ANALYSIS OF THE NET ENERGY VALUE OF TWO SOLUBLE FIBERS

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Prepared for

SlimFast Foods Company
777 South Flagler Drive, West Tower Suite 1400
West Palm Beach, FL 33401

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FOREWORD

The Life Sciences Research Office (LSRO) of the American Society for Nutritional Sciences (ASNS) provides scientific assessments of topics in the biomedical sciences. Reports are based upon literature reviews and the scientific analyses of knowledgeable investigators engaged in work in specific areas of biology and medicine.

This report was developed by the LSRO for SlimFast Foods Co., 777 South Flagler Drive, West Palm Beach, FL 33401, in accordance with a contract between SlimFast and the LSRO. The report was prepared by consultant authors to the LSRO, edited by LSRO staff, and critically reviewed by independent consultants. Potential authors and reviewing consultants were identified by the LSRO based on their qualifications, experience, and freedom from conflict of interest, with due consideration for balance and breadth in appropriate disciplines. The author and reviewing consultants were selected with the concurrence of the LSRO Scientific Advisory Committee (who are appointed by the President, ASNS).

George C. Fahey, Jr., Ph.D., Professor, and Christine M. Grieshop, Ph.D., Department of Animal Sciences and Nutritional Sciences, University of Illinois at Urbana-Champaign, should be cited as the authors of this report. The LSRO acknowledges the efforts of George C. Fahey, Jr., Ph.D., and Christine M. Grieshop, Ph.D. and also the critical assistance of the consultant reviewers: Dennis Gordon, Ph.D., Professor, Department of Cereal Sciences, North Dakota State University; Judith Hallfrisch, Ph.D., Lead Scientist, Diet and Human Performance Laboratory, Beltsville Human Nutrition Research Center, USDA; and David Jenkins, M.D., Ph.D., D. Sc., Department of Clinical Nutrition, St. Michael's Hospital, and Professor, Department of Nutritional Sciences, University of Toronto, who critically reviewed several drafts of the manuscript. Subsequently the draft report and tables were revised by the author, edited by the LSRO scientific staff, and received final concurrence from the author and reviewing consultants.

The scientific literature, data, and information was evaluated and conclusions were drawn by the authors, consultant reviewers, and LSRO staff independently of SlimFast Foods or any other group, governmental or non-governmental. The authors and LSRO accept responsibility for the accuracy of the report and its appendix tables. This final report was reviewed and approved by members of the LSRO Scientific Advisory Committee. Upon completion of these review procedures, the report was transmitted to the Sponsor by the Director, LSRO and the Executive Officer, ASNS.

While this is a report of the LSRO and the ASNS, it does not necessarily reflect the opinion of the membership of the ASNS.

__________________________________________
Date

Michael Falk, Ph.D.
Director
Life Sciences Research Office
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ABBREVIATIONS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>$\Delta H_c$</td>
<td>heat of combustion</td>
</tr>
<tr>
<td>$\Delta E$</td>
<td>partial energy</td>
</tr>
<tr>
<td>AMEn</td>
<td>apparent metabolizable energy, nitrogen corrected</td>
</tr>
<tr>
<td>ATP</td>
<td>adenosine triphosphate</td>
</tr>
<tr>
<td>BW</td>
<td>body weight</td>
</tr>
<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
</tr>
<tr>
<td>CPS</td>
<td>centipoise</td>
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<tr>
<td>D</td>
<td>apparent digestibility</td>
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<td>digestible energy</td>
</tr>
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<td>digestible energy values</td>
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<td>DM</td>
<td>dry matter</td>
</tr>
<tr>
<td>FE</td>
<td>fecal energy</td>
</tr>
<tr>
<td>GA</td>
<td>gum arabic</td>
</tr>
<tr>
<td>GE</td>
<td>gross energy</td>
</tr>
<tr>
<td>GEi</td>
<td>gross energy of intake</td>
</tr>
<tr>
<td>GG</td>
<td>guar gum</td>
</tr>
<tr>
<td>GI</td>
<td>gastrointestinal tract</td>
</tr>
<tr>
<td>GRAS</td>
<td>generally recognized as safe</td>
</tr>
<tr>
<td>$I_s$</td>
<td>amount of supplement ingested</td>
</tr>
<tr>
<td>MCTT</td>
<td>mouth to cecum transit time</td>
</tr>
<tr>
<td>ME</td>
<td>metabolizable energy</td>
</tr>
<tr>
<td>MW</td>
<td>molecular weight</td>
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<tr>
<td>NE</td>
<td>net energy</td>
</tr>
<tr>
<td>NE_m</td>
<td>net energy of maintenance</td>
</tr>
<tr>
<td>NSP</td>
<td>nonstarch polysaccharides</td>
</tr>
<tr>
<td>OM</td>
<td>organic matter</td>
</tr>
<tr>
<td>PHGG</td>
<td>partially hydrolyzed guar gum</td>
</tr>
<tr>
<td>RS</td>
<td>resistant starch</td>
</tr>
<tr>
<td>SCFA</td>
<td>short chain fatty acid</td>
</tr>
<tr>
<td>SIELn</td>
<td>supplement-induced energy losses, non-fecal, estimated</td>
</tr>
<tr>
<td>TE</td>
<td>total energy</td>
</tr>
<tr>
<td>UCC</td>
<td>unavailable complex carbohydrate</td>
</tr>
<tr>
<td>UE</td>
<td>urinary energy</td>
</tr>
<tr>
<td>VFA</td>
<td>volatile fatty acid</td>
</tr>
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</table>
INTRODUCTION

**Guar Gum.** Guar Gum (GG) is a white to off-white powder obtained from the ground endosperm fraction of the seed from the guar plant, *Cyamopsis tetragonolobus*, grown primarily in India and Pakistan (Anderson et al. 1993). It is of particular interest to the food industry because of its viscoelastic properties (a 1% GG solution has a viscosity of 3,200 cps). GG is dispersible in either hot or cold aqueous systems where it is used as a thickener, stabilizer, or emulsifier. The high viscosity of dilute GG solutions is attributable to the polysaccharide fraction of the product, which is largely composed of galactomannans and represents from 66-82% of GG dry matter. Galactomannans have a linear backbone composed of (1-4)-linked β-D-mannopyranosyl residues; along the backbone are interspersed monosaccharide branches, α-D-galactopyranosyl residues linked through the O-6 position of the backbone mannopyranosyl residues. The galactose:mannose ratio in GG hydrolysates is approximately 38:62, indicating one branch point per 1.6 backbone residues. The branch points appear to occur along the backbone chain in a random or irregular pattern. However, it has been suggested that side-chain units are dispersed alternately along the D-mannan backbone. The galactomannans of GG cannot be described by a single MW value due to their polydispersity. The number-average MW of GG galactomannans is estimated in the range of 240,000 daltons, and weight-average values of 950,000 daltons have been reported (Anderson et al. 1993). Comparative studies of the intrinsic viscosity, chemical composition, and enzyme susceptibility of 11 different GG varieties indicate the galactomannan fractions of different GG varieties are essentially identical (McCleary and Neukom, 1982). In addition to carbohydrates, GG also contains from 3-7% crude protein.

**Gum Arabic.** Gum Arabic (GA) is the exudate from African *Acacia* trees, predominantly *A. senegal* (L.) Willd. The terms “gum arabic” and “acacia gum” have been used synonymously in the past, so it is crucial to take into account the variation in composition of exudates from different species of the genus. Although some variation exists, structural variations are not large but could be significant in the development of other acacia gums for special purposes. In addition, there are extreme differences in MW, and uronic acid and deoxyhexose content among other acacia gums (i.e., those not from *A. senegal*).

