Gut microbiota in obese women: effects of supplementation with green banana flour

Microbiota intestinal em mulheres obesas: efeitos da suplementação com farinha de banana verde

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ABSTRACT
The excess weight resulting from the imbalance in food consumption stimulates the abnormal expression and production of mediators (adipokines) involved in the genesis of insulin resistance, of which glucose intolerance, dyslipidemia, and arterial hypertension are examples, and may lead to an important number of metabolic diseases, as well as high health costs. The gut microbiota is fundamental because it plays a symbiotic role and ensures several metabolic functions essential in the treatment and control of obesity. An adequate diet rich in dietary fibers leads to a fermentation generating short chain fatty acids, a source of energy for epithelial cells. Moreover, this can be the mechanism by which the fiber exerts a positive impact on the gut epithelium. One of the food supplementation alternatives is green banana (Musa ssp.) flour, which is a functional food rich in vitamins, minerals, and fibers, with several physiological effects. Food patterns have significant effects on the composition of gut microbiota and metabolites produced by gut bacteria. Nutritional interventions may imply modifications in the composition and function of gut microbiota resulting in fast changes in the relative abundance of microbial phyla.

Keywords: microbiota, obese women, green banana flour.

RESUMO
O excesso de peso resultante do desequilíbrio no consumo de alimentos estimula a expressão anormal e a produção de mediadores (adipocinas) envolvidos na gênese da resistência à insulina, dos quais a intolerância à glicose, dislipidemia e hipertensão arterial são exemplos e podem levar a um número importante de doenças metabólicas, bem como a altos custos de saúde. A microbiota intestinal é fundamental porque desempenha um papel simbiótico e garante várias funções metabólicas essenciais no tratamento e controle da obesidade. Uma dieta adequada rica em fibras dietéticas leva a uma fermentação que

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gera ácidos graxos de cadeia curta, uma fonte de energia para as células epiteliais. Além disso, este pode ser o mecanismo pelo qual a fibra exerce um impacto positivo sobre o epitélio intestinal. Uma das alternativas alimentares é a farinha de banana verde (Musa ssp.), que é um alimento funcional rico em vitaminas, minerais e fibras, com vários efeitos fisiológicos. Os padrões alimentares têm efeitos significativos sobre a composição da microbiota intestinal e dos metabólitos produzidos pelas bactérias intestinais. Intervenções nutricionais podem implicar modificações na composição e função da microbiota intestinal, resultando em rápidas mudanças na abundância relativa da phyla microbiana.

Palavra-chave: microbiota, mulher obesa, farinha de banana verde.

1 INTRODUCTION

The gastrointestinal tract, especially the colon, is densely composed of bacteria, fungi, archaea, and viruses. To this biome is given the name gut microbiota and it is estimated that it has 100 trillion microorganisms, a number ten times higher than the amount of cells of the human body (Lopez-Lagarrea et al., 2014; Shen et al., 2013).

The gut microbiota is unique and can vary from individual to individual, part of it is genetically defined but factors such as birth, breastfeeding, diet, age, and use of antibiotics may interfere with its composition (Lang et al., 2014; Raymond et al., 2016).

Bacterial colonization has a fundamental role in health maintenance, in the protection against pathogens and modulation of the immune system, in the digestion of food, energy regulation, synthesis of vitamins, and production of short chain fatty acids (SCFA) (Aziz et al., 2013; Kaplan & Walker, 2011).

The composition and diversity of the gut microbiota are subject to important variations. Some studies confirm a direct correlation of the gut microbiota and tissue inflammatory process with a wide range of metabolic abnormalities (Arora & Bäckhed, 2016; Everard & Cani, 2013; Janssen & Kersten, 2015; Patterson et al., 2016). This microbial diversity may exert influence on food behavior and on the central nervous system, influencing the central regulation of appetite and satiation (Kotzampassi et al., 2014; Muccioli et al., 2010).

The gut microbiota is fundamental because it plays a symbiotic role, ensuring several metabolic functions that are essential in treating and controlling obesity, a world pandemic of diverse etiology and multiple comorbidities (Ng et al., 2013; Grundy, 2016; Haslam & James, 2005; Smith & Smith, 2016).

