# Role of Dietary Fiber in Promoting Immune Health – An EAACI Position Paper

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## Abstract

Microbial metabolism of specific dietary components, such as fiber, contribute to the sophisticated inter-kingdom dialogue in the gut that maintains a stable environment with important beneficial physiological, metabolic, and immunological effects on the host. Historical changes in fiber intake may be contributing to the increase of allergic and hypersensitivity disorders as fiber-derived metabolites are evolutionarily hardwired into the molecular circuitry governing immune cell decision making processes. In this review, we highlight the importance of fiber as a dietary ingredient, its effects on the microbiome, its effects on immune regulation, and potential mechanisms for dietary fibers in the prevention and management of allergic diseases. In addition, we review the human studies examining fiber or prebiotic interventions on asthma and respiratory outcomes, allergic rhinitis, atopic dermatitis, and overall risk of atopic disorders. While exposures, interventions and outcomes were too heterogeneous for meta-analysis, there is significant potential for using fiber in targeted manipulations of the gut microbiome and its metabolic functions in promoting immune health.

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*Abstract*

Microbial metabolism of specific dietary components, such as fiber, contribute to the sophisticated inter-kingdom dialogue in the gut that maintains a stable environment with important beneficial physiological, metabolic, and immunological effects on the host. Historical changes in fiber intake may be contributing to the increase of allergic and hypersensitivity disorders as fiber-derived metabolites are evolutionarily hardwired into the molecular circuitry governing immune cell decision making processes. In this review, we highlight the importance of fiber as a dietary ingredient, its effects on the microbiome, its effects on immune regulation, and potential mechanisms for dietary fibers in the prevention and management of allergic diseases. In addition, we review the human studies examining fiber or prebiotic interventions on asthma and respiratory outcomes, allergic rhinitis, atopic dermatitis, and overall risk of atopic disorders. While exposures, interventions and outcomes were too heterogeneous for meta-analysis, there is significant potential for using fiber in targeted manipulations of the gut microbiome and its metabolic functions in promoting immune health.

## Introduction

Recent decades have seen a rapid increase in chronic inflammatory disorders due to inappropriate or misdirected immune responses accompanied by insufficient development of immune regulatory networks. It is generally accepted that changes in environment, lifestyle and dietary factors may play a role in the miseducation or deficient training of the immune system.[1-3] A shift away from traditional diets rich in plant-based foods to highly processed foods is thought to be particularly important for negatively affecting microbiome diversity and composition, species-specific characteristics, microbial metabolism, and immunological tolerance (Figure 1). Whilst we acknowledge that a range of nutritional factors may play a role in influencing immune function and immune regulation, in this review we will focus specifically on one dietary component – fiber.

Dietary fiber is a complex dietary component, including carbohydrate polymers and oligomers, which makes up the non-digestible components of food.[4,5] All dietary fibers resist digestion in the small bowel and pass into the large bowel intact but differ in their physiochemical characteristics (e.g. solubility, viscosity, and fermentability), which determine their functionality in the gut and to what degree they are accessible by microbes. Most soluble fibers can be fermented by the gut microbiota, partially or completely, dependent on their chemical structure. Dietary fibers can be defined on the basis of their chemical compounds, on the basis of their functional compounds, or both. Slight differences in definitions of dietary fibers exist due to the wide range of non-digestible fibers that occur in nature. The European Food Safety Authority (EFSA) defines dietary fiber as "non-digestible carbohydrates plus lignin".[6] These include non-starch polysaccharides (NSP) (cellulose, hemicelluloses, pectins, hydrocolloids (i.e. gums, mucilages, β-glucans), resistant oligosaccharides, resistant starch (consisting of physically enclosed starch, some types of raw starch granules, retrograded amylose, chemically and/or physically modified starches), and lignin associated with the dietary fiber polysaccharides (Table 1).

