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# Does Dietary Fiber Affect the Levels of Nutritional Components after Feed Formulation?

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**Abstract:** Studies on dietary fiber and nutrient bioavailability have gained an increasing interest in both human and animal nutrition. Questions are increasingly being asked regarding the faith of nutrient components such as proteins, minerals, vitamins, and lipids after feed formulation. The aim of this review is to evaluate the evidence with the perspective of fiber usage in feed formulation. The consumption of dietary fiber may affect the absorption of nutrients in different ways. The physicochemical factors of dietary fiber, such as fermentation, bulking ability, binding ability, viscosity and gel formation, water-holding capacity and solubility affect nutrient absorption. The dietary fiber intake influences the different methods in which nutrients are absorbed. The increase in the total fiber content of the diet may delay the glycemic response. Soluble fiber decreased blood glucose content whereas purified insoluble fiber has a little or no effect on the blood glucose levels after a meal. Dietary fiber and prebiotics influence the host animal well-being by regulating blood glucose or insulin levels, stool bulking effects, increasing the acidity of the gut, constructive synthesis of short chain fatty acids (SCFAs), decreasing intestinal transit time, stimulating the growth of intestinal microbes, and increasing blood parameters. Previous studies suggest that fiber affects the bioavailability of nutrients, and maintains the host wellness.

**Keywords:** dietary fiber; prebiotics; bioavailability; fermentation; SCFAs

## 1. Introduction

Micronutrients, such as vitamins and minerals are required in minor quantities for significant roles in the body [1]. The absorption of these micronutrients has been an interesting area for research since the start of nutrition as a scientific field. However, there is a greater misunderstanding regarding the estimation of nutrient absorption in a diet. The objectives of most studies in this field are to explain vividly the role of fiber as a determining factor in the usage of nutrients in a diet. Several studies have been carried out in the past decades to better explain the physicochemical interactions between dietary fiber and these nutrients [2–4]. Nevertheless, most of these studies used *in vitro* digestive systems to investigate the absorption of dietary nutrients [5–7]. The dietary fiber intake influences the mechanisms by which nutrients are absorbed in both humans and animal feeding [8]. The rise in the total fiber content of a diet may delay the glycemic reaction in different age groups [9]. The absorption

of dietetic nutrients involves the transfer of food via the gut, the breakdown of complex nutrients to simple molecules by digestive enzymes, and the uptake of these molecules by cells within the small intestines [10]. The use of dietary fiber can change these mechanisms, causing a low amount of nutrient uptake and a change in the point of absorption within the small intestines to a distal point [11].

Dietary fibers are known for their beneficial actions on the gut health. Such actions are vital for the survival of the host organism [11]. Studies continue to discover the importance of dietary fiber, and many questions are raised regarding its use in both animals and humans. The aim of this review is to evaluate the evidence with the perspective of fiber usage in feed formulation.

## 2. Interactions of Dietary Fiber and Nutrient Components

The consumption of dietary fiber can affect the uptake of nutrients in diverse methods. It was hypothesized that the occurrence of dietary fiber in the upper gastrointestinal tract could lead to a decrease in the rate of intestinal absorption of nutrients. The physicochemical factors of dietary fiber, such as fermentation, bulking ability, binding ability, viscosity and gel formation, water-holding capacity, and solubility, influence nutrient absorption [12].

### 2.1. Dietary Fiber and Mineral Bioavailability

The supplementation of feed with different fiber content has several roles on the bioavailability of minerals in an organism. Minerals are inorganic nutrients that are important to the nutrition of human and animals, such as calcium, chloride, copper, iodine, iron, magnesium, manganese, molybdenum, phosphate, potassium, selenium, sodium, sulfate, water, and zinc.