In overweight women, intestinal permeability and disturbance in the metabolism
have been observed to increase, with a rise of inflammatory markers and decreased insulin sensitivity (Moreno-Navarrete et al., 2012; Zak-Gołąb et al., 2013).

Few studies investigate the impact of diet on intestinal permeability in obese women, especially in well-nourished patients (with macro/micronutrients and energy adequacy) (Zak-Gołąb et al., 2013). The effect of the diet and its nutrients on intestinal permeability may have an important role in regulating energy for the epithelial cells of the intestine (Manary et al., 2010; Mokkala et al., 2016; Rao & Samak, 2012).

An adequate diet rich in dietary fibers leads to a fermentation generating SCFA, a source of energy for epithelial cells. Furthermore, this can be the mechanism by which the fiber exerts a positive impact on the gut epithelium (Russo et al., 2012).

One of the food supplementation alternatives is the consumption of green banana (biomass and/or flour), a functional food rich in vitamins, minerals, and fibers, with several beneficial physiological effects (increase of the fecal bolus and decrease of plasma levels of glucose and insulin) (Carmo, 2015).

The benefits of a healthy diet with adequate intake of vitamins and minerals improve intestinal permeability in adverse situations such as obesity in obese women, permeability which may be related to immunomodulatory and nutritional alterations (Manary et al., 2010; Mokkala et al., 2016; Raftery et al., 2015).

In this way, diets and eating patterns have significant effects on the composition of the gut microbiota and of the metabolites produced by intestinal bacteria. Nutritional interventions may imply modifications in the composition and function of gut microbiota resulting in fast changes in the relative abundance of microbial phyla (Kovatcheva-Datchary et al., 2015; Walker et al., 2011).

**NON-COMMUNICABLE CHRONIC DISEASES**

Non-communicable chronic diseases (NCD) are the main causes of mortality in Brazil and in the world. The diseases that most afflict the population are diseases of the circulatory system, cardiovascular diseases, malignant neoplasias, diabetes mellitus, and chronic respiratory diseases (Malta et al., 2017).

The Brazilian population's mortality profile has changed constantly due to the increase of deaths caused by NCD, a big public health problem (Rocha-Brischiliari et al., 2014). In 2018, the NCD were responsible for 54.7% of deaths and 11.5% of death by aggravation (Brasil, 2021).

The NCD are characterized by having a multifactorial etiology linked to the life
conditions of the person. The main risk factors leading the population to get sick arise from the excessive consumption of tobacco, excessive consumption of alcohol, non-healthy eating habits, and physical inactivity, conditions which can be changed from the behavioral point of view (Brasil, 2021).

The NCD, known as cardiometabolic diseases related to obesity, share environmental factors in their etiopathogenesis and physiopathological mechanisms (such as chronic subclinical inflammation and insulin resistance) (Calder et al., 2011).

Obesity is characterized by excessive fat accumulation that compromises the person's health because it associates with risk factors giving rise to cardiac diseases, arterial hypertension, hyperlipidemias, among other comorbidities (Kunen, 2016; Fogaça & Silva et al., 2019).

The excess weight resulting from the imbalance in food consumption stimulates the abnormal expression and production of mediators (adipokines) involved in the genesis of insulin resistance, such as glucose intolerance, dyslipidemia, and arterial hypertension. It may lead to a significant number of metabolic diseases, as well as to high health costs (Caricilli et al., 2011; Kotzampassi et al., 2014; Tehrani, 2012).

Obesity is a chronic inflammation state favoring cardiometabolic events. In this context, an interest in the role of the gut microbiota as an intermediary factor between environmental and behavioral components in treating obesity and metabolic disorders, is found (Tchernof & Després, 2013).

**OBESITY IN ADULT WOMEN**

Obesity is considered a public health problem, in that it is highly disabling and has a high rate of early mortality and body adiposity accumulation (Kadooka et al., 2010; Ley et al., 2005).

Metabolic alteration is closely related to the adoption of a modern lifestyle accompanied by the high consumption of food rich in energy and physical inactivity (Conterno et al., 2011; Kotzampassi et al., 2014).

The imbalance proposes ways of founding based on increasing evidence involving a combination of factors such as environment, genetics, diet, lifestyle, adipose tissue, and systemic inflammation (Kotzampassi et al., 2014; Moran & Shanahan, 2014; Guida & Venema, 2015).