Prebiotics are often equated with dietary fibers, but only a subset of dietary fibers qualifies as prebiotics. The term "prebiotic" was first defined by Gibson and Roberfroid over 25 years ago as "a non-digestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, and thus improving host health".[7] This definition has evolved to a more simplified version - "a substrate that is selectively utilized by host microorganisms conferring a health benefit".[8] The most common prebiotic fermentable fibers that have been studied for immune health benefits to date include inulin, fructooligosaccharides (FOS), galactooligosaccharides (GOS) and xylooligosaccharides

(XOS). The most recent definition of prebiotics also allows for non-fiber substrates to be potentially classified as prebiotics.

### The importance of fiber as a dietary component

Diets rich in dietary fiber and prebiotics are those with high levels of plant foods including fruits, vegetables, whole grains, legumes, nuts and seeds (Table 2 and Table 3). Such diets are associated with improved gastrointestinal, cardiovascular and metabolic health.[9] In fact, the American Gut Study showed that eating 30 plant-based foods per week was associated with the highest levels of gut microbial diversity.[10] In addition to their high fiber content, these foods also typically have a lower energy density and lower glycaemic index, and contain important micronutrients, essential fatty acids and other bioactive substances that contribute to overall health. EFSA recommends 25g dietary fiber per day for adults to promote adequate laxation, while recommendations for prevention of type 2 diabetes, cardiovascular disease, colorectal cancer, overweight and obesity are higher (25-38g/day).[11] Some studies have found a greater risk reduction as more dietary fiber was consumed. However, this was not consistent across studies. Evidence is currently too limited to recommend specific types of fiber, so instead a diet rich in vegetables, fruits, and whole grain cereals is advised. There is less information available to set dietary fiber recommendations in children and current guidelines have been based on those for adults and vary according to energy requirements. EFSA suggests an intake of 2 g/MJ (megajoules) is considered adequate for normal laxation in children from the age of one year. There are no guidelines for fibre intake below 1 year of age. As research advances, recommendations should expand to include individual fibers and consider the effects and physiochemical properties of specific fiber rich foods in combination with other supplements.

### Fiber effects on the microbiome

Certain fibers, also termed microbiota-accessible carbohydrates, are an essential food source for the microbiome in that they provide resources for microbial growth. They are central to food-webs in the gut microbiota established through cross-feeding, and reduced fiber intake has been shown to be associated with the loss of ancestral microbes.[12] Overall, species diversity and richness have been shown to be reduced by about one third in North Americans compared to Malawians or Amerindians, which might be due in part to changes in dietary fiber consumption.[13] A high fat/low fiber diet and obesity have been associated with alterations in gut microbiota composition and metabolic activity.[14,15]The degradation of dietary fibers requires specific CAZymes (carbohydrate active enzymes), which are not encoded in the human genome, but are encoded in the genomes of specific bacterial strains.[16,17] Therefore specific subsets of microbes are supported by different types of dietary fibers, which highlights the potential for using selected fiber structures to achieve targeted functional, metabolic, and perhaps immunological outcomes.[18] During the neonatal period, human milk oligosaccharides (HMOs) selectively support the growth of some*Bifidobacterium* and *Bacteroidetes*lineages.[19,20] Following on from breast feeding, complementary feeding and weaning drives a diversification of the gut microbiota towards an adult-like state. However, the relative contribution for each of these newly introduced dietary fibers post-weaning on microbiome development, and how this relates to development of the immune system, has not been adequately studied.

