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The Influence of Food Variety and Quality on the Anatomical and Physiological Status of the Digestive System Organs

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Abstract: This study focuses on the influence of food variety and quality on the anatomical and physiological status of the human gastrointestinal system (GIS). Emphasizing the interconnection of nutrition and medical research, the study shows how different food types influence the digestive process, particularly concerning the secretion of gastrointestinal juices and digestive enzymes, the functional and mechanical response of the gastrointestinal organs such as the oral cavity, stomach, small intestine, and colon, and entirety of the gut. This research contributes to the understanding of the relationship between food composition and digestive organs structure and physiology. An "Gut on a chip" model is designed to recreate the gastrointestinal environment under controlled laboratory conditions, allowing for the analysis of mechanical and biochemical breakdown of food ingested, without the need for *in vivo* trials (Valei et al., 2023). This model also allows for the observation of food substrate disintegration and quantification of secretions from various gastrointestinal organs. Through comparative evaluation of dietary components—including dietary fiber, roughage, macronutrients, and bioactive compounds—the study sheds light on their role in mastication, enzymatic hydrolysis, nutrient absorption, and microbiome balance (Conlon & Birth, 2014; Lattimer & Haub, 2010). Additionally, also examines how food quality influences the functional integrity and efficiency of digestive organs, including the role of dentition in the initial phase of digestion. The objective is to identify which food varieties best support gastrointestinal function and mucosal health, thereby informing evidence-based dietary recommendations.

Keywords: Food quality, Gastrointestinal system, Physiology of digestion, "Gut on chip" model.

Introduction

In recent years, modern medical understanding of nutrition has largely emphasized not just the quantity of food intake, but the importance of food variety and quality in maintaining digestive system health. The gastrointestinal (GI) tract is a highly complex organ system, primarily responsible for food's mechanical and chemical breakdown into its absorbable components. These components are important not only for providing nutrition to the body but also for supporting the immune system, maintaining metabolic balance, and keeping the gut microbiome healthy. A balanced gut environment is important for overall health, with disruptions often linked with the onset of various systemic diseases.

Processing methods such as juicing, cooking, and food preservation significantly alter the physical and chemical properties of foods (Palermo et al., 2014). These modifications can influence nutrient bioavailability, digestive mechanisms, and even the physiological state of digestive organs over time. Therefore, to appreciate how different food forms affect the GI system, it is first crucial to understand the fundamental methodology by which digestion occurs. The digestive process involves two main interrelated mechanisms: mechanical and enzymatic digestion.

Mechanical digestion begins in the oral cavity with mastication and continues through the stomach's churning process, by breaking down large food particles into smaller components. Simultaneously, enzymatic digestion plays a pivotal role, wherein specific digestive enzymes chemically dissociate macronutrients into their fundamental absorbable units—monosaccharides, amino acids, and fatty acids—which can then enter the bloodstream to support physiological functions (Particia & Dhamoon, 2025). Additionally, hormonal regulation and the involvement of accessory digestive organs such as the pancreas, liver, and gallbladder further contribute to the complexity of this system.

The form in which food is consumed significantly impacts these digestive processes. For instance, whole fruits are rich in dietary fiber, which promotes slow glucose absorption, regulates insulin response, and nurtures a diverse and healthy gut microbiome. On the other hand, fruit juices, although often thought of as nutritious, lack fiber and contain high concentrations of free sugars, leading to rapid glucose spikes just after ingestion.

Similarly, the preparation of vegetables plays a vital role in nutritional value. Raw vegetables are abundant in heat-sensitive vitamins and bioactive phytochemicals; however, cooking methods such as boiling or frying can degrade these micronutrients, lessening their bioavailability and potentially risking gut health by altering intestinal function and microbiome composition. In the case of protein sources, fresh meat and fish provide high-quality proteins and essential micronutrients that support digestive efficiency and metabolic homeostasis. However, processed meats, such as sausages, often contain additives such as sodium and nitrates, which have been associated with increased risk of gastrointestinal diseases and disruptions in enzymatic activity and microbial homeostasis.