The prevalence of obesity in Brazil's Central-West region was 13.3% for men and 16.3% for women (Instituto Brasileiro de Geografia e Estatística, 2011). In the research
of Monitoring of Risk Factors and Protection for Chronic Diseases by Telephone Survey of 2016, 13% of the world population were diagnosed with obesity (11%, males; 15%, females) (Brasil, 2017).

Although this is a disease of multifactorial and complex cause, among its determinants we stress food abundant in fats, sugars, and ultra-processed products associated with the lack of practice of physical activity. Furthermore, we should highlight that obesity is one of the food and nutritional insecurity manifestations (Dias et al., 2017).

According to the last research of Monitoring of Risk Factors and Protection for Chronic Diseases by Telephone Survey, of 2019, in the 27 participating Brazilian cities the frequency of obese adults was 20.3%, with no difference between men and women (Brasil, 2020). However, the frequency increased with age until 54 years in women. Furthermore, the research found an inversely proportional relationship between frequency of obesity and education.

In a study that analyzed the prevalence of overweight and obesity and associated factors in women in the municipality of São Leopoldo, RS (Brazil), the authors found that the highest rates of obesity were in women aged more than 50 years, widows, with low schooling, and who had three or more pregnancies (Lisowski et al., 2019). Thus, one notes that characteristic changes in the lifestyle of women as matrimony and maternity, for example, are factors that influence the nutritional state.

GUT MICROBIOTA

The gastrointestinal tract, especially the colon, is densely composed of bacteria, fungi, archaea, and viruses, a biome called gut microbiota. It is estimated that the microbiota contains 100 trillion microorganisms, a number ten times higher than the amount of cells of the human body (Lopez-Legarrea et al., 2014; Shen et al., 2013).

The gut microbiota is unique and can vary from individual to individual, part of it is genetically defined but factors such as birth, breastfeeding, diet, age, and use of antibiotics may interfere with its composition (Lang et al., 2014; Raymond et al., 2016).

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Intestinal permeability and disturbance have been observed to increase in the metabolism in women with excess weight, with increase of inflammatory markers and decrease of insulin sensitivity (Moreno-Navarrete et al., 2012; Zak-Gołąb et al., 2013).

Few studies investigate the impact of diet on intestinal permeability in obese women, especially in patients considered well-nourished (with macro/micronutrients and energy adequacy) (Zak-Gołąb et al., 2013).

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One of the likely hypotheses for such diversification in the food habit of species of the same family and/or genus is in the association of bacteria in the intestinal tract of animals, which shows a close relationship between the microbiota and host. This association, in the process of evolution, is considered common and essential for biological diversification (Brockhurst & Koskella, 2013).

It has long been known that the microbiota is closely related to health, growth stage, and evolution of diet in mammals, and has a crucial role in nutritional processes in the gut, complementing the digestive capacity of the host (Lee & Mazmanian, 2010; Savage, 1977; Turnbaugh & Gordon, 2009).

The gut microbiota composition consists of a complex community of archaic cells and 41,000 commensal bacterial species. The microbiota houses essential genes necessary for the metabolism in the ingestion of food (energy and homeostasis) (Qin et al., 2010).

The human intestine is colonized by a large population of 100 trillion microbial
cells organized into several taxa and constituting the gut microbiota. This microbiota is of approximately 1 kg and concentrates mainly in the large intestine, where about 1,012 bacteria are found per gram of colonic tissue (Chow et al., 2010; Guinane & Cotter, 2013).

**GUT MICROBIOTA IN OBESE ADULT WOMEN**

The gut microbiota impact on the metabolism is increasingly recognized (Sekirov et al., 2010). Dysbiosis interferes with the gut microbiota composition and has been associated with several diseases (Munukka et al., 2014).

Obesity and physical inactivity induce changes in the human gut microbiota composition (Allen et al., 2017). Studies reveal that the induction of inflammation is a characteristic of adult overweight women, while the gut microbiota induces, too, an inflammatory process (Clark & Mach, 2017), which is mediated by bacterial molecules that recognize Toll-like receptors (McKenzie et al., 2017).