### Fiber effects on the immune system

Dietary fibers can have direct and indirect effects on the host immune system.[21] Before being fermented by microbes in the colon, dietary fibers are known to have a substantial impact on the intestine via modulation of intestinal barrier function and immune responses. Specific fiber subunits are recognised by pattern recognition receptors (PRRs) such as C-type lectin receptors (CLRs), galectins or Toll-like receptors (mainly TLR-2, 3 and 4) on epithelial cells and cells of the innate immune system. Via PRRs, different fiber ligands support a functional intestinal epithelial barrier by modulation of tight junction protein assembly, goblet cell function, regulation of epithelial cell growth and glycocalyx maturation.[22,23]Pectins, for example, have been shown to strengthen the mucus layer by activating goblet cells and by forming hydrogen bonds with mucins.[24] Dietary fibers directly modulate chemokine and cytokine production by intestinal epithelial cells, dendritic cells and macrophages, in part mediated by activation of PPARγ.[21]

Following microbial fermentation, a wide range of potent immunological metabolites are produced (Figure 2). The best described metabolites are short-chain fatty acids (SCFAs), which are primarily acetate, propionate, and butyrate (Table 4).[25] SCFAs are potent immunomodulators that promote IL-10 secretion by dendritic cells and lymphocytes, influence Treg numbers and effectiveness, influence bone marrow haematopoiesis, reduce effector T cell activity, improve epithelial barrier, support IgA secretion by B lymphocytes, inhibit mast cell degranulation and modulate ILC2 activation.[26-30]Fiber consumption or SCFA administration in experimental models protects against colitis, inflammatory arthritis, respiratory syncytial virus infection, allergic airway inflammation and food allergy.[31-34] SCFAs exert effects on the host immune system via binding to G protein-coupled receptors (GPCRs) such as GPR41, GPR43 and GPR109A, via epigenetic modifications that inhibit histone deacetylase (HDAC) activity, and most recently butyrate has been described as an aryl hydrocarbon receptor (AhR) ligand. Epigenetic mechanisms seem particularly important for the induction of T regulatory cells in the gut as butyrate enhances histone acetylation of the Foxp3 promoter thereby driving Treg development.[35,36]Importantly, consumption of fruits and vegetables during the first year of life is associated with increased levels of fecal butyrate and those children with the highest fecal levels of butyrate and propionate were less likely to develop allergies and asthma later in life.[32]

**Systematic Review: Importance of fibers for allergy prevention and treatment**

For the purposes of this review, we focused on studies published during the last 5 years. In our search, we included observational epidemiological studies and clinical trials/intervention studies with application of dietary fiber and/or prebiotics to prevent or treat allergic diseases. Search terms are given in supplement 1 . Based on these, 542 papers (235 from Pubmed and 307 from EMBASE) were retrieved. After removal of duplicates, 512 papers remained. Finally, after abstract and full text screening, we identified 16 studies that involved either dietary prebiotic (n=7) or fiber (n=9) intake and measured allergy-relevant outcomes. Exposures, interventions, and outcomes were deemed to be too heterogeneous with respect to prebiotic/fiber type and assessment of the outcome to attempt to pool the data for meta-analysis, so results are summarised as a narrative systematic review only.

Several guidelines and systematic reviews have previously examined the role of both fiber and prebiotic supplementation with respect to allergy outcomes. A 2015 review by Orel et al. concluded that "the strongest evidence on beneficial effects of prebiotics in children exists in relation to the fight against constipation, poor weight-gain in preterm infants and prevention of eczema in atopic children."[37] The World Allergy Organization (WAO) GLAD-P document stated that prebiotics could be added to the diet of not-exclusively breastfed infants, both at high and at low risk for developing allergy, however not in exclusively breastfed infants. This is a conditional recommendation with very low certainty of evidence.[38] The supporting GRADE analysis for this document regarding the use of prebiotics given to infants stated there is "a possible effect of prebiotic supplementation in infants on the reduction in the risk of asthma or wheezing", in that prebiotics might reduce the risk of recurrent wheezing in infants, but this had a very low level of certainty due to "risk of bias, indirectness of the evidence, and imprecision due to low number of events of the estimated effect".[39] The Philippine guidelines on dietary primary prevention state that prebiotics are not recommended to prevent allergic diseases (with a strong recommendation level due to low quality evidence).[40] A systematic review from the United Kingdom on dietary recommendations for infants and pregnant or lactating mothers also reports that there is no clear evidence that prebiotic supplementation reduces eczema at age [?] 4 years (RR 0.75; 95% CI 0.56±1.01; $I^2$ = 57%) and no association at age 5 to 14 years.[41] This was followed by a systematic review from Skorka et al.[42] who noted inconclusive effects of prebiotic supplementation in infant formula in influencing the development of allergic diseases, with only a possible (though methodologically limited) single study noting supplementation of infant formula with GOS/FOS may decrease "some allergic reactions" and GOS/FOS/AOS supplementation may reduce the risk of eczema. Lastly, a systematic review supporting the new EAACI food allergy prevention guidelines noted little to no effect for the role of prebiotics, though also stated that the evidence for this is very limited.[43]