GA is composed of spiral chains of β-galactopyranose linked β-(1, 3) with side chains of (1, 6)-linked galactopyranose, arabinopyranose, rhamnose (12% of the total), glucuronic acid (16% of the total), and crude protein (3% of the total). The MW is ≈500,000 (range: 191,000-600,000). The special importance of GA in food processing and formulation stems from its extremely high solubility in water, coupled with the low viscosity of solutions of the GA at the concentrations normally used in food products (Stephen and Churms, 1995).

INTAKE DATA ON GUAR GUM AND GUM ARABIC

Gums usually are added in small quantities (0.1-2%) to food items and constitute ≤2% of the total dietary fiber intake by humans (Behall, 1997). Mixtures of gums, as well as single gums, are used in a wide array of food items.

**Guar Gum.** GG is a Generally Recognized As Safe (GRAS) food ingredient (Office of the Federal Register, 1993) permitted for use in many foods at levels ranging from 0.35-2.0%. Intake estimates range from 16.6-45 mg/d × capita, although values as high as 1.9-3.9 g/d have been suggested for individuals 2-65 y, respectively (Select Committee on GRAS Substances, 1973). These latter numbers are thought to be large overestimations of GG intake.

Significant decreases in food intake, BW gain, and food efficiency of rats have been reported by the
National Toxicology Program (1982), Poksay and Schneeman (1983), Calvert et al. (1985), and Shah et al. (1986, 1987) when diets containing 5 or 10% GG were fed for 3- to 103-wk periods. For example, rats fed a diet containing 50 g/kg GG experienced a significant decrease in weight gain (321 g/25 wk) compared to rats fed a basal diet (17% crude protein, 20% fat), or diets supplemented with 50 g/kg low- or high-methoxyl pectin, or 200 g wheat bran (352.3, 369.4, 337.4, and 343.9 g weight gain/25 wk, respectively (Asp et al., 1981). The lower weight gain/kJ in rats on the GG diet, implies that GG may have a lower energetic value than pectin or wheat bran (Asp et al., 1981). In contrast, Jacobs and Lupton (1984) reported no effects of 10% GG on caloric intake or weight gain of rats in a 4-wk study.

In some 15 human studies, in which healthy subjects as well as those with diabetes and (or) hypercholesterolemia consumed 9-32 g GG/d as part of a self-selected or controlled diet for periods ranging from 3 to 48 wk, no BW changes were observed (Anderson et al. 1993). In three other clinical investigations with humans consuming 15 g GG/d for 8 to 40 wk, significant weight losses were reported (Anderson et al. 1993). French and Read (1994) found that 3% GG added to high- or low-fat soups fed to 8 healthy male subjects (22-30 y) during four meals, each separated by ≥1 wk, had a much more profound effect on satiety when added to a meal rich in fat than when added to a low-fat meal. Moreover, the satiating effect of GG added to a high-fat meal was not related to a delay in gastric emptying, whereas there was a strong relationship between a delay in gastric emptying and hunger suppression when GG was added to a low-fat liquid meal. Pasman et al. (1997a) studied the effects on weight maintenance of one-wk supplementation (40 and 20 g GG/d) in 20 obese females (21.4±7.4y). In the first study (40 g GG/d), hunger and satiety scores were studied under free-living conditions. In the second study (20 g GG/d), energy intake was fixed at 6 MJ/d (their normal energy intake at the time) or at 4 MJ/d (low-energy intake).

During four wk, subjects were exposed in random order to four different conditions for one week each. The two fixed energy intake levels were compared with and without fiber supplementation. In the first study, hunger and satiety scores did not change. In the second study, at the low-energy level of 4 MJ, hunger scores were significantly decreased after fiber supplementation. No changes in these scores were seen at the 6 MJ energy level. The reduction in energy intake by soluble fiber under free-living conditions and the hunger-reducing effect of fiber at the low-energy intake level suggest that fiber may be useful in the treatment of obesity by facilitating compliance to low-energy intake. Pasman et al. (1997b) found no effect on weight maintenance in weight-reduced obese females after a 56-wk supplementation of 20 g GG/d.

Gum Arabic. Intake estimates, such as those noted above for GG, are not available for GA. In two separate 90-d tests, rats were fed dietary concentrations of 0, 1, 2, 4, 8, or 20% GA for 13 wk. Parameters studied were BW, food and water consumption, urinalysis, liver and kidney weights, clinical chemistry, hematology, and histology (Anderson et al., 1982). No untoward effects were noted for male or female rats when fed 5.2 (8.6% of diet) and 13.8 g (18.1% of diet) GA/kg diet/d, respectively.

DIGESTION, ABSORPTION, AND METABOLISM OF GUAR GUM AND GUM ARABIC

Guar Gum - Animal Studies. GG is not digested in the small intestine of the rat but is almost completely fermented in the colon (Nyman and Asp, 1982; Lupton et al., 1988) to short-chain fatty acids (SCFA), gases, and other metabolites. Bayliss and Houston (1984) isolated human fecal organisms all of which were able to ferment a GG substrate and produce large quantities of CO₂. In an in vitro fermentation of GG with dog and cat fecal microflora, the disappearance of organic matter (OM) after 24 h of incubation was ∼75% (Sunvold et al., 1995a, 1995b). Brunsgaard et al. (1995a) found that the hindgut of the rat requires at least 2 to 3 wk to develop the capacity needed for maximal GG fermentation. Tulung et al. (1987) reported that SCFA absorption increased rapidly and was near maximal within 10 d in rats fed 15% GG-containing diets.
It is interesting, that inclusion of 5-10% GG in rat diets has been shown to increase secretion and activities of pancreatic enzymes (viz., amylase, protease, and lipase). Total bile acids, pancreatic weight, and concentrations of DNA, RNA, and protein also increased (Ikegami et al., 1990). Significant increases have been reported in intestinal lipase, protease, and amylase activities in rats fed diets containing 10% GG (Poksay and Schneeeman, 1983) and intestinal lipase and protease activities in rats fed 5% GG (Ikegami et al., 1990).

Ehrlein and Stockmann (1998) found that using the miniature pig model, absorption rates of carbohydrates, protein, and fat, and the TE declined linearly with increasing concentrations (0-4.4 g/L) of GG added to infused enteral diets. Relationships between concentration of GG and viscosity showed an exponential pattern (absorption of nutrient declined exponentially as viscosity of the chyme increased). GG (1 g/L) diminished absorption of energy by 4-10% relative to the GG-free control diets.

In rats fed diets containing 5 or 10% GG, weights of the small intestine, large intestine, and cecum were increased significantly (20-40%) (Poksay and Schneeeman, 1983; Ikegami et al., 1990; Brunsgaard et al., 1995b). Jacobs and Lupton (1984) observed a 51.2% increase in cecal mucosal wet weight, 124.5% increase in mucosal DNA, and 93.3% increase in mucosal RNA content in rats fed 10% GG compared with rats fed a fiber-free diet. Brunsgaard et al. (1995b) suggested that these changes may reflect a depression in digestion and absorption resulting from decreased accessibility of absorbable nutrients to the mucosal surface, an effect created by the viscosity of the GG.

GG-induced increased gastric emptying times were reported in rats (Osilesi et al., 1984; Shah et al., 1986) and pigs (Rainbird and Low, 1986).

Tulung et al. (1987) found that GG added to diets at the 15% level increased the quantity (or pool) of SCFA in the cecum (acetate, ~100 mmol/L, propionate, ~60-70 mmol/L, butyrate, ~10-20 mmol/L) in rats. Cecal pH dropped from 7.0 for rats on a fiber-free diet to 6.05-6.1 for rats fed the GG diet for 21 d. In contrast, McIntyre et al. (1991) found that feeding 10% GG-containing diets increased cecal concentrations of butyrate but not acetate or propionate, had no effect on fecal SCFA concentrations, and did not influence the pH of either the cecal contents or feces. Thus, it is difficult to predict the effect of GG on nutrient availability.