Sedentarism in conjunction with the excess of body fat, interferes with the gut microbiota pattern differently when compared to sportswomen or active women’s, even with a diet rich in nutrients and fibers. Women with weight inside the normal range have a microbiota pattern different from sedentary women (Bressa et al., 2017).

**LIPOPOLYSACCHARIDES**

The dietary composition aids in modulating the gut microbiota. High-fat diets favor the translocation of lipopolysaccharides at a plasmatic level by means of intestinal capillaries through a mechanism involving Toll-like receptors. The lipopolysaccharides known as luminal antigens induce the production of numerous inflammatory cytokines (Cani, Neyrinck et al., 2007; Cani, Bibiloni et al., 2008; Caricilli et al., 2011; Moran & Shanahan, 2014; Neal et al., 2006; Zhang et al., 2010).

The intestinal permeability is affected by the increase in the uptake of lipopolysaccharides and induces immune response via the secretion of inflammatory mediators. This process is characterized by the high deposition of fat in the liver, increased absorption of fatty acids, accumulation of triglycerides in the adipocytes, and high circulating levels of interleukin-1, interleukin-6, plasminogen activator inhibitor-1, and tumor necrosis factor alpha in the blood (Cani, Bibiloni et al., 2008; Conterno et al., 2011).

The increase of body fat tends to raise the production of pro-inflammatory cytokines (such as tumor necrosis factor alpha, interleukin-6, interleukin-2, and gamma...
interferon) secreted both by adipocytes and by monocytes that infiltrate this tissue, altering the host's expression of genes and inducing a pathogenic state (Cani, Neyrinck et al., 2007; Vijay-Kumar et al., 2010). Other studies revealed increased plasmatic levels of lipopolysaccharides to be associated with the induction of hyperphagia and obesity (Dockray, 2013; La Serre et al., 2010).

Thus, high circulating concentrations of lipopolysaccharides associated with the ingestion of unbalanced diets interfere with the genesis of obesity and other pathologies. This is because diets rich in fat induce the high intestinal absorption of endotoxins and favor weight gain regardless of the excessive ingestion of calories. One of the alternatives would be a dietotherapeutic posture that balances the ingestion of nutrients according to the physiological need of each individual (Cani, Amar et al., 2007; Tsukumo, Carvalho Filho et al., 2007).

Other authors observed that the increase of intestinal alkaline phosphatase is associated with reduced translocation of lipopolysaccharides and reduction of plasmatic endotoxins. Inversely the reduction of this enzyme has been associated with obesity (Bates et al., 2007; Everard et al., 2012; La Serre et al., 2010).

Dysbiosis, so induced by obesogenic factors, damages substantially the intestinal permeability modulating the expression of zonula occludens-1 and occludin epithelial junction genes. This condition leads to the infiltration of bacterial lipopolysaccharides from the intestinal lumen into the intestinal epithelium, bloodstream, and the liver contributing to metabolic endotoxemia (Arslan, 2014; Cani, Lecourt et al., 2009; Cani, 2012; den Besten, Lange et al., 2013; Kelly et al., 2015).

As regards the abundance of some bacterial phyla present in the gut microbiota, there exists therefore an influence of the diets. In fact, the quantitative identification of bacteria using the 16S ribosomal RNA gene showed that obesity is associated with a notable decrease in the abundance of Bacteroidetes and Firmicutes by showing a 40:60 ratio in thin patients (Delzenne et al., 2011; Ley et al., 2005; Turnbaugh et al., 2006).

That said, the gut microbiota modulation may be by the diet, a simpler way, and physiological, via the promotion of beneficial changes as a therapeutic target in the case of inflammatory diseases.

**SHORT CHAIN FATTY ACIDS**

The gut microbiota plays a symbiotic role and holds several metabolic functions that are essential for the host. The intestine is capable of digesting dietary fibers due to
the synthesis of enzymes by the microbiota. Those enzymes are responsible for the metabolization of non-digestible polysaccharides to monosaccharides and SCFA, especially formic, acetic, propionic, butyric, isobutyric, valeric, isovaleric, and caproic acids (Bergman, 1990; Chow et al., 2010; Roberfroid et al., 2010).

