for the hypocholesterolemic effects--i.e. acceleration of cholesterol catabolism or inhibition of cholesterol biosynthesis.

It is speculated that plant fibers increase bile acid and neutral sterol excretion by binding these sterols and preventing their reabsorption (Anderson and Chen, 1986). Neutral sterols include cholesterol and coprostanol--the bacterial metabolate of cholesterol. Reduction in bile acid reabsorption is thought to cause the liver to divert cholesterol from lipoprotein synthesis. Subsequently, less cholesterol-rich lipoproteins are available for secretion into the circulation, resulting in lowered serum cholesterol levels. Interruption of the enterohepatic circulation of bile acids stimulates liver hepatocytes to synthesize primary bile acids such as cholic and chenodexycholic acids. Illman and Topping (1985) report increased excretion of cholate in rats fed oat bran. Population studies of individuals who consume high fiber diets have also indicated a higher ratio of primary to secondary bile acids in their feces.

Both animal (Fisher and Griminger, 1967; Illman and Topping, 1985) and human (Kretsch et al 1979; Kirby et al, 1981; Anderson et al 1984; Judd and Truswell, 1981) studies have reported an increase in bile acid excretion after oat bran ingestion. In relation to fecal cholesterol excretion, there are some inconsistencies. Fisher and Gruminger (1967) did not observe neutral sterol changes in the feces of chicks, whereas Illman and Topping (1985) observed in rats a 480% increase in neutral sterols consisting primarily of coprostanol. It is thought when dietary fiber binds bile acids, they interfere with cholesterol miscelle formation and absorption (Anderson and Chen 1986). Decreased cholesterol absorption may further contribute to the hypocholesterolemic effect of these fibers.

A second theory proposed is based on the observation that oat fiber is extensively degraded and fermented by colonic bacteria, with the generation of the short-chain fatty acids (SCFA) acetate, proprionate and butyrate (Storer et al, 1983). These short

chain fatty acids are believed to be rapidly absorbed from the lumen of the colon (Cummings, 1983). Proprionate has been shown to significantly inhibit cholesterol synthesis in isolated rat hepatocytes (Anderson and Bridges, 1981) and in rats fed propionate supplemented diets (Chen et al, 1984). Illman and Topping (1985) examined inhibition of cholesterol synthesis via propionate formed through colonic fermentation in rats fed oat bran. The concentration of propionate in the hepatic portal vein although increased by oat bran ingestion, was less than 2% of that observed to inhibit cholesterol synthesis in vitro. Thus the actual impact on cholesterol hemeostatus remains speculative.

Another possible influence of oat consumption on serum cholesterol levels is the presence of a compound in oats with Vitamin E activity identified as alpha-tocotrienol. Qureshi and coworkers (1986) isolated this compound in barley and showed it suppresses hepatic HMG-COA reductase activity, the first rate-limiting enzyme in the synthesis of cholesterol. Of the cereal grains, oats and barley contain the highest concentrations of the tocotrienols. The alpha-tocotrienol content of oats is apparently similar to that of barley and presumably functions as a cholesterol biosynthesis inhibitor. However, the precise role these compounds may have relative to the beta-glucan cholesterol lowering properties of oats is unclear.

III. OTHER HEALTH IMPACTS

(i) Glycemic Effect

Much of the interest in the use of water soluble dietary fiber in the management of diabetes was stimulated by the work of Jenkins et al (1978, 1981) which demonstrated that incorporating purified fibers (i.e. guar gum, pectin) into meals could lower the glycemic index of a food. The glycemic index is defined as the blood glucose response following the consumption of a 50 g carbohydrate portion of a food expressed as a percent of the response after a standard 50 g starch portion of white bread taken by the same individual (Jenkins et al, 1981; Wolever and Jenkins, 1986).