**Guar Gum - Human Studies.** An in vitro study by Adiotomre et al. (1990) using human fecal inocula incubated with 9 different fibers indicated that pectin yielded the largest amount of total SCFA (82 mmol/L), followed by GA (74 mmol/L) and GG (71 mmol/L). Acetate and butyrate were in the same rank order but GG resulted in relatively greater propionate production (19 mmol/L) than did GA (15 mmol/L) or pectin (12 mmol/L).

Tomlin et al. (1986) demonstrated that incubation of a human fecal homogenate with GG resulted in the production of H2 and decreased viscosity and pH. Bayliss and Houston (1985) observed a decrease in fecal pH in one human subject following ingestion of 14 g/d GG for a 21-d period. The pattern of SCFA production from the fermentation of GG by human fecal bacteria in vitro was 57.7% acetate, 27.2% propionate, and 8.0% butyrate (Adiotomre et al., 1990). McBurney and Thompson (1990) found comparable values from the fermentation of vegetable fiber (61.4% acetate, 24.7% propionate, and 13.7% butyrate). Twenty-four h SCFA production values (mmol SCFA/g OM fermented) for 6 human subjects ingesting a typical Western diet were 5.19 for acetate, 2.90 for propionate, and 1.29 for butyrate (McBurney and Thompson, 1989a). GG fermentation is complete by 12 h (McBurney and Thompson, 1987), with little additional SCFA or gas produced after this time. Compared with pectin, tragacanth gum, psyllium gum, soy fiber, and cellulose, more propionate was produced upon fermentation of GG (2.58
mmol/g dry matter (DM) fermented for 12 h (McBurney and Thompson, 1989b).

In vitro studies with enzymes present in human intestinal flora indicated that GG is fermented by normal colon flora. The β-1,4 mannosidic linkages in the mannose backbone of GG are hydrolyzed by mannases present in the intestinal flora (Emi et al., 1972; Balascio et al., 1981). The resulting shorter chains of galactomannans are hydrolyzed to galactose and mannose units by bacterial α-galactosidases and mannases (Salyers et al., 1977a; Gherardini et al., 1985). The monosaccharides are assimilated by the gut flora and metabolized (Salyers et al., 1977b). The SCFA resulting from this fermentation may be metabolized to CO₂ or used to synthesize other compounds within cells of the intestinal mucosa, liver, or peripheral tissues, utilized as an energy source for certain colonic bacteria, or excreted in feces (Fleming and Arce, 1986). In vitro results show that rat and human colonocytes utilize SCFA for energy, suppressing glucose metabolism (Roediger, 1980, 1982).

Like other forms of soluble fiber, GG has some effect on stool weight, although few studies have been conducted examining this parameter. Drasar and Jenkins (1976) fed three healthy male subjects (22-25 y) 35 g GG/d as a liquid meal and demonstrated an increase in stool weight from 100 g/d to 204 g/d (3.5 g/g fiber fed). Lesser increases were noted by Cummings et al. (1978) in healthy males (20-38 y), where fecal weight increased, although not significantly, by 20% with 20 g GG/day. Penagini et al. (1986) reported that 6 healthy males (21-28 y) showed a nonsignificant 8 g/d increase in stool weight when fed 10 g GG (0.8 g/g fiber) baked in bread. These latter researchers determined that of the GG ingested, 82 to 95% was metabolized in the gut. On average, GG increased stool weight in humans by 1.6 g/g fiber fed. There was no change in stool frequency. No changes in mouth-to-cecum (MCTT) or whole-gut transit times were noted. MCTT was 54 h for subjects consuming GG and 46 h for controls.

GG (9 or 14.5 g) has been shown to delay gastric emptying in 14 healthy male and female subjects (18-31 y) and to inhibit small intestinal fluid absorption. GG may reduce access of nutrients to the epithelium by inhibiting convective solute movement within the intestinal lumen (Blackburn et al., 1984).

In general, the delaying action of fibers on small bowel transit time was directly proportional to the viscosity of the solution, without having any significant action on gastric emptying (Read, 1986). If absorption is impaired sufficiently, it could mean that a portion of nutrients escapes absorption from the small intestine and passes into the colon, where its absorption may be incomplete and the energy yield to the host reduced (McNeil, 1984). These effects may be partially compensated for by an increase in small bowel transit time (Read, 1986), which would be expected to increase the net amount absorbed by increasing the residence time of digesta in the small intestine.

**Gum Arabic - Animal Studies.** McLean Ross et al. (1984) detected GA via precipitation in the contents of the stomach and small intestine, but not the cecum, colon, or rectum, of rats fed 200 g GA/kg diet for 4 wk. After cecectomy, GA was detected throughout the length of the GI tract and in feces, supporting the hypothesis that the cecum is the primary site of fermentation in the rat. Extensive cecal fermentation of GA also was observed by Johnson et al. (1988) in rats fed diets containing 10% GA. OM disappearances by in vitro fermentation of GA of 24.6 and 28.5% were reported after 24h of incubation with either dog or cat fecal microflora, respectively (Sunvold et al., 1995a, 1995b). Annison et al. (1995) found that GA fed to rats at the 8% level resulted in 10-fold increases in dry weights of cecal contents, indicating that the GA was accumulating in this digestive compartment.

Several researchers have noted increases in cecal SCFA concentrations when rats were fed GA, implying that this substance is fermentable in the cecum of rats (Mclean Ross et al., 1984; Topping et al., 1985, 1988; Tulung et al., 1987; Walter et al., 1988; Annison et al., 1995). Younes et al. (1995) fed a wheat
starch-casein-based diet to rats and found total cecal SCFA concentrations in the fiber-free control to be 93.3 mmol/L (molar ratio of acetate, propionate, and butyrate, 59:27:14), whereas the cecal SCFA concentration for rats fed a 7.5% GA-containing diet was 142.0 mmol/L (molar ratio of acetate, propionate, and butyrate, 61:25:13). Monsma et al. (1992) found that 5% GA-supplemented diets increased the amount of mucin-derived carbohydrate available for fermentation two-fold. This extends the findings of Satchithanandan et al. (1990), who observed increases in total luminal mucin from the stomach and small intestine when rats were fed a diet containing 5% GG compared with that in rats fed a fiber-free control.

**Gum Arabic - Human Studies.** Five healthy male subjects (30-55 y) ingested 25 g GA daily for 21 d, following a 7-d control period, during which a wide range of hematological measurements were made, along with glucose absorption and biochemical assays of components of urine and feces (McLean Ross et al., 1983). Results revealed no effect on glucose tolerance, stool weight, or on daily excretion or concentrations of fecal fat, bile acids, VFA, or neutral sterols. In 4/5 subjects the intestinal transit time increased (mean increase 26±9 h); in 1/5 subjects the transit time decreased by 18 h. Failure to recover GA from feces suggested that it was degraded extensively in the human colon. The mean breath of H₂ excretion increased ~5-15 ppm. Adiotomare et al. (1990) determined the pattern of SCFA production from the fermentation of GA by human fecal bacteria in vitro to be 68.2% acetate, 19.6% propionate, and 8.2% butyrate. Bourquin et al. (1993) showed that the OM disappearance of GA after 24 h of fermentation was 70%, with SCFA production values (mmol/g GA DM) of 5.38, 1.87, and 0.93 for acetate, propionate, and butyrate, respectively. In addition, they measured potential water-holding capacity and found GA to have one of the lowest values (1.92 g water/g GA DM) of any fiber tested, agreeing with reports that GA consumption has only a minimal effect on stool weight.