#### 2.1.1. Iron Bioavailability

Iron is present in the blood as hemoglobin and in the muscle tissues as myoglobin [13]. It has a significant role as an oxygen carrier in the blood and is vital in the metabolic activities, energy metabolism, and DNA synthesis. The daily requirement of iron by an organism depends on factors such as sex, age, and body weight [13]. Iron occurs in nature as either heme or non-heme. Heme iron is the most bioavailable [14]. Daily body activities maintain the availability, re-utilization, and regulation of iron [15]. Iron is mostly absorbed in the duodenum. However, sufficient amounts of iron are not absorbed from the diet. Iron absorption in the body can be influenced by conditions such as the secretion of gastric acid and the presence of chelating substances. Comparatively, women have about four times more iron transporter proteins than men within the epithelial cells, because of the greater loss of iron during menstruation. Most ionic irons are absorbed via the active transport in acidic conditions into the mucosal cells for the production of hemoglobin. Moreover, the heme-iron form may be absorbed by ingestion of hemoglobin [16]. The presence of fiber and fiber components in a diet can significantly affect the absorption of iron. Drago and Valencia [17] observed higher iron absorption in whey than in casein protein. Also, the absorption of iron decreased when locust bean gum was introduced in a casein diet compared with whey protein in dairy infants diet [18]. Low iron concentrations in the body cause disorders such as anemia [19]. However, high concentrations of iron may be harmful to mammals, due to the lack of physiological means of its elimination [16,19]. For instance, Bird, et al. [20] indicated that high dietary iron consumption may increase the incidence of colon cancer, due to the *in vivo* synthesis of free radicals by iron. Also, Graf and Eaton [21] observed that high phytate decreased iron-reliant colorectal cancer and iron-induced oxidative insults in rats. The effects of dietary fiber on iron absorption vary based on the type of fiber components, the individual dietary iron supplement, sex, and the age of the individual. With the exception of high mortality and anemia, iron deficiency is the leading nutritional health concern with about two billion of the world's population being affected [22]. Iron insufficiency is a prominent nutritional concern, whereby about 20–50% of the world's population is affected [23].

### 2.1.2. Calcium Bioavailability

Calcium is the most available mineral in the body. It is present in most foods, abundant as a dietary supplementation, and forms part of some medicines. It is needed for vasodilation, muscular contraction and relaxation, nervous functions, intracellular signaling, and hormonal synthesis, although <1% of total body calcium is required for the vital metabolic roles [24]. The serum calcium concentration is strongly regulated, and not dependent on dietary calcium consumption; the body utilizes bone tissue as a source of calcium to maintain the persistent/homeostatic levels of calcium in the blood, muscle, and intercellular fluids [24]. There are two main mechanisms that explain the absorption of calcium from the intestinal lumen. These pathways include active transcellular absorption and passive paracellular absorption. The active transcellular absorption occurs in the duodenum during low calcium intake. This mechanism involves the importation of calcium into the enterocytes, distribution across the cells, and final exportation into extracellular fluids and blood. Through the high voltage insensitive channels, calcium is transported into the intestinal epithelial cells, and exported out of the cells by the actions of the calcium-ATPase. The transport of calcium across the epithelial cells is the restrictive effect of the active transcellular absorption, masterminded by the calbindin protein carrier. However, the presence of vitamin D in the body influences the synthesis of calbindin [25]. The second mechanism, passive paracellular absorption, occurs in the jejunum and the ileum. However, passive paracellular absorption may occur in the colon with the presence of a high or moderate amount of calcium. Calcium ions are transported into the enterocytes and thus into the blood. This mechanism leads to bulk intake of calcium during high calcium availability [25]. The absorption of calcium can be influenced by the occurrence of soluble fiber, such as galactomannan gums. The use of locust bean gum and methoxyl pectin decreased the absorption and *in vitro* bioavailability of calcium, whereas inulin supplementation decreased calcium absorption [6]. In the Maillard reaction, there was a reduction in the absorption and availability of calcium. The addition of calcium in a phytate-containing diet affects mineral absorption as a result of the formation of insoluble calcium-phytate complexes [26]. The same authors observed that dietary supplementation of calcium in a rape seed meal reduced the hydrolysis of phytate in the colon of swine. Caeca fermentation of dietary fiber increased calcium and magnesium absorption in the large intestines [27,28]. However, some studies involving human and animal models observed that soluble dietary fiber, such as pectin and guar gum, have no significant effects on the bioavailability of mineral [29,30]. It could be generalized that soluble dietary fiber decreased the absorption of calcium in the body. However, the effect of insoluble dietary fiber on calcium bioavailability is limited in the literature.