*Asthma/Respiratory Outcomes*

We identified 7 studies that involved either dietary prebiotic (n=1) or fiber (n=6) intake in 3 interventional studies and 4 observational cohort studies detailing an association with asthma/respiratory outcomes.

*Fiber*

Andrianasolo et al. [44] studied multiple types of dietary fiber intake in association with reported asthma control (assessed at 6 months longitudinal intervals) as indicated by the Asthma Symptom Score and the Asthma Control Test score. They noted that higher quintiles of dietary fiber intake (total, soluble, insoluble fibers from cereals, fruit and seeds) was associated with lower Asthma Symptom Score (0.73, 95 % CI 0.67-0.79 in women; and 0.63, 95 % CI 0.55-0.73 in men, both $p<0.001$) compared to participants in the lowest quintile of total dietary fiber intake, indicating that higher fiber intake was associated with fewer reported asthma symptoms. Higher total fiber intake, mostly insoluble fiber and fiber from cereals was also associated with lower odds of an ACT score indicating impairment (OR 0.72, 0.55-0.95, p=0.01 for women, OR 0.45, 0.26-0.79, p=0.01 for men). Bseikri et al.[45] noted no overall association between consumption of a high fiber nutritional supplement bar (CHORI-bar) and pulmonary function testing, ACT score and PedsQoL Am score, although they did note that among treatment-compliant subjects with non-eosinophilic asthma, 8 weeks of CHORI-bar consumption was associated with increased FVC, FEV-1, and FEF-25-75. McLoughlin at al.[46] noted that a 7 day trial of inulin (12g per day) supplementation was associated with improved Asthma Control Questionnaire score exceeding the minimal important difference, though not associated with objective parameters of improved lung function, but they noted a subgroup effect among those with the poorest asthma control in that the inulin supplementation was associated with decreased eosinophilic airway inflammation, and better overall control among those with eosinophilic vs. non-eosinophilic asthma. Saeed et al. [47]noted an association between low dietary fiber intake and increased odds of reported asthma among US respondents on the NHANES survey. They noted increased odds of asthma with lower fiber intake (lowest vs. highest reported quartile, OR, 1.4; 95% CI 1.0– 1.8; P = 0.027) with significant interactions between fiber and both sex and race/ethnicity, in particular among women and non-Hispanic white adults. Lowest quartile fiber intake was associated with increased odds of reported wheeze (OR, 1.3; 95% CI, 1.0–1.6; P = 0.018) and cough (OR, 1.7; 95% CI, 1.2–2.3; P = 0.002).

Two Australian studies looked at the effects of fiber during pregnancy. Grieger et al.[48] noted that, after adjusting for total energy intake, pregnant women with uncontrolled asthma had higher intakes of fiber (OR 1.07, 1.03-1.13, p=0.003). Pretorius et al.[49] noted that higher reported maternal dietary intake of resistant starch was associated with reduced odds of doctor diagnosed wheezing in the infant (aOR 0.68 (95% CI 0.49-0.95, p = 0.02).