Wyatt et al. (1986), using a most-probable-number technique, estimated the concentrations of total anaerobes and GA fermenters in feces of one human volunteer during control period and treatment periods when 10 g GA/d was added to the diet. The proportion of fecal flora able to degrade GA rose from an initial level of 6.5% to more than 50% during GA ingestion, and subsequently returned to the control level after ingestion ceased. The principal GA fermenters were species of *Bacteroides* and *Bifidobacterium*. Undegraded GA was not detected in any fecal sample nor were there significant differences in concentrations of total sugars in acid-hydrolyzed feces between GA and control periods. These data indicate a direct and rapid change in fecal flora in response to GA addition to a human diet and stress the need for an adaptation period prior to data collection.

**Digestibility of Gum Arabic and Guar Gum – Animal Studies.** Booth (1963) found that the digestibilities of GG (76%) and GA (71%) were similar. In contrast, diets containing GA were ~94% digestible by guinea pigs over 10 d (O’Dell et al., 1957). Even when added at the 10% level to basal rat diets over 12 wk, no change in stool weight due to GA inclusion was noted (Walter et al., 1986, 1988), although wet cecal-sac weight, cecal-contents dry weight, and fecal and cecal bacterial mass all increased with GA inclusion. SCFA (mostly acetate) increased in the cecum and feces (Walter et al., 1988).

**DETERMINATION OF THE ENERGY CONCENTRATION OF GUAR GUM AND GUM ARABIC**

**Gross Energy.** The total amount of energy in a food, the gross energy (GE) or the heat of combustion (ΔHᵢₒₚ), can be determined as the amount of heat released during complete oxidation. GE (kJ) values are determined by adiabatic or ballistic bomb calorimetry. Dietary GE content can be calculated using detailed compositional information and the predetermined ΔHᵢₒₚ for select food components (Livesey, 1993).
Energy Balance Method. Although the GE values of foods provide information on the TE content, they are not physiologically based. Energy losses in urine, feces, and gases in the breath and flatus must be accounted for.

The digestible energy (DE) is an estimation of the GE intake (GEi) minus the fecal energy (FE), or

\[ \text{DE} = \text{GEi} - \text{FE}. \]

Metabolizable energy (ME; kJ) is an expression of the GEi minus the urinary energy (UE) and fecal energy (FE), or

\[ \text{ME} = \text{GEi} - (\text{UE} + \text{FE}). \]

When determining the energy value of complex carbohydrates, UE loss is usually assumed to be negligible (Southgate and Durnin, 1970; Kelsay et al., 1978), although it should be noted that even a small energy loss in this form, in the context of such a small potential caloric contribution to whole-body metabolism, would be significant. Brown and Livesey (1994) also reported a highly reproducible thermogenic effect of GG, but after reviewing numerous potential mechanisms for this increase concluded that no single mechanism could be identified for this phenomenon.

It is necessary to assess DE or ME values over several days for greater accuracy. These assessments typically involve the use of an indigestible marker that allows the fecal and urinary collections to be related to food ingested during the balance period (Livesey, 1993). A slightly altered approach to the calculation of DE can be used to determine the energy value of carbohydrates such as GG and GA added to a basal diet.

The partial energy value is calculated as the \( \Delta E \) of a diet brought about by use of a supplement.

Factorial Calculation of the Metabolizable Energy Value. The apparent ME value is much less precise but is commonly used when energy balance studies are not possible. This approach allows for the calculation of the amount of energy contained in foods by using compositional information. An early example of this is the Atwater apparent ME system (Atwater, 1910, as cited by Livesey, 1993). The ME values for fat, protein, and carbohydrates in this equation are 37.5 (9.0), 16.7 (4.0), and 16.7 kJ (4.0 kcal)/g, respectively (Livesey, 1993). Carbohydrates, including dietary fiber, are a complex group of very different compounds with highly variable monosaccharide subunits and linkages. Variations in the caloric values of carbohydrates have been proposed due to wide ranges in digestibilities. The Atwater equation does not account for the low digestibility of some complex carbohydrates and therefore will overestimate the ME content of a diet containing significant amounts. Additional methods of estimating DE and ME using factors such as digestibility and efficiency of conversion of fermented energy to DE have been reviewed elsewhere (Livesey, 1988, 1990, 1991; Wisker and Feldheim, 1992; Smith et al., 1998).

Calculation of Net Energy of Maintenance (NE\textsubscript{m}). The NE\textsubscript{m} is the energy provided to maintain the organism. This expression of energy status takes into account the energy losses during metabolism of the nutrients. The unavailable complex carbohydrate (UCC) is dietary fiber including any starch and non-starch polysaccharides (NSP) that resists enzymatic degradation in the small intestine during fiber analysis and is unabsorbable. An equation has been designed to calculate the NE\textsubscript{m} of the UCC using the assumptions that the quantity of combustible gases produced is 3%, FE is 30%, and heat generated is 4% of the carbohydrate fermented (British Nutrition Foundation, 1990). It is also assumed that each calorie of
SCFA traps ~15% less energy as ATP than does glucose (Livesey and Elia, 1985, as cited by British Nutrition Foundation, 1990). Based on these assumptions, the resulting equation used to calculate NE\text{m} is

\[ \text{NE}_\text{m} = 4.1 \times \text{UCC (g)} \times 0.54 \text{ D}, \]

where UCC is the amount (g) of unavailable complex carbohydrate and D is the apparent digestibility of the UCC (British Nutrition Foundation, 1990).

Assuming that the D of complex carbohydrates in human is ~70%, the NE\text{m} is calculated to be 77% of the estimated DE or 6.27 kJ (1.5 kcal)/g (British Nutrition Foundation, 1990).

Two alternative equations proposed by Livesey et al. (1995) are used to calculate the net ME, which is the GE of a compound minus energy losses in urine, feces, gas, and heat. These equations are

\[ \text{NE}_\text{m} = 0.7 \times \text{DEV}, \]

where DEV is the digestible energy (DE) value, and

\[ \text{NE}_\text{m} = 0.5 \times \Delta H_c \times D, \]

where \( \Delta H_c \) (kJ/g) is the heat of combustion of the supplement and D is the digestibility.

This equation assumes that the carbohydrates are being used only by fermentation.

Smith et al. (1998) also developed a method to estimate the net ME value of a supplement from the DEV\text{s}, (kJ/g), or digestible energy value of a supplement (calculated from the GE or \( \Delta H_c \); kJ/g), less the non-fecal supplement-induced energy losses (SIEL\text{sf}) (which comprise gaseous and fermentative energy and heat of fermentation, UE, heat losses due to the relatively inefficient ATP gain, and supplement-induced energy expenditure), divided by the amount of supplement digested (I\text{s}, g), or

\[ \text{NEV}_s = \text{DEV}_s - (\text{SIEL}_{sf})/I_s. \]

In principle, the SIEL\text{sf} can be estimated from DE intakes and changes in body composition.

**Indirect Calorimetry.** Indirect calorimetry is a determination of the NE of a food by measuring the \( O_2 \) consumed and the \( CO_2 \) produced while consuming that food. Indirect calorimetry also can be used to assess the amount of carbohydrate used in energy metabolism (Livesey and Elia, 1988). However, it is not possible to differentiate between oxidation of directly absorbed carbohydrates and oxidation of carbohydrates via fermentation to SCFA in the large intestine (Livesey, 1993).