To explore how different food varieties influence GI physiology at a cellular and molecular level, advancements in technology have provided specific laboratory tools, among which the "Gut-on-a-chip" model stands out. This innovative model replicates the three-dimensional architecture of the human intestine, simulates peristaltic motion, and maintains an oxygen gradient, thereby providing an environment closely resembling in vivo conditions. The model is constructed using live human intestinal cells, often integrated with endothelial cells within microfluidic channels, and uniquely supports the co-culture of human cells with gut microbiota. This co-culture capability allows for the investigation of host-microbe interactions, a crucial aspect of digestive health research (Particia & Dhamoon, 2025).

Understanding the significance of host-microbe interactions is essential, as recent research highlights that each individual's gut microbiome constitutes a highly personalized ecosystem of trillions of microorganisms. These microbes can metabolize the same dietary components differently across individuals, leading to variable health outcomes. Such findings underscore the need for personalized nutrition strategies to optimize digestive and systemic health.

Method

This paper aims to integrate knowledge from nutritional biochemistry, gastrointestinal physiology, and technological models to provide a comprehensive understanding of how dietary patterns influence anatomical structure, physiological processes, and long-term digestive health outcomes.

Main Body

Fiber-Power vs Sugar Shock: Gastrointestinal Processing of Whole Fruit Versus Fruit Juice

Oral Phase: Mechanical and Chemical Initiation

Upon ingestion, both fruit juice and whole fruits undergo initial mechanical and chemical processing in the oral cavity, though via different mechanisms:

Fruit Juice

The ingestion of fruit juice requires minimal mechanical processing. The liquid immediately contacts the oral mucosa, stimulating salivary secretion (pH 6.7–7.0).

Saliva lubricates the bolus for swallowing and contains **α-amylase**, which initiates minor carbohydrate digestion. Since fruit juice predominantly consists of free monosaccharides (glucose, fructose) and disaccharides (sucrose), enzymatic action at this stage is limited.

Whole Fruit

Consumption of whole fruits necessitates **mastication**, a coordinated process involving:

- The **maxilla** (upper jaw), which serves as a stationary platform (BD Chaurasia, 2025).
- The **mandible** (lower jaw), which performs dynamic movements essential for grinding and tearing food (BD Chaurasia, 2025).

These movements are driven by the masticatory muscles, operating under both voluntary and reflexive control. Mechanical breakdown during mastication reduces fruit particle size, increases the surface area for enzymatic action, and mixes the food thoroughly with saliva. This chewing action not only facilitates safe swallowing but also enhances enzymatic access to the nutrients (Guyton & Hall, 2020). Additionally, **taste receptors** on the tongue detect chemical stimuli (sweet, sour, bitter, salty), initiating the **cephalic phase** of digestion via vagal nerve activation, leading to gastric acid and enzyme secretion in preparation for downstream digestive processes (Guyton & Hall, 2020).

Esophageal Phase: Bolus Transit

Following oral processing, both the chewed fruit bolus and the swallowed juice are transported through the esophagus via coordinated **peristaltic contractions**. No significant digestion occurs during esophageal transit; the primary function of this phase is to propel the ingested material into the stomach (Guyton & Hall, 2020).

Gastric Phase: Chemical Processing and Gastric Emptying

Upon entry into the stomach, distinct physiological differences arise between the digestion of fruit juice and whole fruit:

- *Acid Secretion:* Gastric glands secrete hydrochloric acid, reducing the intragastric pH to between 1.5 and 3.0, aiding in food sterilization and protein denaturation.

- *Pepsin Activity:*
  - In the case of fruit juice, the minimal protein content results in negligible activation of pepsinogen to pepsin.
  - In whole fruit ingestion, although fruits are not rich in proteins, stomach wall distension and neurohormonal signals promote modest pepsinogen activation, contributing slightly to proteolysis (Conlon & Bird, 2014).

- *Gastric Lipase:* This enzyme is released in response to lipid presence; however, given the low-fat content of fruits, gastric lipase plays a minimal role in both scenarios (Kuzma et al.,2017).