Oat bran or oatmeal supplementation studies with normal or diabetic subjects have also been conducted. One of the first studies that measured the glucose response after ingestion of an oat product (porridge), reported the glycemic index to be 49 compared with 75 after wheatabix consumption, and 80 after corn flakes consumption (Jenkins et al, 1981). Comparison of plasma glucose and insulin responses among healthy volunteers after eating whole groats, rolled oats and oatmeal were similar (Heaton et al, 1988). This was in contrast to wheat and maize consumption, where peak plasma insulin response increased stepwise in the following manner: Whole grains < cracked grains < coarse flour < fine flour. Smaller glucose and insulin responses were evoked from oat based meals than from wheat or maize based meals. Milled wheat and maize resulted in significantly faster digestion in vitro and enhanced absorption and insulin response in vivo than its coarsely milled equivalent. The structural integrity of oats was less important in mediating postprandial glycemia. The viscous properties of the oat beta-glucans has been cited as the factor responsible for this observation. It is suggested that this component imparts a viscous microclimate in the intestinal lumen that impedes the rate of glucose diffusion and absorption.

Preliminary studies utilizing high beta-glucan oat gum confirm that beta-glucan is the active component which inhibits postprandial rise in glucose and insulin (Braaten et al, 1988a, 1988b). An oat gum preparation containing 80% beta-glucans or guar gum was fed to seven healthy volunteers in conjunction with a glucose test load. After 30 minutes, peak blood glucose was significantly less in the presence of oat gum (6.6 ± 0.4 mM/L) or guar gum (6.5 ± 0.5 mM/L) than in the presence of glucose alone (8.4 ± 0.5 mM/L). Peak insulin levels at 40 minutes, paralleled these findings.

Extension of this investigation was carried out on Type II non-insulin dependent diabetics using preparations of oat bran and oat gum containing 15% and 80% beta-glucan respectively (Braaten et al, 1988b). Three different meals were given to the subjects: Cream of wheat, cream of wheat supplemented with oat gum or oat bran supplying approximately 8 g of soluble fiber. After 30 minutes, blood glucose levels were 50% and 40% for the oat gum and an oat bran supplemented product respectively. Peak glucose response was delayed 40 minutes with oat gum and oat bran supplementation compared to the control. The insulin response corresponded to the glucose response. These results clearly implicate a promising therapeutic role for oat beta-glucan in diabetes management. Future work is needed to elucidate appropriate doses and long term effects of oat beta-glucan supplementation. One of the major drawbacks of aggressive supplementation with guar gum has been its low tolerance (e.g. nausea and vomiting) in a significant percentage of subjects. To date, much of the research with oat bran and oat gum has indicated these are relatively well tolerated by most subjects.

The current mechanism of action proposed for the hypoglycemic response observed with the consumption of viscous fibers incorporates some of the concepts included in Burkitt's original fiber hypothesis. Jenkins et al (1986a) proposes that the consumption of fiber dilutes the nutrients in the lumen of the bowel and subsequently releases nutrients in a more energy dilute form from the stomach and along the length of the small intestine. In contrast, energy dense foods would be rapidly absorbed high up in the small intestine followed by a rapid rise in blood glucose with possibly an undershoot due to excessive insulin release. Changes in the rate of gastric emptying or nutrient delivery to the small intestine; alterations in intestinal motility with possible increases in thickness of the unstirred water layer; and overall impedence in the diffusion of nutrients may all be soluble fiber effects which contribute to a flattening of postprandial glycemia. Prolongation of the rate of absorption of carbohydrates may result in more effective uptake by peripheral tissues, a phenomenon that is of specific significance in the treatment of diabetes.

(ii) Effects related To Cancer Risk

On the basis of epidemiological data, Burkitt (1974) proposed that high fiber diets may provide a protective role against colon cancer. This premise is based on the potential of dietary fiber to (1) increase fecal bulk and decrease the concentrations of interluminal carcinogens and (2) reduce transit time and decrease bacterial conversion of potential carcinogens.

Increase in fecal bulk and reduced transit time may be of less significance for soluble fibers than for insoluble fibers. Wheat bran for example provides an average increase in fecal weight in humans of 5.7 ± 0.5 g per each gram fed in comparison to oat bran or rolled oats which provides an average increase of 3.9 ± 1.5 g per each gram fed (Pilch, 1987). The increased fecal bulk observed with some fibers may be due to increases in bacterial cell mass promoted by the fermentable substrates in the colon (Cummings, 1983). Transit time has also been observed to be decreased with wheat bran, whereas pectin and other soluble fibers have limited or no effect (Pilch, 1987).