The SCFA are organic acids with a composition of one to six carbons absorbed and metabolized by the intestinal cells. The foremost and most found are acetate, propionate, and butyrate, which make up 90% to 95% of all SCFA present in the colon. They can be used as an energy source by the intestinal cells themselves (40%), are absorbed, fulfilling a metabolic role in the peripheral tissues (60%), and aid in improving insulin sensitivity and reducing adiposity (Bouter et al., 2018; Gill et al., 2020; Miranda et al., 2019; Sowah et al., 2019).

Acetate is in greater abundance in the bloodstream. Only part of this metabolite is extracted in the liver, which increases the availability to fulfill functions in other organs. Moreover, the acetate can increase the synthesis of fatty acids through epigenetic mechanisms and regulate favorably arterial pressure because of the affinity with receptors involved in pressure control (Bloemen et al., 2009; González Hernández et al., 2019).

Propionate has a fast absorption by the hepatic circulation. Furthermore, it demonstrates a great capacity to connect to specific receptors and trigger varied functions, such as stimulating the liberation of gut hormones related in the appetite regulation and in the metabolism of glucose, as glucagon-like peptide-1 and peptide YY. An important effect that propionate develops is the synthesis of fatty acids and cholesterol, because of the \( H_2O \) reduction and its possible incorporation into the hepatocytes, which can explain the dietary fibers' hypocholesterolemic effect (Arora et al., 2011; Canfora et al., 2019).

Butyrate has a low concentration in the bloodstream. It can be produced through the phosphorylation of butyryl-CoA and by the transference of the CoA portion of butyryl-CoA to acetate by the butyryl-CoA:acetate-CoA transferase enzyme resulting in the production of butyrate and acetyl-CoA. Although it is found in reduced concentrations, it can play fundamental roles in cellular metabolism and in the generation of energy. Furthermore, this is the main SCFA used as energy source by enterocytes (Liu et al., 2018).

The increase of butyrate concentration is associated with the improvement of metabolic health. Butyrate administration in mice with insulin resistance and hepatic steatosis and inflammation revealed that the transaminases showed normal levels, as well as improvement in insulin resistance and glucose tolerance (Mattace Raso et al., 2013).
Thus, the intestinal bacteria produced by butyrate play an important role in regulating glycemia and lipid metabolism, as demonstrated by fecal transplant studies (Udayappan et al., 2014; Vrieze et al., 2012).

The varied composition of the gut microbiota producing SCFA may affect the genetic/epigenetic regulation in obesity (Remely et al., 2014). The SCFA absorption contributes to maintaining the acid/base balance (homeostasis) and promotes the absorption of Na+ (sodium). Furthermore, it contributes, significantly, to total caloric intake and the SCFA metabolized releases energy. The SCFA contribute approximately 5-10% to energy needs (Gupta et al., 2006; McNeil, 1984).

Studies have observed the altered formation of SCFA in mice with diets with low-fat content or high-fat content with fermentable dietary fibers, in that a high-fat diet reduced the formation of butyrate but increased succinate and cholesterol, and increased inflammation and hepatic fat, while the dietary fiber neutralized those effects (den Besten, Lange et al., 2013; Jakobsdottir et al., 2013; Kelly et al., 2015; Singh et al., 2015).

Research in animal models demonstrates that oral supplementation with some SCFA can aid in controlling body weight by way of some mechanisms. It was observed that treatment with SCFA reduced weight gain and adiposity. In mice receiving a high-fat diet and butyrate, results demonstrated that the animals developed adaptive thermogenesis with increased oxidation of fats. Both in the skeletal musculature and in the brown adipose tissue they identified an increase in the mitochondrial function (den Besten, Bleeker et al., 2015; Gao et al., 2009; De Vadder et al., 2014).

The oral acetate supplementation in mice with a high-fat diet without food intake reduction, generated a decrease in total body fat and hepatic lipid content. Conversely, the hepatic expression of proteins linked to thermogenesis increased (Gao et al., 2009; Kondo et al., 2009).