**Breath \( H_2 \) Determination.** Fermentation of carbohydrates such as GG and GA result in the formation of SCFA and the gaseous products, \( CO_2 \), \( H_2 \), and \( CH_4 \). Although the SCFA are rapidly absorbed and utilized as an energy source, the gaseous products represent an energy loss and are excreted either in flatus or breath. Measurements of gaseous products, particularly \( H_2 \), have been used as indicators of carbohydrate utilization. Poppitt et al. (1996) designed a study to quantify the relationship between substrate fermentation and total 24-h \( H_2 \) and \( CH_4 \) excretion. Twelve healthy males were fed controlled diets containing 16 or 38 g NSP and 16 or 19 g resistant starch (RS) for 3-wk each. Total \( H_2 \) and \( CH_4 \) excretion were determined during 24 h within a whole body calorimeter. Absolute excretion of \( H_2 \) and \( CH_4 \) did not increase with addition of NSP and RS to the diet, implying that rate of excretion of these gaseous products was not an accurate predictor of degree of fermentation. Likewise, McNamara et al. (1986) previously found a lack of relationship between breath-gas excretion and fiber digestion by free-living human subjects.
consuming self-selected diets for 5 d followed by metabolic diets, in random order, for 10 d each. Metabolic diets consisted of a high energy, fiber-free Ensure® liquid diet supplemented with 30 or 60 g of soy fiber/d.

**Alternative Radiolabel Techniques.** Radiolabel techniques also have been used to estimate the energy value of partially fermented carbohydrates in animals and humans. The amount of dietary substrate not metabolically available is determined via quantification of the radiolabel in the excreta, while the amount of substrate used by the tissue is determined via quantification of radiolabel in the breath. Juhr and Franke (1992) modified this technique by measuring the tissue label directly, since dietary substrates that are fermented by colonic bacteria are only partially available to the host animal. To define the site and extent of fermentation of dietary carbohydrates, these researchers compared germfree and conventional rats, both in the intact and cecetomized states. Although neither GG nor GA was evaluated, when cellulose was administered, 65% was recovered in feces and an available energy value of 3.5 kJ (0.84 kcal)/g was calculated. This technique, however, may lead to an overestimation of available energy because of the higher efficiency of digestive metabolism in germfree rats. The energy value of 3.5 kJ/g is more than 2.1× greater than the DE value of cellulose determined by Harley et al. (1989). If a similar comparison is made between the DE value of GA determined by Harley et al. (1989), the resulting available energy value would be 30.87 kJ (7.38 kcal)/g, a nonrealistic value higher than any other reported and greater than the ΔHₐ value of 17.5 kJ/g.

**ENERGY VALUES FOR GUAR GUM AND GUM ARABIC**

Quantification of the energetic values of GG and GA in humans is time consuming, expensive, and difficult because of the severe restrictions that must be placed on the subject (Phillips, 1998). Because of these complications, animal models are commonly used to estimate these values. Unfortunately, the use of various species, diets, inclusion levels, and conditions contribute to the high degree of variability and serious contradictions in the data. The remainder of this paper will review the data currently available concerning the energetic values of GG and GA, highlighting particular strengths and weaknesses of the studies where they may exist.

The ΔHₐ of GG and GA are 17.5 and 17.2 kJ/g (4.18 and 4.11 kcal/g), respectively (Livesey, 1992). In comparison, the ΔHₐ of starch is 17.5 kJ/g (4.18 kcal/g) (Livesey, 1992). Most dietary fibers are fermented in part to SCFA, which provide energy to the host. The amount of available energy depends on the fermentability of the specific fiber studied. Several regulatory bodies have adopted an available energy value of 0 kcal/g for dietary fiber. This value is based on the assumption that ingestion of dietary fibers leads to a greater production of feces which may, in turn, decrease energy availability by trapping energy-yielding dietary components in feces (Southgate and Durin, 1970). This value may be close to the “true” NE value of diets with low or moderate dietary fiber concentrations. Phillips (1998) published a review in which the caloric value of GA was evaluated. From the studies reviewed, it was concluded that no usable data on humans for quantification of the utilisable energy of GA. Utilizable estimates derived from these experiments after certain allowances were made for energy losses from volatile and gaseous fermentation products, an upper level of 2 kcal/g was set for rats.

In adult humans, if fermentation capacity is sufficiently developed, the SCFA produced may provide up to 8.37 kJ (2 kcal)/g and may contribute to daily energy needs (Livesey, 1990). However, if an infant is presented with a substrate that it is unable to ferment, the substrate will be excreted unmetabolized, pulling water with it and causing an increase in stool output.

Livesey et al. (1995) conducted an animal experiment to 1) compare energy and fermentability values from
five different European laboratories and determine the reproducibility of these inter-laboratory measurements; 2) establish whether the extent of NSP fermentation predicts the availability of energy from NSP-rich dietary fiber supplements; and 3) provide standard energy and fermentability values for five dietary fiber products and their NSP content, respectively. Neither GG nor GA was included in this study; however, pectin, a soluble dietary fiber, was included. Male rats were fed a basal, NSP-free diet supplemented with either 50 or 100 g/kg of the dietary fiber supplement for 21 d. The five laboratories determined the digestible DEVₜ and fermentability of the dietary fiber sources at five and three occasions, respectively. The mean DEVₜ for pectin, 10.4±1.1 (2.48) and 10.3±0.4 kJ (2.46 kcal)/g dry weight for the low and high doses, respectively, were independent of dosage. Factorial analysis incorporating all dietary fiber sources at both doses showed no significant differences of DEVₜ among times of analysis; however, there were significant differences (up to 12% of the ΔHₜ) among laboratories. Fermentability of pectin was independent of dosage, 0.92±0.03 and 0.95±0.02 g/g dry weights, for the low and high doses, respectively.

Factorial analysis incorporating all dietary fiber supplements at both doses showed that there were no inter-occasional or inter-laboratory differences in fermentability, although variation was frequently large. The mean DEVₜ of the dietary fiber supplement and fermentability of the NSP were converted to net ME using the equations

\[
\text{NE}_m = 0.5 \times \Delta H_c \times D, \quad \text{and}
\]

\[
\text{NE}_m = 0.7 \text{ DEV}_t,
\]

where \(\Delta H_c\) is the heat of combustion of the fiber supplement and \(D\) is the fermentability of the NSP supplement.

The calculated net ME values for pectin are 7.2 (1.72) and 7.3 kJ (1.74 kcal)/g, respectively (Livesey, 1995).

The International Programme of Chemical Safety (1982) reported a caloric value of 16.74 kJ (4 kcal)/g for GA (WHO, 1982, as cited by Anderson and Eastwood, 1989). In contrast, Staub and Ali (their unpublished data, as cited by Staub and Ali, 1982) calculated a value of 10.5 J [sic] (2.6 calories [sic])/g for GA. Since then, researchers have attempted to determine the “true” values of DE, ME, and NE for both GG and GA in animals and humans. The NE values for gums range from \(\leq 4.2\) kJ (1 kcal)/g-13.9 kJ (3.4 kcal)/g (as cited by Behall, 1997).

**Guar Gum - Animal Studies.** Brown and Livesey (1994) investigated the influence of feeding a low- or high-fat (0 or 11% added lard) basal diet supplemented with 10% GG (100 g/kg) on FE and UE loss and energy expenditure in rats. GG contributed 9.8 (2.3)-13.1 kJ (3.1 kcal)/g to DE on the low-fat diet and only 5.6 kJ (1.3 kcal)/g on the high-fat diet. GG also increased energy expenditure by 11.6 (2.8) to 14.8 kJ (3.5 kcal)/g, resulting in a negative net ME value between -1.3 (-0.3) and -9.7 kJ (-2.3 kcal)/g. These results are similar to those of Davies et al. (1987, 1991) who calculated the DE value of GG to be 10 kJ (2.4 kcal)/g GG in rats fed a control diet supplemented with 10% GG. After accounting for a reduction in body fat that occurred in supplemented rats, the calculated ME value for GG was -7.1 kJ (-1.7 kcal)/g GG. These researchers proposed that an increased intestinal mucosal mass and cell turnover could explain part of this apparent increase in energy demand (Davies et al., 1987).