### 2.1.3. Selenium Bioavailability

Selenium is a trace mineral that is normally present in food, and abundant as a dietary supplement. Selenium is a dietary essential mineral for both humans and animals. It plays a vital role in reproduction, DNA synthesis, protection mechanisms from infections and oxidative damage, and metabolism of thyroid hormones, and is a constituent of more than two dozen selenoproteins [31]. There are two forms of selenium: inorganic (selenate and selenite) and organic (selenomethionine and selenocysteine) [32], and both forms of selenium are used as a dietary source of selenium [33]. The absorption rate of selenium depends on the species of animal and the forms (organic or inorganic) of selenium supplemented. Though organic forms of selenium are completely maintained in the body, they have lower absorption rates in comparison with the inorganic forms. The determining factor that influenced the metabolism of selenium is the type of selenium present in the plasma. Different forms of selenium can be transformed into selenide for the synthesis of selenoproteins and its egestion in urine as selenosugar. However, selenomethionine interacts with meat protein structures through the methionine substitution reaction pathway [34].

#### 2.1.4. Copper Absorption

Copper is a trace element that forms part of several enzymes and proteins that are important for the proper use of iron in the body, and low copper levels are related to different conditions, such as high cholesterol concentration and increased incidence of cardiovascular diseases. The bioavailability of copper is affected by many factors, such as zinc, carbohydrate and fiber, and vitamin C consumption [35]. The mechanisms of dietary fiber may have an indirect impact on the availability of copper by varying the bioavailability of other mineral adversaries. The detrimental impact of phytate on copper absorption is not as severe as its effect on other minerals, such as calcium and zinc [36]. Turnlund, et al. [37] observed that dietary supplementation of sodium phytate or  $\alpha$ -cellulose has no influence on the copper absorption. There is a notion that in the presence of excess calcium, copper may be precipitated with phytate [38]. Davis, et al. [39] reported that dietary supplementation of crude soybean proteins decreased the bioavailability and deficiency of copper in broilers. In addition, Lönnerdal, et al. [40] reported about 90% decrease in copper bioavailability in infants after feeding on purified soybean protein. Moreover, after feeding different fiber forms to adolescent males, Drews, et al. [41] observed a decrease in copper balance among subjects that were fed hemicellulose, though pectin and intact cellulose had no effect on the copper concentration. Behall, et al. [42] concluded that fiber forms such as locust bean, karaya gums, and carboxymethylcellulose, increased or had no effect on the trace mineral bioavailability, including copper. The absorption of copper follows a similar pathway as the absorption of calcium. However, it has been indicated that disorders in the intestinal absorption of copper enhance Menkes disease, as a result of the disabling mutations of the gene encoding for the intracellular copper-ATPase. Lutsenko, et al. [43] indicated that dietary absorption of zinc and molybdenum may lead to copper deficiency disorders. The bioavailability of copper is decreased by different dietary forms of fiber in the diet.

#### 2.1.5. Zinc Absorption

Zinc is a trace mineral required for normal growth and healthy immune functions. Zinc is important for cell differentiation, DNA multiplications, bone forming ability, skin protection, immune functions, and sexual maturity [44]. It is required by enzymes for various chemical reactions and for the natural sense of smell and taste. The absorption or loss of zinc in the small intestines may be considered as a regulation mechanism for zinc homeostasis. The intestinal egestion of zinc is via the pancreatic cells and the biliary secretions through the shedding of the epithelial cells. Dietary conditions, such as fiber, phytates, and animal proteins, influence the absorption of zinc. The main cause of zinc deficiency in human and animal body is due to the consumption of phytate-rich diets. There is increasing evidence that dietary phytate, as well as supplemented phytate, decreased zinc homeostasis [45]. A serious deficiency may damage the central nervous system and the brain, hence affecting the cerebral and motor maturation [15], as well as motility, respiratory tract pneumonia, diarrhea, and growth retardation [46]. Previous studies using animal models indicated that phytate inhibits the absorption of zinc [47,48]. Fiber is mostly referred to as having a deleterious impact on the absorption of zinc. However, this may be a result of the phytate content in most fiber-rich diets. Hence, differentiating the effects of phytate from fiber is mostly difficult. A previous study by Knudsen, et al. [49] observed that high fiber-containing diets decreased the absorption of zinc. Barbro, et al. [50] reported that leavening bread improved zinc absorption to a concentration similar to low fiber bread, indicating that fiber has a little or no impact on the absorption of zinc [51]. Therefore, the effect of fiber on zinc bioavailability may depend on the type of fiber, fiber composition, and the animal or human subjects used.