**DIET**

The gut microbiota is composed mostly of non-pathogenic and health-promoting bacteria and a minor part of potentially pathogenic bacteria (Moraes et al., 2014). The potential of the diet for microbiota is due to the epithelium that covers the intestine. It is well known that the intestinal epithelium absorbs metabolic compounds produced by intestinal bacteria from nutrients of the diet. In turn, the bacterial metabolism can reach the organic system by crossing the intestinal barrier. Therefore, those interactions affect the host’s metabolism and depend on food stimulation, leading to an increase in the risk...
of inflammation and metabolic diseases (Calças et al., 2017).

However, such imbalance may lead to negative consequences, including intestinal inflammation, allergies, infections, cancer, gastrointestinal disorders, and others (Robles Alonso & Guarner, 2013). Hence the importance of the diets as a determining factor in intestinal colonization, and in turn influenced by eating habits (Moraes et al., 2014).

One of the current challenges in the nutrition area is the elucidation of eating habits and/or supplementation as contributors to the modulation of gut microbiota (Shen et al., 2013). It is evidenced that eating habits associate with different cardiometabolic risk profiles. Currently, there is a great deal of evidence that the gut microbiota plays a relevant role in the diet and risk of diseases interaction (Kim et al., 2013; Koeth et al., 2013).

Studies have demonstrated that some types of dietary patterns can optimize symbiosis. In this way, the quality of the diet is responsible for 57% of the microbiota composition variation and 12% related to genetic factors, while diets rich in fruits, vegetables, legumes, and fibers have been considered cardioprotective (Sabaté & Wien, 2015; Wu et al., 2011; Zhang et al., 2010).

It is also suggested that food choices have direct effects on the microbiota, resulting in biochemical reactions in the intestinal lumen (Moraes et al., 2014). Studies also report that the gut microbiota can affect eating behavior, affecting appetite and satiety (Muccioli et al., 2010).

The gut microbiota affects the individuals’ nutritional state and is related to the inflammatory state of obesity, caused by the imbalance of the gut microbiome (Tsukumo, Carvalho et al., 2009).

In turn, the dysbiosis occasioned by excess weight impacts the gut microbiota, and despite strong evidence of the microbiota participation in the nutritional state, the implications for obesity control are not yet well clarified (Moraes et al., 2014).

GREEN BANANA FLOUR AS A DIETARY ALTERNATIVE

Dietary fiber has been widely studied because of its beneficial action on inflammatory diseases and is associated with the increase of longevity (Maslowski et al., 2009; Park et al., 2011; Thorburn et al., 2015).

Fibers cannot be digested without being fermented by the gut microbiota generating metabolites. Studies demonstrate that supplementation with prebiotics increases the amount of Bifidobacterium, which in turn are capable of improving glucose
tolerance and improving the inflammatory process by reducing lipopolysaccharides. Prebiotics are also capable of reducing intestinal permeability and the expression of pro-inflammatory cytokines (Delzenne et al., 2011; Tan et al., 2014).

The anti-inflammatory functions of fibers and their metabolites suggest that the microbiota DNA promotes the differentiation of T-cells, clearly indicating the interaction between microbiota and the host's immune system (Hall et al., 2008).

One of the food supplementation alternatives is the consumption of green banana (biomass and/or flour), a functional food rich in vitamins, minerals, and fibers, with several beneficial physiological effects (increase of the fecal bolus and decrease of plasma levels of glucose and insulin) (Carmo, 2015).

The benefits of a healthy diet with adequate intake of vitamins and minerals improve intestinal permeability in adverse situations such as obesity in obese women, permeability which may be related to immunomodulatory and nutritional alterations (Manary et al., 2010; Mokkala et al., 2016; Raftery et al., 2015).

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2 CONCLUSIONS

It is concluded that, with the population's change of lifestyle one still sees obesity as a severe public health problem, which affects mainly females. Obesity and inadequate gut microbiota affect negatively intestinal permeability by way of dysbiosis. Furthermore, these are considered important factors for metabolic health. The gut microbiota is unique genetically for each person.

Dysbiosis has an almost direct relationship with the high amount of circulating lipopolysaccharides, which is derived from bad eating habits, sedentarism, and genetic factors.