*Prebiotics*

In adult asthmatic patients, a randomised, double-blind, placebo-controlled, cross-over design study examined the effects of 3 weeks supplementation with 5.5 g/day Bimuno-galactooligosaccharide (B-GOS). Supplementation with this prebiotic reduced the severity of hyperpnoea-induced bronchoconstriction (HIB, a surrogate for exercise-induced bronchoconstriction), as well as concomitant markers of airway inflammation.[50] Recipients displayed a 40% improvement in FEV1 decline after EVH, and B-GOS supplementation reduced baseline concentrations of CCL17, CRP and TNF-α as well as EVH-induced increase in TNF-α.

*Allergic Rhinitis and Pollen Sensitization*

We identified 1 intervention study using fiber supplements in the form of a fermented beer and 1 open label study investigating a prebiotic.

*Fiber*

Derakhshan et al. [51] studied the effect of 15mg dried Ma-al-Shaheer versus fexofenadine in adults with allergic rhinitis (AR) for 21 days, noting AR control was improved in both groups ($p<0.001$) and symptoms were significantly reduced in both groups, although slightly better for nasal congestion, post-nasal drip, and headache among those receiving the Ma-al-Shaeer treatment.

*Prebiotics*

In an open label and non-controlled study, atopic adults receiving the prebiotic lactosucrose (3.2 g/day for 52 weeks) had significantly decreased serum IgE levels (especially to pollen allergens) as well as allergy symptoms at the end of the study period.[52]

*Eczema and atopic dermatitis*

We identified 6 studies that involved either dietary prebiotic (n=4) or fiber (n=2) intake in 4 interventional studies and 2 observational cohort studies.

*Fiber*

For fiber, Matano et al.[53] noted that in Japanese adults on antihistamines with poor control of their chronic urticaria, total fiber intake was not significantly associated with UCT score, although urticaria patients had significantly higher fiber intake than controls (p=0.01). A review paper by Pretorius et al. [49] noted that higher maternal intakes of resistant starch were associated with higher odds of parent reported eczema (aOR 1.27 95% CI 1.09, 1.49, $p < 0.01$), doctor diagnosed eczema (aOR 1.19, 95% CI 1.01, 1.41, $p = 0.04$), and doctor diagnosed eczema in non-sensitized infants (aOR 1.29, 95% CI 1.06, 1.57, $p = 0.01$). Higher maternal intake of fiber from green vegetables was associated with higher odds of doctor diagnosed eczema in the infant (aOR 1.32, 95% CI 1.06, 1.64, $p = 0.01$), and also in non-sensitized infants (aOR 1.36, 95% CI 1.04, 1.79, $p = 0.03$).

*Prebiotics*

For prebiotics, Bozenky et al. [54] performed a randomized controlled trial in 6-8 weeks old high-risk infants (family history of allergy in first-grade relatives), who were given a hypoallergenic formula, either supplemented with or without 0.5g/100 ml of galacto-oligosaccharides. They noted a decreased, but not statistically significant, SCORAD score in both groups. Similarly, Boyle et al. [55] showed in an international multi-center study that in high-risk infants, partially-hydrolysed whey protein formula (pHF-OS) supplemented with neutral scGOS, lcFOS and pectin-derived acidic OS (pAOS) (vs the same formula without the prebiotics) did not prevent eczema in the first year of life. In the PIPA study (Prebiotics in the Prevention of Atopy), galacto-oligosaccharide/polydextrose (GOS/PDX)-supplemented formula showed no significant difference in the cumulative incidence of eczema in the first year of life in high-risk infants compared to standard formula and breastfeeding.[56] Lastly, daily administration of kestose, the smallest FOS, for 6 weeks in 2- to 5-year-olds was significantly correlated with higher fecal *F. prausnitzii* levels and an improvement in SCORAD severity scores (rs =0.52, $p = 0.04$).[57]