#### 2.1.6. Magnesium Bioavailability

Magnesium is the second most abundant intracellular cation that is important for the wide range of basic reactions, and its absence in an organism may cause adverse biochemical changes [52]. There

is an increase in the recommendation of dietary fiber consumption as having health-promoting effects. However, fiber is associated with *in vitro* mineral-binding abilities, hence impairing the absorption of magnesium. Moreover, some studies showed that fiber fermentation may increase magnesium absorption in the large intestines. Previous studies suggested that fiber-rich diets may have undesirable effects on mineral absorption [53]. For example, the consumption of Bazari bread significantly reduced the absorption and availability of magnesium in human [54]. Also, Thebaudin, et al. [55] indicated that there was a decrease in the fractional magnesium absorption and a substantial increase in the absorption of net magnesium after consuming magnesium-rich oat bran diet. For the past twenty years, studies have concluded that the effects of dietary fiber on mineral absorption depend largely on the type of fiber, the quantity of the dietary fiber, the existence of related components, like phytates, and the homeostasis of the minerals [52]. Kayne and Lee [56] reported that magnesium is mainly absorbed in the distal small intestine. Some studies also reported that magnesium intake is associated with the luminal concentration of magnesium in a curvilinear fashion, such as transcellular mechanisms. However, Coudray, et al. [57] indicated that there is a direct relationship between magnesium absorption and dietary magnesium concentrations. Usually, magnesium absorption occurs in the cells through osmosis and diffusion processes [58]. The absorption of magnesium in human and animals may vary between 35–70% [57]. The main mechanism of magnesium uptake occurs at the renal level [59]. The kidneys store magnesium in the body at times of limited magnesium supplementation. However, excess magnesium in the body is excreted in urine after magnesium reabsorption. In kidneys, the reabsorption of magnesium occurs in the Henle's loop, where approximately 70% of filtered magnesium is reabsorbed [57]. The influence of dietary fiber and its components on magnesium absorption has been observed. The supplementation of resistant starch in the diet of rats increased the relative and net magnesium absorption compared with the control [60]. Also, resistant starch increased the diameter of the cecum and small chain fatty acid production, increased the absorption of magnesium, and decreased the phytic acid effects in phytic acid-rich diets [61]. Delzenne, et al. [62] reported that oligofructose increased the magnesium absorption. Therefore, magnesium absorption depends largely on the type of fiber, the quantity of the dietary fiber, the existence of related components, like phytates, and the homeostasis of magnesium.

#### 2.1.7. Manganese Bioavailability

Manganese is a trace element that is essential as a nutritional component and also potentially toxic. The diverse effects of manganese insufficiency and manganese toxicity in most organisms are yet to be known [63]. It is essential in several physiological mechanisms, such as forming part of several enzymes and activators of different enzymatic reactions [64]. The absorption of manganese has been stated as low as 1% [65] to as high as 40% [66] in rats. Dietary conditions that may affect manganese bioavailability have received little attention because manganese deficiency is not considered to be a major problem in animal health. Hence, it is not clear whether dietary fiber supplementations affect manganese absorption. However, limited studies suggests that high dietary calcium and phosphorus availability may reduce manganese bioavailability [67].

#### 2.1.8. Phosphorus Bioavailability

Phosphorus is a component of human and animal cells, mostly in body fluids, bones and teeth, and is vital in core genetic processes, such as RNA and DNA, and in health protective mechanisms. The absorption of phosphorus takes place in the proximal part of the small intestine. Phosphorus is transferred into the epithelial cells by a co-transport mechanism with sodium. The effects of fiber (cellulose) on phosphorus availability are less unique. Raboy [68] observed a reduction in phosphorus absorption, while others found no effect with different fiber levels. Here, the effects may be reliant on the solubility of dietary phosphate and, to a broader or lesser extent, of its adsorption to the fiber matrix. Phytate is the primary source of phosphorus in animal diets of plant source, but this phosphorus is not present for absorption unless the phosphate groups are separated from the phytate molecule.