Among protective factors, the increase of butyrate is related to a better prognosis of metabolic improvement. Thus, a diet rich in nutrients such as fruits, vegetables, legumes, and fibers is in fact cardioprotective with a promising effect on gut health.
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Figure 1: Effects of green banana flour supplementation on gut health.
Table 1. Effects of green banana flour supplementation

<table>
<thead>
<tr>
<th>Physiological and metabolic</th>
<th>Effects population/treatment</th>
<th>Time/applied dose references</th>
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<tbody>
<tr>
<td>GBF</td>
<td>14 male rats with ulcer</td>
<td>Best et al., in <em>The anti-ulcerogenic activity of the unripe plantain banana</em> (Musa species) 1984</td>
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<tr>
<td>Anti-ulcerogenic activity</td>
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<td>GBP</td>
<td>121 male rats with an injury to the stomach</td>
<td>Dunjić et al., in <em>Green banana protection of gastric mucosa against experimentally induced injuries in rats. A multicomponent mechanism?</em> 1993</td>
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<tr>
<td>Protection of gastric mucosa against experimentally induced injuries in rats</td>
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<tr>
<td>GBP</td>
<td>62 boys (age 5-12 months) with persistent diarrhea</td>
<td>Rabbani, Teka, Zaman, et al., in <em>Clinical studies in persistent diarrhea: Dietary management with green banana or pectin in Bangladeshi children</em> 2001</td>
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<tr>
<td>Control of persistent diarrhea</td>
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<tr>
<td>GBF</td>
<td>10 ileostomized adults (50% males; age 28-70 years)</td>
<td>Langkilde et al., in <em>Effects of high-resistant-starch banana flour (RS(2)) on in vitro fermentation and the small-bowel excretion of energy, nutrients, and sterols: an ileostomy study</em> 2002</td>
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<tr>
<td>Knowledge of how resistant starch influences</td>
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<td>small-intestinal absorption of nutrients, sterol</td>
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<tr>
<td>metabolism, and colonic fermentation</td>
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<tr>
<td>GBP</td>
<td>57 boys (5-12 months) with persistent diarrhea (14 days)</td>
<td>Rabbani, Teka, Saha et al., in <em>Green banana and pectin improve small intestinal permeability and reduce fluid loss in Bangladeshi children with persistent diarrhea</em> 2004</td>
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<tr>
<td>Physiological and metabolic</td>
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<tr>
<td>GB</td>
<td>10 healthy adults (non-diabetic, 18-40 years)</td>
<td>Bahado-Singh et al., in <em>Food processing methods</em> (2006)</td>
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<tr>
<td>Knowledge of GB glycemic index. GB presented low glycemic index when boiled or fried</td>
<td>80 children of both genders with ages ranging from 1 to 28 months, with persistent diarrhea (14 days)</td>
<td>Alvarez-Acosta et al., in <em>Beneficial role of green plantain [Musa paradisiaca] in the management of persistent diarrhea: A prospective randomized trial</em> (2009)</td>
</tr>
<tr>
<td>GBP</td>
<td>30 patients with type 2 diabetes, obese, aged between 40 and 60 years</td>
<td>Ble-Castillo et al., in <em>Effects of native banana starch supplementation on body weight and insulin sensitivity in obese type 2 diabetics</em> (2010)</td>
</tr>
<tr>
<td>Reduction of body weight and increase of insulin sensitivity in obese type 2 diabetics</td>
<td>18 healthy adults aged 22-40 years</td>
<td>Menezes et al., in <em>In vitro colonic fermentation and glycemic response of different kinds of unripe banana flour</em> (2010)</td>
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<td>GBF</td>
<td>25 adult overweight women. Effects of the consumption of 20 g of GBF/day for 45 days</td>
<td>Silva, Santos, Girondoli et al., in Women with metabolic syndrome improve anthropometric and biochemical parameters with green banana flour consumption (2014)</td>
</tr>
<tr>
<td>Improvement of anthropometric and biochemical parameters</td>
<td>25 adult overweight women. In vivo overweight women consumed daily 20g of GBF for 45 days</td>