- *Fiber Influence:*
  - Whole fruits contain soluble fibers such as **pectin**, which hydrate and form a viscous gel, significantly slowing gastric emptying, moderating nutrient release, and promoting prolonged satiety (Dreher, 2018), (Slavin & Lloyd, 2012).
  - Fruit juice, lacking fiber, leads to rapid gastric emptying and a swift release of sugars into the small intestine.

Small Intestine: Enzymatic Digestion and Absorption Dynamics

As the chyme (processed bolus) enters the **duodenum**, several digestive processes are triggered:

- *Pancreatic Secretions:* Bicarbonate is secreted to neutralize gastric acid, adjusting the pH to between 7.0 and 8.0, thereby optimizing conditions for enzymatic activity. Pancreatic enzymes, including amylase, proteases, and lipase, continue macronutrient digestion (Guyton & Hall, 2020).

- *Brush Border Enzymes:* Sucrase, maltase, and lactase at the intestinal brush border complete the breakdown of carbohydrates into monosaccharides.

- *Sugar Absorption:*
  - In fruit juice ingestion, free glucose and fructose are rapidly available for absorption.
  - Glucose is absorbed via the **SGLT-1** (sodium-glucose co-transporter) and **SGLT-2**, while fructose is absorbed through **GLUT5** by facilitated diffusion.
  - In whole fruit ingestion, the presence of intact fiber slows the enzymatic accessibility to sugars, prolonging digestion time and promoting a more gradual absorption curve (Kuzma et al., 2017).

- *Micronutrients Absorption:*
  - Vitamins such as **vitamin C**, **folate**, **potassium**, and various bioactive phytochemicals are absorbed in both cases.
  - However, the slower digestion of whole fruits enhances micronutrient bioavailability and attenuates the post-ingestion glycemic burden.

- *Fiber's Role:*
  - Soluble fibers continue to slow carbohydrate absorption, stabilize blood glucose levels, and prolong nutrient contact with the absorptive surfaces of the intestinal lining.

Hepatic Processing: Metabolic Consequences

Following absorption in the small intestine:

- **Glucose** enters the hepatic portal circulation, where it may be immediately used for energy, stored as **glycogen**, or converted into lipids via **de novo lipogenesis** when in excess (Dreher, 2018).

- **Fructose** is primarily processed in the liver. A rapid influx of fructose from fruit juice can overwhelm hepatic metabolic capacity, promoting **increased triglyceride synthesis**, **hepatic steatosis**, and **insulin resistance** over time.

- *Glycemic Impact:*
  - Fruit juice consumption leads to a more rapid systemic appearance of sugars, resulting in a greater glycemic spike.
  - In contrast, whole fruits, through fiber-mediated delayed absorption, promote a moderated glycemic response (Dreher, 2018).

Hormonal Responses and Appetite Regulation

- *Insulin Response:*
  - Rapid glucose absorption following fruit juice ingestion stimulates a stronger and faster insulin response compared to whole fruit consumption.
  - Chronically elevated insulin responses are associated with an increased risk of developing **insulin resistance** and **metabolic syndrome** (Niu et al., 2025).
  - *Leptin and Ghrelin Regulation:*
  - Whole fruits, rich in fiber, enhance **leptin** signaling (promoting satiety) and suppress **ghrelin** (stimulating hunger).
  - Fruit juices, lacking significant fiber content, fail to adequately stimulate satiety responses, thereby increasing the risk of overconsumption and subsequent metabolic dysregulation (Guyton & Hall, 2020).

Large Intestine: Microbiota and Fermentation

- *Whole Fruits:*
  - Undigested dietary fibers reach the colon and are fermented by the gut microbiota, producing **short-chain fatty acids** (SCFAs) such as **butyrate**, **acetate**, and **propionate** (Facchin et al., 2024)

- SCFAs support **gut barrier integrity**, **reduce inflammation**, and serve as an energy source for colonocytes (Facchin et al., 2024).
- Regular intake of whole fruits promotes the proliferation of beneficial bacterial genera such as *Bacteroides* and *Parabacteroides*, thereby enhancing **microbial diversity** and overall **gut health** (Facchin et al., 2024).

- *Fruit Juices:*
- The minimal fiber content of fruit juice limits the availability of fermentable substrates, thereby reducing SCFA production and diminishing the positive modulation of the gut microbiome (Dreher, 2018; Facchin et al., 2024).