The removal of the phosphorus from phytate may be achieved by integral dietary phytase or intestinal phosphatase. The phytate phosphorus complex occurs in most plants as a mixture of phytic acid molecules. There is evidence that most plant foods contain 50–80% of phytate as total phosphorus [69].

#### 2.1.9. Chromium Bioavailability

Chromium is a trace element that is required in trace quantities, however, the mechanisms of action in the body and the quantities needed for the optimum health are not well elucidated. There are two forms of chromium found in nature: trivalent ( $\text{Cr}^{3+}$ ), which is biologically active and present in food; and hexavalent ( $\text{Cr}^{6+}$ ), which is toxic and present as an industrial pollutant. Chromium is showed to increase the action of insulin [70], important for hormonal actions in carbohydrate, fat, and protein metabolism and storage [71]. Keim, et al. [72] observed that the presence of chromium in rat diet was not affected by phytate. Also, Harland [73] indicated that there was no change in urinary and tissue chromium concentration after twenty Sprague-Dawley rats were incubated with  $100 \mu\text{Ci}^{51}\text{Cr}$  for 24 h. However, there are limited investigations on the influence of fiber and fiber components on chromium bioavailability.

#### 2.1.10. Other Minerals

The bioavailability of dietetic iodine has not received much attention; absorption of dietary iodine is about 90%. The insufficient absorption of iodine and high consumption of cyanogenic foods appear to be a risk factor for the deficiency of iodine [74]. The effects of dietary fiber on iodine bioavailability are limited in literature. Sodium is a major element present in the fluid surrounding the cells in the body. Sodium and potassium perform similar task in regulating blood pressure and the fluid volume. Sodium also functions in the maintenance of pH balance and plays a key role in the muscles and nervous system. There is limited information on the effects of dietary fiber on the bioavailability of sodium and potassium. Hence, at this juncture, it is hard to state whether dietary fiber affects the bioavailability of these minerals.

### 2.2. Interactions of Dietary Fibre on Protein Bioavailability

The estimation of the amount of proteins in the diet has been of utmost importance since the start of nutrition as a scientific discipline. The application of dietary fiber on protein utilization and metabolism has received scientific attention in the past few decades. Fiber contains a given amount of protein which is usually undigestible and could influence the protein digestibility value. This protein value within fiber increases fecal nitrogen concentration [75]. Hence, undigested protein in the fiber source could influence dietary protein digestibility. Generally, fermentable and viscous fiber (pectin and guar gum), decreases the digestion of protein more than non-viscous and non-fermentable fiber (cellulose), based on weight. Fermentation may decrease protein digestion by the activity of stimulating the growth of microbes, while viscosity may decrease digestion by reducing the rate of protein metabolism in the small intestine. Most refined fiber, with respect to its type and source, decreases protein digestibility in animals. For example, inulin and resistant starch have been stated to decrease protein metabolism in humans and monogastric. Phytate forms a strong association with some proteins which withstand proteolysis [76]. There was an observation that protein phytate interaction negatively influenced protein digestibility in *in vitro* conditions [76]. However, there were other observations that stated that protein levels increased in the small intestines during dietary consumption of cellulose or wheat bran [77]. Meanwhile, in a rat study, the protein efficiency ratio (PER) of feed with 10 to 12% cellulose was considerably high [78], low [79] or unaffected [80] compared to the control with free fiber sources. Hence, regarding the alterations in the protein and/or fiber levels of the feeds, and the procedure of fiber supplementation into the feeds, evaluations among studies using similar fiber sources are usually not promising. From the accessible literature, it is clear that dietary fiber and fiber-rich diets decrease protein digestion, in a linear manner.

### 2.2.1. Dietary Fiber Modulation

The procedure of incorporating fiber into a diet is of significance, since it directly determines the protein-to-calorie percentage of the diet [81]. There are two methods through which dietary fiber is introduced into animal feed for experimental purposes.