<td>Silva, Santos, Carraro et al., in Farinha de banana verde não altera perfil lipídico e inflamatório de mulheres com excesso de peso (2015)</td>
</tr>
<tr>
<td>GBF</td>
<td>42 diabetic and 6 non-diabetic rats. Blood glucose; relative liver weight; relative kidney weight; relative heart weight; relative pancreatic weight; AST, ALT, and alkaline phosphatase; serum amylase, lipase, total, and conjugated bilirubin; and chemical analysis of the test feed were determined using standard techniques</td>
<td>Eleazu &amp; Okafor, in Use of unripe plantain (Musa paradisiaca) in the management of diabetes and hepatic dysfunction in streptozotocin induced diabetes in rats (2015)</td>
</tr>
<tr>
<td>Promoted colonic fermentation and influenced glycemic control, improving insulin sensitivity in mice.</td>
<td>Wistar male rats were fed either a control diet, a UBM diet (5% resistant starch) or a UBS diet (10% resistant starch) for 28 days. In vivo (oral glucose tolerance test)</td>
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<td><strong>GBF</strong></td>
<td>and in vitro (cecum fecal fermentation, pancreatic islet insulin secretion) analyses were performed</td>
<td>Sardá et al., in <em>Impact of resistant starch from unripe banana flour on hunger, satiety, and glucose homeostasis</em> (2016)</td>
</tr>
<tr>
<td>Decreased hunger and increased satiety and glucose homeostasis</td>
<td>22 healthy adults (27.6 ± 5.1 years). In vivo experiment. Healthy volunteers consumed GBF, rich in resistant starch (5 g/8 g GBF), nondaily (3 times a week) for six weeks. The hunger and satiety parameters were evaluated by the visual analog scale and area under the curve of ghrelin and peptide YY hormones</td>
<td><em>in healthy volunteers</em> (2016)</td>
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<tr>
<td><strong>GBP</strong></td>
<td>60 rats with and without diabetes. In vivo study. Formulations containing 25, 50, and 75% of GBP were included in a 12-week diet of Wistar rats with type 1 DM. They evaluated preventing oxidative damage in kidneys and liver homogenates in rats were evaluated using the TBARS and DNPH assay fasting glycemia, fructosamine levels, renal function, liver function, and lipid profile in the serum of rats</td>
<td>Silva, Cerdeira et al., in <em>Green banana pasta diet prevents oxidative damage in liver and kidney and improves biochemical parameters in type 1 diabetic rats</em> (2016)</td>
</tr>
<tr>
<td><strong>GBF</strong></td>
<td>In vitro experiment analyzing soluble and insoluble</td>
<td>Arun et al., in <em>Dietary fibre and phenolic-rich extracts</em></td>
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<tr>
<td>Ameliorates type 2 diabetes and associated cardiovascular risks</td>
<td>dietary fiber, glucose, and cholesterol adsorption capacity. The ethyl acetate and methanol extracts were analyzed for phenolics content, antioxidant activities, antidiabetic, and cardiovascular protection efficacy</td>
<td>from <em>Musa paradisiaca</em> inflorescence ameliorates type 2 diabetes and associated cardiovascular risks (2017)</td>
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<tr>
<td>GBP</td>
<td>80 children and adolescents (5-15 years) with functional constipation. Randomized in vivo study with 80 children and adolescents with functional constipation divided into five groups: (1) GBB alone; (2) GBB plus PEG 3350 with electrolytes; (3) GBB plus sodium pyrosulfate; (4) PEG 3350 with electrolytes alone; and (5) sodium picosulfate alone.</td>
<td>Cassettari et al., in <em>Combinations of laxatives and green banana biomass on the treatment of functional constipation in children and adolescents: A randomized study</em> (2019)</td>
</tr>
<tr>
<td>GBF</td>
<td>30 obese rats (5 weeks old). Group (1) diet H; group (2) HF + banana flour; group (3) HF + MX</td>
<td>Alvarado-Jasso et al., in <em>Prebiotic effects of a mixture of agavins and green banana flour in a mouse model of obesity</em> (2020)</td>
</tr>
</tbody>
</table>

**Note:** GB - green banana product; GBF - green banana flour; GBP - green banana pulp; GBB - green banana biomass; AST - aspartate aminotransferase; ALT - alanine aminotransferase; DM - diabetes mellitus; DNPH - dinitrophenylhydrazine; HF - high fat content; H - high; MX - boot mix; PEG - banana subtype; TBARS - thiobarbituric acid; UBS - green banana starch; UBM - green banana biomass.