*Food allergy and overall risk of atopic disorders*

There were no food allergy or food sensitization studies identified that examined fiber or prebiotic interventions. We identified 2 interventional studies of prebiotic supplementation in healthy infants reporting on general allergic outcomes. No difference in allergic outcomes at 5 years of age were noted among healthy infants given either non-hydrolyzed cow milk-based formula supplemented with neutral sc-GOS, lcFOS, pAOS, and compared to non-supplemented formula or breastfed children before the age of 8 weeks of life.[58] However, healthy day-care children aged between 1-4 years given a cow's milk-based beverage (CMBB) supplemented with docosahexaenoic acid, polydextrose, GOS, and yeast β-glucan, and additionally fortified with micronutrients (zinc, vitamin A, iron), 3 times/day for 28 weeks had fewer episodes of allergic manifestations in the skin and the respiratory tract, including allergic rhinitis or conjunctivitis, wheezing, allergic cough, eczema and urticaria (HR 0.64; CI 95% 0.47, 0.89; p=0.007).[59]

## Summary and Concluding Remarks

In summary, fibers are essential components of a healthy diet with multiple health benefits, and fiber intake has decreased at the same time as allergy rates have increased. There are a wide variety of fiber types, and specific fibers may contribute to maintaining a tolerogenic mucosal environment and may protect against allergic disorders. However, the optimal prevention or treatment strategies involving fibers in humans have yet to be defined. One mechanism by which fiber impacts the immune system is dependent on microbial fermentation and secretion of bioactive metabolites. Thus, fiber supplementation alone may not be sufficient and simultaneous replacement of missing microbes may be required for optimal benefits to be observed. Given the varied functional properties of different fiber types, it is unlikely that one type of fiber will provide all immune-relevant signals, and regular consumption of diverse fiber types may be superior to supplementation with individual fibers, which is consistent with our previous recommendations regarding the importance of dietary diversity in general for allergy prevention.[60] However, as our understanding progresses on the role and mechanisms mediating specific fiber-microbiota-immune interactions, there is significant potential for using fiber in targeted manipulations of the gut microbiome and its metabolic functions in promoting immune health. We suggest that the current classification of different dietary fiber types would benefit by being updated to include their specific immune functional properties. Overall, fiber diversity may be more important immunologically than any single individual fiber type.

We also need to be aware of potentially inconsistent fiber effects across different disease endotypes, which depends on the distinct pathophysiological mechanisms in operation for the given endotype. This is of particular importance in studying heterogeneous diseases like allergic diseases and asthma and highlight the need for sufficiently powered studies. Deciphering the molecular alphabet that underpins this cellular dialogue is a significant challenge, but one that once overcome will yield the critical insights needed to prevent and treat allergic disorders in the 21$^{st}$ century. Future research on fiber-microbe-host interactions should be strongly encouraged as these discoveries will provide fundamental knowledge on the molecular communication networks that underpin life as a multicellular metacommunity and will progress our appreciation for the principle of biological diversity as a driver of physiological resilience and immune tolerance.

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Figure 1

Legend: The imbalance between high fiber versus high fat diets negatively affects the microbiome with subsequent defects in immune tolerance induction.

Figure 2

Legend: Microbial metabolism of dietary fibers generates metabolites (e.g. SCFAs) that promote differentiation and survival of regulatory immune cell subsets.

**Table 1: Classification of Dietary fibers[4-10]**

| Category | Fiber | Fermentability By gut microbiome | Food sources |
|---|---|---|---|
| Non-starch polysaccharides (NSP) | Cellulose | 10-30% | Grains, fruits, vegetables and nuts. |