#### Substitution Method

The most frequently used procedure is the substitution method, whereby the fiber is supplemented at the expense of the digestible carbohydrate. In the substitution process, the amount of protein is intact with regards to weight, but protein-to-calorie ratio is augmented. Manuel, et al. [79] stated that rats fed with cellulose by the substitution process experience a decrease in the protein efficiency ratio (PER) with an increase in cellulose levels. Therefore, when the supplementation of fiber is based on the substitution method, animals consume most of their diet as protein, compared to low fiber diets or fiber-free diets. The monogastric mainly feed to meet their energy requirements, supplementing adequate quantities of fiber mainly causes an improved feed consumption.

#### Addition Method

The second procedure involves the addition of fiber to the basal diet, hence initiating the dissolution of all dietary components. This method is also known as the dilution method. Comparatively, in fiber diluted diet, protein-to-calorie ratio is unaffected. However, feeding a fiber diluted feed, animals obtain approximately the same protein as the control. However, dilution of the cellulose does not influence the PER, except at maximum cellulose level, which registered a decrease. Hence, it could be observed that dilution is a reliable way to supplement fiber.

### 2.3. Interactions of Dietary Fibre on Vitamins Bioavailability

Vitamins are subdivided based on their solubility, fat-soluble (A, D, E, and K) and water-soluble (B and C). The differentiation between fat-soluble and water-soluble vitamins is essential, as it helps in estimating the quantity of vitamins available in the body.

#### 2.3.1. Bioavailability of Fat-Soluble Vitamins

There is a strong association between the intake of fat-soluble vitamins and triglycerides. The conditions related to fat absorption are always linked to the chaos of the intake of fat-soluble vitamins. The esters of fat-soluble vitamins are soluble in dietary fat, and are hydrolyzed by the pancreatic carboxylic ester hydrolase within the lumen of the intestines [82]. It is shown in a rat model that there was no reduction in vitamin A concentrations in the liver when carotene and pectin (3%) were supplemented in the diet [83]. Again, postprandial serum vitamin A levels were not affected by the supplementation of 5–10% of microcrystalline cellulose [84]. Kim, et al. [85] observed that the supplementation of 8 g of hydrophilic mucilloid extracts did not affect the vitamin A and carotene synthesis in both plasma and feces even after long-time feeding. It was stated that vitamin D forms a bond with the fiber bile acid complex, and is transported out of the gut unabsorbed [86]. The supplementation of pectin was stated to decrease bioavailability of vitamin E while, the absorption of vitamin E in non-diseased and diabetic subjects was decreased by the supplementation of konjac mannan (glucomannan) [87]. It is unclear whether dietary fiber affects the consumption and metabolism of vitamin K. To date, there is no single study connecting the effects of dietary fiber on vitamin K bioavailability. The process by which the fat-soluble vitamins are hydrolyzed and absorbed is simple and less complex than the water-soluble vitamins.

#### 2.3.2. Bioavailability of Water-Soluble Vitamins

Most water-soluble vitamins undergo transformation during the process of absorption in the lumen. The impact of high or low fiber diets is observed on the bioavailability of vitamins. For instance,

urinary excretion of riboflavin (vitamin B2) increased after consuming cellulose, coarse and fine bran, and cabbage, more so than in a low fiber diet, after 8 h of supplementing with 15 milligrams of riboflavin-5-phosphate [88]. It was stated that dietary fiber increases gastrointestinal absorption of riboflavin [89]. It is stated that in human as well as animals, the form of the dietary fiber did not affect the bioavailability of vitamin B6 in food, and serum folic acid concentrations were not affected at high fiber diet in diabetic subjects [90]. Also, the supplementation of glucomannan konjac mannan in non-disease and diabetic subjects does not affect vitamin B12 intake. When 14 g of hemicellulose was added to a diet comprising of 100 milligrams of ascorbic acid, there was an escalation in the urinary ascorbic acid synthesis in healthy volunteers [91]. However, pectin and cellulose supplementation did not affect urinary ascorbic acid concentration. It could be an indication that non-digestible fiber influences the stimulation of vitamin production in the intestines.