Increased fecal energy (FE) loss due to GG supplementation presents another potential significant source of lost energy. Hara et al. (1994) compared the effects of adding GG and cellulose, either as a 1:1 mixture or a three-dimensional complex, to weaning male rats fed a fiber-free basal diet for 22 d. The three-dimensional complex was prepared by separately dissolving cellulose and GG in sodium hydroxide, then combining both alkaline solutions. The combined solution was extruded into an acid solution as filaments.
The filaments were washed, cut, dried and milled into particles (≤300 μm). Fecal energy (FE) excretion was increased in rats fed ad lib 22.8 (5.4), 82.0 (19.6), 73.6 kJ (17.6 kcal)/3 d for the fiber-free, GG-cellulose complex, and GG-cellulose mixture diets, respectively. For meal-fed rats, the measured FE values were 13.8 (3.3), 56.6 (13.5), 54.2 kJ (13.0 kcal)/3 d for the fiber-free, GG-cellulose complex, and GG-cellulose mixture diets, respectively. Fermentable energy values were calculated by applying the equation

$$\text{Fermentable energy in dietary fiber [DF] (%) = \left( \frac{\text{Energy in DF consumed}}{\text{Fecal energy [FE] excretion derived from DF}} \right) \times 100}$$

The fermentable energy values for the GG-cellulose complex and GG-cellulose mixture were 34 and 40%, respectively. Feed intake by meal-fed rats was reduced 40%, but the fermentable energy values were similar to those of freely fed rats, suggesting that the inflow of absorbable nutrients into the cecum of meal-fed rats was not increased (Hara et al., 1994). Rats fed GG-cellulose mixture ad lib gained less weight than those fed the fiber-free control diet (132 vs 162 g/22 d). De Deckere et al. (1993) also observed an increase in H2 excretion by rats as the GG content of the diet was increased from 0 (H2 excretion of ~0 μmol/4 h) to 8.8 g/MJ (H2 excretion of ~105 μmol/4 h). Rose et al. (1998) observed a reduced body fat gain in lean rats fed 100 g GG/kg diet compared with lean rats fed a control diet.

In contrast, Takahashi et al. (1994) observed no significant differences in BW gain of growing rats fed a casein-cornstarch diet supplemented with intact GG (5%) or partially hydrolyzed GG (PHGG, 5 or 10%) for 3 wk. Rats fed the GG diet had a significant reduction in feed intake (288 vs 330 and 329 g/3 wk for the GG, control, and PHGG diets, respectively). TE retained was significantly reduced 31 and 41% for the 10% PHGG and 5% GG diets, respectively. DE was significantly reduced in rats fed all supplemented diets (16.74, 16.47, 15.90, 16.44 kJ/g of diet for the control, 5% PHGG, 10% PHGG, and 5% GG diets, respectively, as was ME (16.25, 15.99, 15.44, 15.98 kJ/g of diet energy for the control, 5% PHGG, 10% PHGG, and 5% GG diets, respectively). Efficiency of energy utilization was decreased only in rats fed the 10% PHGG and 5% GG diets.

In broiler chickens, no negative effects of 0.5% GG addition to mash diets compared to 0.5% pectin additions were observed on BW, but with pelleted diets, BW was reduced in chicks fed GG compared to pectin diets. The feed:gain ratio for chicks fed the GG diet was 7% higher than for the pectin diet, which could have been due to a 4% reduction in the nitrogen-corrected apparent metabolizable energy (AMEn) values of the GG diet. According to BW results, birds fed the mash diets were able to compensate for the reduction in AMEn but not those fed the pelleted diets (Carré et al., 1995). Both water and lactic acid losses were increased with GG compared with pectin. The authors proposed that a large part of this overexcretion of water induced by GG was mediated by lactic acid concentration (Carré et al., 1995). These results are in agreement with those of Rogel and Vohra (1983) who observed reduced growth and AMEn when growing chicks were fed a semi-purified diet containing 2% GG.

**Guar Gum - Human Studies.** Warshaw and Powers (1993) reported an energy value for GG of 1.1 kJ (0.27 kcal)/g for GG. They noted that GG was >80% dietary fiber and provided the benefits of fiber upon ingestion. They obtained this information from the manufacturer of the GG. Harmuth-Hoene (1983) evaluated the effect of inclusion of 22.5 g GG/d for 12 d in the diets of 6 healthy female subjects (21-54 y). During the first 2 to 3 d fed the GG diet, subjects reported having a feeling of satiety, slightly decreased appetite, and gas. The mean energy intake in the basal diet was 8.07 MJ/d, with 0.46 MJ/d excreted in the
feces over a 4-d collection period. The DE values of the basal and GG-supplemented diets were 94.3 and 93.3%, respectively. GG increased the daily energy intake by 379 kJ, while the mean daily energy loss in feces increased by only 107 kJ. This represents 28% of the energy content of the GG consumed; intestinal flora probably metabolized 72% of the GG. GG increased significantly the mean feces dry mass (4.12 g/d), whereas the fecal dry mass was unchanged.

**Gum Arabic – Animal Studies.** GA has a low calculated caloric value, ~11 kJ (2.6 kcal)/g, (their unpublished data, as cited by Staub and Ali, 1982). The energy value of GA has been estimated both by animal growth assays and energy balance trials. Fournier et al. (1987) fed rats a cereal-based diet with increasing concentrations of GA ranging from 15-60% over an 8-wk period. During the first 3 weeks of the experiment, rats fed the GA-containing diet grew more slowly than did controls, and then lost weight. The authors concluded that depending on the intake level, GA may contribute between 0 and 4.2 J [sic] (1 cal [sic])/g. As indicated above, the levels of GA supplementation were very high in the latter part of this experiment. Therefore, the results observed were possibly a consequence of “gross over-dosing” and feeding an imbalanced or deficient diet (Anderson and Eastwood, 1989).

Hove and King (1979) assessed the energetic value of GA using an animal growth assay. Weanling rats fed 1.0 or 2.0 g GA plus 5.0 g of a basal diet/d for 7 d gained only 3.7±2.2 and 3.8±4.0 g, respectively, compared to a gain of 6.4±2.5 g for rats fed either 0 or 0.5 g GA/d. The weight gain of rats fed GA were lower than those of rats fed comparable levels of sucrose, 9.8, 12.7, and 18.5 g, or starch, 7.5, 11.6, 16.9 g. Anderson et al. (1982) also found that male rats fed diets supplemented with 0, 2, 4.3, or 8.6% GA for 13 wk experienced no reduction in mean weight gain, but those fed 18.6% GA showed a 22% reduction in mean weight gain. In contrast, female rats fed a similar level of GA (18.1%) had no decrease in weight gain over the 13-wk period compared with the control group.

Harley et al. (1989) determined the DE value of GA using the energy balance method under well-defined conditions. The energy balance method is the gold standard for determining the availability of energy. Male rats were fed a formula diet, free of NSP, supplemented with 100 g GA or cornstarch or Solka-floc cellulose/kg of basal diet for 28 d. Data obtained by bomb calorimetric analysis of feed and fecal samples were used to calculate a partial digestibility of the supplementary energy from GA of 84% and a DE value of 14.7 kJ (3.5 kcal)/g. No differences in growth rate during the 28 d balance period were detected in animals fed the GA vs cornstarch vs Solka-floc cellulose supplemented diets. These results conflict with those of Shue et al. (1962, abstract) who also found that up to 80% of the GA (0.25, 0.5, 1, 2, or 4 g GA added to 5 g basal diet) fed to weanling rats was absorbed, but weight gain was negatively related to dose. More specifically, at an intermediate dietary level of 16%, weight gain was ~75% that observed with sucrose. Since these data are only published in abstract form, a critical review is not possible.