| Category | Fiber | Fermentability By gut microbiome | Food sources |
|---|---|---|---|
| | **Hemicelluloses e.g.arabinoxylan** | 50-70% | Cereals |
| | Pectins | ˜100% | Fruit and vegetables |
| | Hydrocolloids i.e. gums, mucilages, β-glucans | ˜100% | Gums: plant exudates, seeds and seaweed Mucilage: Natural gums Cereals: barley and oats, sorghum, rye, maize, triticale, wheat, and rice |
| Resistant oligosaccharides | (fructo-oligosaccharides (FOS) | 100% | FOS: fruits, vegetables and cereals |
| | galacto-oligosaccharides (GOS) | 100% | GOS: Fruit and Vegetables |
| | other resistant oligosaccharides) | 100% | Raffinose oligosaccharides: Seeds of legumes, lentils, peas, beans, chickpeas, mallow, and mustard |
| Resistant starch | physically enclosed starch, some types of raw starch granules, retrograded amylose, chemically and/or physically modified starches | ˜100% | Whole grains, legumes, cooked and chilled pasta, potatoes and rice, and unripe bananas. |
| Lignin associated with the dietary fiber polysaccharides | | 0% | Celery and grains |

**Table 2: Evolution of the definition of prebiotics**

| Reference | Year | Definition |
|---|---|---|
| Gibson GR &Robefroid[11] | 1995 | Non-digestible food ingredient that beneficially affects the host by selectively stimulatin |
| Reid et al.[12] | 2003 | Nondigestible substances that provide a beneficial physiologic effect on the host by selec |
| Gibson et al.[13] | 2004 | selectively fermented ingredients that allow specific changes, both in the composition an |
| Robefroid et al.[14] | 2007 | A selectively fermented ingredient that allows specific changes, both in the composition |
| Pineiro et al.[15] | 2008 | A non-viable food component that confers a health benefit on the host associated with |
| Gibson et al.[16] | 2010 | Dietary prebiotics' as "a selectively fermented ingredient that results in specific changes |
| Bindels et al.[17] | 2015 | Non-digestible compound that, through its metabolization by microorganisms in the gu |
| Gibson et al.[18] | 2017 | A substrate that is selectively utilized by host microorganisms conferring a health bene |

**Table 3: Dietary fiber recommendations**

| Region/Country | Dietary fibre (g/day)-adults | Dietary fibre (g/day)-children |
|---|---|---|
| EU EFSA,[19 20] 2010 | 25g/day | 2g/MJ from 1 year |
| UK SACN, 2015[21] | 30g/day | 2-5 years: 15g/day 5-11 years: 20g/day 11-16 years: 25g/day |
| USA[22] IOM, 2020 | *Men* 19- 30: 34 g/day 50 years: 31g/day >50 years: 28g/day *Women* 19- 30: 28 g/day 31- 50 years: 25g/day >50 years: 22g/day | Male/Female: 2-3 years: 14 g/day Male: 4-8 years: 20 g/day 9-13 years: 25 g/day 14 – 18 years: 31 g/day Female: 4-8 years: 17 g/day 9-13 years: 22 g/day 14 – 18 years: 25 g/day |

**Table 4: Sample menu of how to meet recommended fiber intake**

| Meal | Foods |
|---|---|
| Breakfast Snack Lunch Evening meal | Muesli Dairy/non-dairy milk Strawberries Small handful of nuts 1 apple 1 slice who |

Figure 1. Fiber, fat and the microbiome

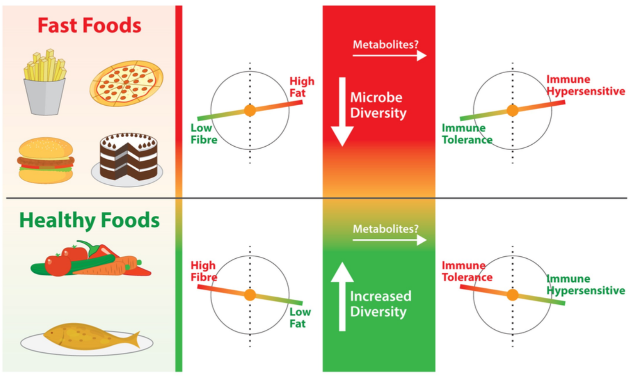

Figure 2. Fiber and microbial metabolites