#### 2.4. Interaction of Dietary Fiber on Lipid Bioavailability

Most studies support the notion that blood cholesterol levels may be decreased by viscous soluble fiber, that generates high viscosity within the gastrointestinal tract (GIT) [92,93]. The viscous soluble and viscous insoluble dietary fiber can bind with bile acids and micelle constituents, like free fatty acids, macro glycerides, and cholesterol, to reduce the uptake and increase the fecal egestion of these compounds [94,95]. However, the binding effect of insoluble fiber is lower than the viscous soluble fiber. Moreover, cholesterol and free fatty acids that bind to the dietary fiber matrix are not absorbed by the body, and are excreted. Dietary fiber may change the metabolism of lipids by affecting the expression of key genes. The restrictive enzymes in lipogenesis is controlled by the AMP-activated proteins kinase (AMPK). For example, supplementing 5 g of *Plantago ovata* to the diet of rats increased the phosphorylation of AMPK, and hence, affecting acetyl-CoA carboxylase [96]. Also, supplementing 10 g per 100 g of fructooligosaccharide in rats' diet reduced hepatic acetyl-CoA carboxylase expression [97]. Kimura, et al. [98] observed the egestion of higher amounts of cholesterol in rats fed diets comprising of 1000 milligrams per kilogram of degraded alginates, in comparison with the control. Kaur, et al. [99] reported a significant decrease in triglyceride levels in the blood and liver of rats fed inulin-supplemented diets. There was a decrease in liver lipid levels after injecting dexamethasone and ethanol in rats [100]. Trautwein, et al. [101] showed a decrease in the synthesis of very low-density lipoprotein (VLDL) in male golden Syrian hamsters raised on a 16% inulin diet for five weeks, due to the changes in hepatic lipid metabolism, and the reduction of about 29% of plasma cholesterol. The synthesis of SCFA from the fermentation of inulin reduced the capacity of the liver to produce triglyceride and fatty acids by inhibiting the activities of fatty acid synthase and glycerol-3-phosphate acyltransferase. Pedersen, et al. [102] indicated that there was no change in blood lipids after adding 14 g of inulin in the diet of normolipidemic patients for four weeks. In animals, inulin supplementation decreased the cholesterol levels through the production of bile acids [103].

#### 2.5. Fiber and Prebiotics on Gut Microbiota

The interactive relationship between dietary fiber and prebiotics is reliant on their colonic degradation and variations in the gut microflora. Dietary fibers comprise of soluble fiber components, for example, guar gum, inulin, oligosaccharides, pectin, resistant starch, and insoluble structural polysaccharides, such as cellulose and lignin, which are barely fermentable by intestinal bacteria in the colon [104]. Prebiotics are non-digestible food substances that are beneficial to the host by selectively motivating the growth and action of one or more of the colonic bacteria, thus improving their health [105]. Food components that are categorized as prebiotics need to confirm the three conditions: (a) ability to resist the low pH in the gut, undergo hydrolysis by enzymes, and absorption within the gut; (b) fermented by intestinal microflora; and (c) selectively stimulate the growth and activities of intestinal bacteria related to gut health and wellbeing of the host animal [106]. The carbohydrate and indigestible oligosaccharide fermentation in the distal part of the large intestines is carried out by microbial organisms such as *Enterobacteria*, *Roseburia*, *Bacteroides*, *Bifidobacterium*, and *Fecalibacterium* [107]. Fiber is



a typical model of fermentable prebiotic associated to health benefits, as it is converted into SCFAs, predominantly acetate, butyrate, and propionate by the specific colonic bacteria, which, in turn, lowers the colonic pH to an acidic environment that may oppose the multiplication of pathogenic and putrefactive bacteria [108]. The SCFAs also act as an energy source to the host, for instance, it has been declared that the microbial fermented SCFAs from the consumption of a basic Western diet approximately constitutes 6–15% of the total energy needed, and they are expected to be higher in herbivores and humans ingesting high fiber diets. The quantity and level of produced SCFAs is directly proportional to the composition and volume of the colonic microbiota relative to the type of dietary fiber accessible for microbial fermentation [109]. These microbes are delivered with raw materials from the diet, as well as constituents originating from the host such, as mucin (Table 1). On the other hand, Wichmann, et al. [110] observed an increase in glucagon-like peptide-1 (GLP-1) level in humans and rodents after supplementing the diet with fermentable fibers, and SCFAs can activate GPL-1 secretion *in vitro* that impacts on metabolism, together with inhibition of gastric emptying, an increased feeling of satiety, and stimulation of insulin secretion, suggesting that the abundance of the gut microbiota through the production of SCFAs can stimulate an increasing amount of GPL-1. Consumed fiber stimulates the colonic microbiota proliferation through the process called cross feeding, whereby the end product of polysaccharide fermentation by different bacterial species has symbiotic effects on another species of bacteria within the gastrointestinal tract [111]. Gibson, et al. [112] reported that dietary supplementation of inulin significantly improves the microbial composition by inducing the growth of *Bifidobacteria*. These *Bifidobacteria* change the dynamics of the gut microflora by preventing the growth of harmful bacteria by the production of *Bacteriocins* [103]. The most important role of *Bifidobacteria* is the stimulation of fecal bulkiness [113]. Also, Kleessen, et al. [114] investigated the impact of inulin and oligofructose on the gastrointestinal microbial biology of rats in relation to human fecal microflora. They observed that there was a significant rise in the caeca and colonic butyrate concentration and relative molar proportions in diets containing inulin, than diets containing both inulin and oligofructose. However, they concluded that the population of bacterial *Clostridium* increased higher than *Lactobacilli* or *Bifidobacteria*, involved in the production of butyrate. These SCFAs, such as butyrate, increased mucosal blood flow, hence affecting ileal motility and cell proliferation [115].