**Gum Arabic - Human Studies.** McLean Ross et al. (1983) studied the effect of GA on fermentation energy in five healthy males (30-55 y). Subjects fed GA (25 g/d for 21 d) had no significant change in stool wet or dry weight but increased breath H₂ excretion by ~5-15 ppm. The mean breath H₂ concentration in five fasted males after administration of 50 g anhydrous dextrose before the administration of GA fell and remained at 0 in all subjects by 150 min. After 21-d ingestion of GA, the mean breath H₂ concentration increased at 120 min after GA ingestion and remained significantly raised at 240 min after GA ingestion. To exclude the possibility that GA was carrying dextrose to the cecum and generating H₂, two males were given a 25 g GA solution, free of dextrose. In both subjects H₂ excretion increased after 200 min to levels reported after the combined administration of GA and dextrose. In a separate experiment, five different male subjects who had not previously taken GA were given 25 g GA alone. Their excretion of breath H₂ and CH₄ over the next 5 h was unchanged from the fasting concentration.
EVALUATION OF AVAILABLE ENERGETIC DATA

The energetic values of GG and GA have been evaluated via animal growth assays and animal and human balance trials, but the results of these studies are highly variable and contradictory. For this reason and those outlined below, it is impossible to provide a precise caloric value of GG and GA.

Because of the complexity of energy value determinations in humans, much of the research in this area has been conducted using various animal species. The anatomical and physiological differences in digestion and fermentation between humans and animals make suspect the application of this research to the human. Fermentative differences between humans and small animals include faster transit through the GI tract in small animals, variations of anatomical sites and rates of fermentation, and differing efficiencies of conversion of undigestible carbohydrates to fermentation end-products. Wisker et al. (1996) determined that the digestibility of NSP tended to be lower in rats than humans fed either a high-fiber diet containing fine whole meal bread (74 g NSP/kg DM; 59.6 vs 68.0%, respectively) or a low-fiber diet (37 g NSP/kg DM; 72.1 vs 80.5%, respectively). In contrast, NSP digestibilities were similar in rats and humans fed a high-fiber diet containing coarse whole meal bread (73 g NSP/kg DM; 66.1 vs 65.8%, respectively). When fiber digestion in rats and humans fed GG-containing diets was compared, GG was almost completely fermented in the rat, whereas it was incomplete in humans. In both species, less than 2% of the mannose and galactose were recovered in the feces (Nyman and Asp, 1986). Both Wisker et al. (1996) and Nyman and Asp (1986) concluded that the rat was a suitable model for predicting nutrient digestion and (or) fermentation breakdown in humans. In contrast, Roe et al. (1996) concluded that it was not possible to extrapolate results from rats to humans concerning the effect of cell walls of barley flakes on the extent of starch digestion.

Swine also have been used as models for studies of human digestive processes. For example, Potkins et al. (1992) determined that substitution of either 10 or 50 g GG/kg barley-based diet had no significant effect on apparent nutrient digestibility by growing pigs. In a comparative study between humans and pigs conducted by Van Soest et al. (1983), pigs generally had higher digestion of fiber than humans, despite the considerably higher dietary fiber intake, which is usually negatively associated with digestibility.

In the studies reviewed, the DE values obtained for GG and GA ranged from 6 (1.4)-16.44 kJ (3.1 kcal)/g and 14.7 kJ (3.5 kcal)/g, respectively (Table 2). Although both fibers contributed DE, and the digestibilities were quite high, it is difficult to assign NE values. Since UE loss as a result of complex carbohydrate ingestion is usually assumed to be negligible (Southgate and Durnin, 1970), it is assumed that the ME values are ≈ to the DE values. In the experiments reviewed (Brown and Livesey, 1994; Davies et al., 1987, 1991), the ME values of GG were negative. Factors implicated in this phenomenon include decreased feed intake, increased thermogenesis, increased FE loss, and increased loss of protein and fat in feces. GG-induced increased fecal excretion of fat (nutrient trapping) has been demonstrated in humans fed a mixed diet supplemented with GG (D.J. Jenkins, personal communication). Moreover, Baer et al. (1997) demonstrated that as fiber content of a mixed diet increased, fat and protein digestibilities decreased subsequently, ME content of the diet, decreased in humans. Although neither GG nor GA was included in these diets, it is assumed that they would interact with protein and fat in a mixed diet resulting in an energetic value that is dependent on the complete diet composition. Nutrient trapping in feces has the potential for negative caloric contributions.
Non-quantifiable energy losses due to the production of fermentation products in the colon from complex carbohydrates are discussed in a review by Phillips (1998) and summarized here:

1. Only a small amount of the original energy value is conserved as SCFA and some of the SCFA are excreted.
2. Energy is used in the synthesis of microbial biomass.
3. Energy is lost in the form of gases such as H₂, CH₄, and, possibly, CO₂.
4. Lactic acid also can serve as a source of energy for the bacteria.

Direct human experimental data are not available on the ME or NE values of GA. Although Harley et al. (1989) determined the DE value of GA to be 14.7 kJ (3.5 kcal)/g, it is possible that the same factors that affect the NE value of GG also would decrease the NE value of GA. Absent experimental data, NE values were calculated from the DE data available using the equation

\[ \text{NE}_m = 0.77 \times \text{DE} \] (British Nutrition Foundation, 1990),

and are reported in Table 2. Contrary to the negative ME values available for GG, the calculated NE values are positive. The assumption that DE = ME for these compounds may be in error. Using the DE data for GG (Davies et al., 1991 and 1987) and GA (Harley et al., 1989), the NE values for GG and GA are ≈ 7.7 kJ (1.9 kcal)/g and ≈ 11.3 kJ (2.7 kcal)/g, respectively. The value presented for GA is slightly higher than the arbitrary “available energy” value of ≈1.5 kcal/g suggested by Phillips (1998). However, based on the available ME data, neither of these gums would be expected to contribute any NE to humans or animals, especially at physiological concentrations of the ingested gums. Because the non-quantifiable energy losses are due in part to the viscous nature of GG, and because GA does not share this property, it is possible the NE of GA, while approaching zero, may not be as low as that of GG.

**SUMMARY**

Both GG and GA are fermented in the colon of humans and animals. Estimates of the fermentability of these fibers in vivo and in vitro range from ~70-100%. At the level of the large intestine, both GG and GA increase the absolute amount of SCFA and alter the relative proportions of individual SCFA. Since SCFA are a source of energy, these alterations would be expected to affect the energetic value of the diet.

Because of the difficulties in determining net energy values of non-digestible carbohydrates and the many discrepancies that exist in the literature, it is not yet possible to determine a definite caloric value of GG or GA for humans. Rather, the best approach is to estimate a range of caloric values. We suggest the digestible energies provided in this report be used to provide maximum caloric values and the metabolizable energies be used to provide minimum caloric values.

The available data on digestible energy and the mathematical calculation of the British Nutrition Foundation are used to provide maximum caloric value estimates (net energy values) of 7.7 kJ (1.9 kcal)/g and 11.3 kJ (2.7 kcal)/g for GG and GA, respectively. Given the reduction in growth observed in numerous studies, the reality of non-quantifiable energy losses, and the anatomical and physiological differences in fermentation between humans and animals, these values should be used with caution and considered as maximums.

Based on the available data on metabolizable energy, the minimum caloric content (net energy value) for GG may be zero. There are fewer data on the metabolizable energy for GA. Because the non-quantifiable
energy losses are due in part to the viscous nature of GG, a property not shared by GA, it is possible that the minimum caloric content (net energy value) of GA, while approaching zero, may not be as low as that of GG.