It has been suggested a source of the carcinogens responsible for colorectal cancer are compounds derived from the bacterial action on bile acids or cholesterol (Thorton, 1981). It is proposed that a high colonic pH promotes carcinogen formulation from these compounds (Thorton, 1981). Hence, colonic acidification through soluble fiber

fermentation and SCFA production, may protect against the development of colon tumors. Low colonic pH also inhibits the activity of some of the enzymes responsible for carcinogen formation, such as 7-alpha-dehydroxylase (Cummings, 1983). Reduced activity of this fecal microbial enzyme results in decreased conversion of primary bile acids such as deoxycholic acid to secondary bile acids (Hill, 1986). Hill and his colleagues (1975) have shown correlations between the incidence of colon cancer and total fecal bile acid concentration, proportion of fecal bacterial possessing 7-alpha-dehydroxylase activity, and fecal concentration of deoxycholic acid. Colorectal patients have also been shown to have significantly more 7-alpha-dehydroxylase activity per 100 g of dry feces than normal controls (Mastromarino, 1976). Another mechanism through which SCFA from fermentable dietary fiber may exert an anti-tumorogenic effect is in the release of the volatile fatty acid butyrate. This SCFA has been shown to inhibit the growth of in vitro human colorectal adenocarcinoma cell lines (Kim et al, 1982; Kruh, 1982; Cummings, 1983). The precise mechanism of action is not well known.

Epidemiological studies of populations consuming high fiber diets have suggested a protective effect of a high fiber diet (Bingham, 1986). Distinction between soluble and insoluble fiber intake have not been made in these evaluations. However, a recent study showed the population (Parikkala) with the lowest incidence of cancer also had very high intakes of nonstarch polysaccharides (NSP) (Englyst et al, 1982). The majority, 1/2-3/4% of total NSP intake was derived from cereals, of which 1/4-1/2% was from beta-glucan containing cereals, rye, oats, and barley.

An additional consideration in the relationship of dietary fiber and colon cancer is the report of intestinal cell proliferation and promotion of neoplasia in rats fed various sources of soluble fiber. Studies in which rats fed the various fiber sources injected weekly with a known colon carcinogen, dimethylhydrazine (DMH), had significantly greater incidence of malignant tumors when eating diets containing 20% oat bran, 10% pectin or guar gum (Jacobs and Lupton, 1986). In the same laboratory when rats were fed diets supplemented with the same fibers at similar doses without DMH, no tumors were prevalent but expanded cell proliferative zones in the gastric (Lupton and Jacobs, 1987) and small intestine (Jacobs, 1983) mucosa were observed. Expanded cell proliferative zones are thought to precede neoplasia.

Interpretation of these studies have been difficult in light of current theories and human epidemiological evidence; methodological concerns also make extrapolation to humans difficult. The amount of soluble fiber incorporated into the rodent diet is subject to question--such as the incorporation of oat bran at 20% of the diet. A high dose such as this would not be applicable for long term use in humans. The suitability of the rat model in assessing human colon cancer is also questionable. While histopathology, immunologic parameters and cellular kinetics in the rodent and human are strikingly similar, several other factors are distinctly different between the two species in the development of colon cancer. Colon tumor formation in rats follow a proximal distribution such as the cecum and ascending colon, which contrasts with the distal pattern observed in man (Jenkins et al, 1986b). The metabolic activity of the rat cecum may play a role in increasing tumor development in the adjacent proximal colon; in contrast the human cecum is a small metabolically inactive junction between the ileum and the colon. Intestinal cancers in animals are always multiple, which is uncommon in humans (Nigro and Bull, 1986); also rats do not develop spontaneous tumors as humans do. Induction of tumors in rodents is dependent on the type and dose of the carcinogen, the mode of administration, the background diet, sex, and species used (Jenkins et al, 1986; Kritchevsky, 1986). Furthermore, all animals that develop cancer will die regardless of any treatment thus far attempted (Nigro and Bull, 1986). Indeed the evidence suggests that the cancer challenge in the animal model is far stronger than it is in humans (Nigro and Bull, 1986).