**Table 1.** Some of the predominant anaerobic bacterial species found in the human intestine and studied in pure cultures with selected carbohydrates [116], slightly modified.

Substrate	Degradability	Bacterial Species
Cellulose	Partially fermentable	<i>Bacteroides</i> sp.
Methyl and carboxymethyl cellulose	Partially fermentable or non-fermentable	Not Known
Hemicellulose	Partially fermentable	<i>Bacteroides eggerthii</i> ; <i>Bacteroides fragilis</i> subspecies; <i>Bacteroides ovatus</i> ; <i>B. vulgatus</i> ; <i>Bifidobacterium adolescentis</i> ; <i>B. Infantis</i>
Pectin	Highly fermentable	<i>Bacteroides fragilis</i> subspecies; <i>B. ovatus</i> ; <i>B. thetaiotaomicron</i> ; <i>B. "3452A"</i> ; <i>Eubacterium eligens</i> .
Cereal gums	Highly fermentable	<i>Bacteroides distansnis</i> ; <i>B. thetaiotaomicron</i> ; <i>B. uniformis</i> ; <i>B. "T4-1"</i>
Guar gum, locust bean gum	Highly fermentable	<i>Bacteroides ovatus</i> ; <i>B. uniformis</i> ; <i>Bifidobacterium adolescentis</i> ; <i>Ruminococcus albus</i>
Arabinogalactans	Partially fermentable	<i>Bacteroides ovatus</i> ; <i>B. thetaiotaomicron</i> ; <i>B. uniformis</i> ; <i>B. vulgatus</i> ; <i>B. "T4-1"</i> ; <i>B. "3452A"</i> ; <i>B. Longum</i>
Maillard polymer	Non-fermentable	Not Known
Algal gum	Non-fermentable	Not Known
Mucopolysaccharide	Highly fermentable	<i>Bacteroides fragilis</i> subspecies; <i>B. ovatus</i> ; <i>B. thetaiotaomicron</i> ; <i>B. "3452A"</i>
Mucin glycoprotein	Partially fermentable	Few <i>Bacteroides</i> strains: <i>B. bifidum</i> ; <i>R. torques</i> .

### 3. Conclusions

The dietary fiber intake influences the mechanisms by which nutrients are absorbed in both human and animal diet. The main physicochemical properties that are measured in monogastric nutrition are solubility or fermentability, cation exchangeability, hydration properties, viscosity, particle size and organic compound adsorptive properties, which all affect nutrient absorption. Dietary fiber forms differ based on the physiological and biochemical properties, and hence influence the bioavailability of nutrients, microbial composition, and gastrointestinal functions. Dietary fiber and prebiotics affect the host animal by regulating blood glucose or insulin levels and stool bulking effects, increasing the acidity of the gut, and constructive synthesis of SCFAs, decreasing intestinal transit time, stimulating the growth of intestinal microbes, and increasing blood parameters. Dietary fiber may affect the dynamics of nutrients uptake and gut microflora. However, more research is needed to determine if modulation of the composition and function of the human gastrointestinal microbiota translates to health benefits.

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