A minority opinion was expressed by one of the reviewers, who felt the data supported an estimate of the net energy value of GG of zero and not as a range of values.
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<td>Booth, A. N., Hendrickson, A.P., and DeEds, F. 1963</td>
<td>Digestibility</td>
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<td>McBurney, M. I., &amp; Thompson, L. U. 1989</td>
<td>Digestibility (in vitro fecal fermentation)</td>
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<td>Six healthy humans (3 M and 3 F), of whom 1 M and 1 F were vegetarian.</td>
<td>By 8 h, GG produced most SCFA. By 24 h, 83% of GG was fermented. GG was ranked first over other substrates.</td>
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<td>Davies, I. R., Johnson, I.T., &amp; Livesey, G. 1987</td>
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<td>Basal diet with or without 10% GG, for 28 d at 21°C.</td>
<td>For each diet, n = 14 juvenile M rats.</td>
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<td>DEV$_v$ = 10.1 kJ (2.4 kcal)/g GG; ME = -7.1 kJ (-1.7 kcal)/g GG; NE$_m$ = 7.8 kJ (1.9 kcal)/g GG.</td>
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<td>Davies, I.R., Brown, J.C., &amp; Livesey, G. 1991</td>
<td>Energy balance</td>
<td>Basal diet with or without 10% GG (100 g GG/kg basal diet), 21°C, for 28 d.</td>
<td>For each diet, n = 8 juvenile rats.</td>
<td>Partial DEV$_v$ = 10 kJ (2.4 cal)/g GG;</td>
<td>NE$_m$ = -7.1 kJ (-1.7 kcal)/g GG. GG acutely ↓ feed intake and fat deposition.</td>
</tr>
<tr>
<td>Brown, J. C. &amp; Livesey, G. 1994</td>
<td>Energy balance</td>
<td>Three diets: LF, 28°C; LF, 21°C; and HF, 21°C. Basal diet, with or without 10% GG (100 g GG/kg basal diet), for 28 d.</td>
<td>For each diet, n = 16 (8 pr) juvenile M rats; for UE, n = 7 rats (21°C) or 4 (28°C) rats.</td>
<td></td>
<td>DEV$_v$ = 6 to 13 kJ (1.4 to 3.1 kcal)/g GG (dependent on the fat in the diet); Net ME = -1.3 to -9.7 kJ (-0.3 to -2.3 kcal)/g GG; NE$_m$ = 4.6 to 10 k (1.1 to 2.4 kcal)/g GG (NE$_m$ calculated as 0.77 × DE )</td>
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<tr>
<td>Takahashi, H., Yang, S. I., Kim, M., &amp; Yamamoto, T. 1994</td>
<td>Energy balance</td>
<td>Basal diet with 5 or 10% PHGG or 5% GG fed ad lib. for three wk at 23°C.</td>
<td>For each diet, n = 5 juvenile M rats.</td>
<td></td>
<td>DEV$_v$ = 16.44 kJ (3.9 kcal)/g (5% GG); ME = 15.98 kJ (3.8 kcal)/g (5% GG); NE$_m$ = 12.66 kJ (3.0 kcal)/g (5% GG); DEV$_v$ = 16.47 kJ (3.9 kcal)/g (5% PHGG); ME = 15.99 kJ (3.8 kcal)/g (5% PHGG); DEV$_v$ = 15.90 kJ (3.8 kcal)/g (10% PHGG); ME = 15.44 kJ (3.7 kcal)/g (10% PHGG).</td>
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<td>ENERGETIC VALUES</td>
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<td><strong>GUM ARABIC</strong></td>
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<tr>
<td>O'Dell, B. L., Morris, E. R., Pickett, E. E., &amp; Hogan, A. G. 1957</td>
<td>Digestibility</td>
<td>Three groups of 4 diets: varying P, K, and Mg. 15% GA (implied weight) supplemented each diet, fed for 10 d.</td>
<td>Mature guinea pigs (age ≥ 14 wk or older), with n = 3 or 4/diet.</td>
<td>Partial digestibility of 93.5%.</td>
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<tr>
<td>Shue, G. M., Douglass, C. D., &amp; Friedman, L. 1962 (abstract)</td>
<td>Digestibility</td>
<td>0.25, 0.5, 1, 2, and 4 g GA added to 5 g basal diet.</td>
<td>Weanling rats</td>
<td>Partial digestibility of 80% at level of 16% of diet.</td>
<td></td>
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</table>
| Booth, A. N., Hendrickson, A. P., & DeEds, F. 1963 | Digestibility; Growth study | For digestibility study, rats fed 5 g basal diet with 0.75 g GA/d for 7 d. For growth study, rats fed basal diet with 15% GA for 62 d. | For digestibility study, n = 5 weanling M rats. For growth study, n = 6 weanling M rats. | Digestibility of 71%; weight gain and food efficiency of rats fed GA were similar to the control group. | \( \text{DEV}_s = 3 \text{ kcal/g GA}. \)
| | | | | 15% GA diet caused cathartic effects including bulky, sticky, stringy feces. | |
| Harley, L. J., Davies, I. R., & Livesey, G. 1989 | Digestibility | Rats fed 10% GA (w/w). | Partial digestibility of 84% | \( \text{DEV}_s = 14.7 \pm 0.5 \text{ kcal/g GA}; \)
<p>| | | | | ( \text{NE}_m = 11.3 \text{ kcal (2.7 kcal)/g GA}. ) | |
| International Programme on Chemical Safety (WHO) 1982 (as cited by Anderson, D. M. W., &amp; Eastwood, M. A., 1989) | Digestibility; Growth study | Rats fed at daily dietary intakes up to 8.6% GA (M) and 18% GA (F). | Rats had no ↓ in growth rates or in final BW. | ( \text{DEV}_s = 4 \text{ kcal/g GA}. ) | |
| Hove, E. L., &amp; King, S. 1979 | Growth study | Rats fed 5 g basal diet with or without 0.5, 1.0, and 2.0 g GA/d for 7 d. | For diets (0.5-2.0 g), n = 8 weanling M rats. | No discernible growth noted. | Study flawed because basal diet composition was diluted and deficient for growth. |</p>
<table>
<thead>
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<tr>
<td>Staub, H. W., &amp; Ali, R. 1982 (review)</td>
<td>Growth study</td>
<td>No data provided.</td>
<td>Rats (?)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anderson, D. M. W., Ashby, P., Busuttil, A., Eastwood, M. A., &amp; Street, C. A. 1982</td>
<td>Growth study</td>
<td>In first study, rats fed 0, 1, 2, 4, and 8% GA daily for 13 wk at 20°C.</td>
<td></td>
<td>Growth rates in M and F not ↓ at daily GA intakes ≤ 5 g/kg (8.6%). At 18% (daily intake of ~14 g GA/kg), only M had significantly ↓ growth rate and final BW; average M weight gain was 78% compared to the controls.</td>
<td>( \text{DEV}_{s} = 10.5 \text{ J [sic]} (2.6 \text{ cal [sic]} / \text{g GA (their unpublished data, no details given).} )</td>
</tr>
<tr>
<td>Fournier, P. E., Fournier-Desvaux, M., Crouzette, J., Palombo, S., &amp; Vicaut, E. 1987</td>
<td>Restricted caloric growth rate study</td>
<td>Rats fed 30 g GA/d with 15, 30, 45, and 60% GA in basal diet first 6 wk, and 20 g GA/d for last 2 wk.</td>
<td>Juvenile M rats (( n = 24 )), 6 rats/diet.</td>
<td>Slopes of the mean weight-gain curves were compared to control diet animals. Weight ↓ at wk 3 (45% GA) and significant at 60% GA (both levels had negative slopes). One rat died at the end of wk 7(60% GA).</td>
<td>( \text{DEV}_{s} = 2.9 \text{ kcal/g GA.} )</td>
</tr>
</tbody>
</table>
LITERATURE CITED


National Toxicology Program (1982) Carcinogenesis Bioassay of Guar Gum In F344 Rats and B6C3F1 Mice (Feed Study). NIH Publication no. 82-1785. National Toxicology Program, Research Triangle Park, NC and Bethesda, MD.


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