The role dietary fibers and specifically soluble fibers such as oat beta-glucans, play (if any) in the etiology of colon cancer is still to be determined. Given the complexity of the tumor development process and the heterogeneity of man's diet, it is unlikely an answer will be readily forthcoming. Cancer research in relation to diet is still in its infancy; hence, any judgements at the present time regarding the effects of specific fiber on the development or the inhibition of cancer is premature. The National Cancer Institute endorses a high fiber intake as one component of cancer prevention and advocates the consumption of dietary fiber from a variety of food sources to achieve this end.

(iii) Vitamin and Mineral Bioavailability

There is some concern that the consumption of high fiber diets may lead to reduced bioavailability of vitamins and minerals. A recent review of research examining the effect of dietary fiber on mineral bioavailability indicate conflicting results (Pilch, 1987). Most of these studies examined the effect of insoluble dietary fibers. Results of human balance studies suggest that insoluble fibers such as wheat fiber may have a more deleterious effect on mineral balance than soluble fibers (Pilch, 1987). Diets containing 25 g dietary fiber (primarily soluble) from fruits and vegetables did not affect mineral balance unless oxalic acid in spinach was included (Ink, 1988). Studies utilizing purified soluble fibers such as locust bean gum, karaya, and pectin have reported minor or no effects on mineral balance (Pilch, 1987).

A recent balance study evaluating calcium bioavailability confirmed this trend. Ninety grams of oat bran was supplemented in the diets of healthy males confined to a metabolic ward (Spencer et al, 1987). The oat bran, eaten as muffins, had no effect on the absorption of calcium in the majority of patients and consistently decreased urinary calcium.

The effects of dietary fiber on vitamin bioavailability have not been extensively studied. The few studies that have studied the effects of soluble fibers (i.e. pectin, guar gum) have been conflicting. Kasper et al (1979), Phillips and Brien (1970) found pectin had no effects on Vitamin A accumulation. On the other hand, Schaus et al (1985) observed decreased Vitamin E bioavailability with 6 and 8%, but not 3% pectin supplementation.

Any potential adverse effect of a moderate increase in dietary fiber that includes soluble fiber, may be minimized when consumed as part of a balanced diet. The likelihood of an intestinal and metabolic adaptation to altered vitamin and mineral bioavailability will likely permit moderate increases of dietary fiber without posing a problem. The expert panel on dietary fiber (Federation of American Societies for Experimental Biology) in their report to the Food and Drug Administration recommend the consumption of a wide variety of whole grain products, fruits, and vegetables, leading to a dietary fiber intake of 20-35 grams/day for the healthy, adult population (Pilch, 1987).

IV.   CONCLUSION

Approximately 40% of the total dietary fiber in oats is soluble and 74% of the soluble fraction is comprised of beta-glucans. The total beta-glucan content of oats is dependent on genetic and environmental factors. Research is needed to identify cultivars which have been optimized for yield and nutritional benefits. Processing may enrich the beta-glucan content of oat products, especially in the case of lower containing beta-glucan cultivars.

Oat dietary fiber and beta-glucans have been implicated in many of the physiological effects of oats. The data presented in this review support the position that oats as part of a total dietary plan to modify serum cholesterol, demonstrates a moderate but independent serum cholesterol lowering effect. Oat products may also play a role in mediating the rise in blood glucose following meal ingestion. Enriched oat beta-glucan products obtained through processing have the potential of enhancing both the hypocholesterolemic and hypoglycemic effects observed.

Increased consumption of oats are in tune with the dietary recommendations of U.S. federal agencies such as USDA, Health and Human Services, and health organizations such as the American Heart Association, the American Diabetes Association, and the National Cancer Institute, which advocate an increase in the intake of dietary fiber and complex carbohydrates. Given these findings, there appears to be a sound foundation for advocating increased consumption and increased agricultural interest in this commodity.

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