Gastrointestinal Processing of Raw Versus Cooked (Boiled/Fried) Vegetables

Oral Phase

- *Raw Vegetables:*

Due to rigid cell walls and high insoluble fiber, raw vegetables require extensive mastication. This increases salivary secretion and alpha-amylase activity, initiating carbohydrate digestion. More chewing promotes satiety and slows the eating process (Guiton & Hall, 2020)

- *Boiled Vegetables:*

Softened cell walls reduce mastication needs, resulting in lower salivary stimulation and decreased alpha-amylase activation.

- *Fried Vegetables:*

Crispy texture demands moderate mastication, enhancing salivary production. However, the higher fat content delays lipid digestion initiation, as salivary glands lack lipase activity.

Esophageal Phase

- In both raw and cooked forms, bolus transit through the esophagus is mediated by coordinated peristaltic contractions, without significant digestion occurring.

Gastric Phase

- *Raw Vegetables:*

Bulky fiber content slows gastric emptying and prolongs gastric digestion. Increased fiber volume triggers stomach stretch receptors, enhancing satiety. Higher hydrochloric acid secretion denatures vegetable proteins, activating pepsin for proteolysis. Fiber delays gastric emptying, stabilizing postprandial blood glucose levels. Heat-sensitive nutrients like vitamin C and folate are preserved (Lattimer & Haub, 2010).

- *Boiled Vegetables:*

Soft texture leads to faster gastric emptying. Moderate gastric acid and pepsin activity facilitate digestion of softened proteins and starches.

- *Fried Vegetables:*

High fat content significantly slows gastric emptying (up to 3–4 hours), triggering prolonged hydrochloric acid secretion for fat emulsification. Higher energy density may lead to bloating and delayed satiety signals.

Small Intestinal Phase

- *Raw Vegetables:*

High fiber content physically binds digestive enzymes, reducing their access to macronutrients and lowering nutrient absorption efficiency. Pancreatic enzyme activity (amylase, lipase, protease) is less effective. Minimal bile is required unless raw vegetables are consumed with additional fats. Water-soluble vitamins (C and B-complex) remain intact due to absence of heat exposure (Lattimer & Haub, 2010).

- *Boiled Vegetables:*

Gelatinized starch enhances amylase efficiency, leading to rapid glucose release and absorption. Minimal bile secretion is sufficient due to low fat content (Lee et al., 2017).

- *Fried Vegetables:*

Added fats require substantial bile secretion to emulsify lipids, activating pancreatic lipase. Presence of fat improves absorption of fat-soluble vitamins (A, D, E, K) (Hundt, 2025).

Nutrient Bioavailability

- *Raw Vegetables:*

Retain heat-sensitive vitamins (C and B group) and phytochemicals. However, intact cell walls limit immediate bioavailability of some antioxidants and micronutrients (Kowalska et al., 2021).

- *Boiled Vegetables:*

Cell wall softening releases bound antioxidants, improving their absorption despite loss of some water-soluble vitamins during cooking (Toydemir et al., 2022).

- *Fried Vegetables:*

Fat-rich medium enhances bioavailability of fat-soluble vitamins results in partial degradation of water-soluble vitamins (National Research Council, 1989).

Large Intestine Phase

- *Raw Vegetables:*

Insoluble fibers reach the colon, where gut microbiota ferment them to produce short-chain fatty acids (SCFAs) like butyrate and propionate. SCFAs support gut barrier integrity, modulate inflammation, and promote immune function (Facchin at al., 2024).

- *Boiled Vegetables:*

Retain some fermentable fibers, but depending on cooking method, fiber content may be reduced, moderately impacting SCFA production (Facchin et al., 2024).

- *Fried Vegetables:*

Reduced fiber content after frying limits microbial fermentation and SCFA production, weakening microbiome diversity support (Colon & Birth, 2014; Facchin et al., 2024).

Conclusion and Recommendations

This study highlights that the functioning of the gastrointestinal system is closely linked to the types of food we consume. Advances in nutritional science and technology—such as the gut-on-a-chip model (National Research Counsil (US) on Diet and Health, 1989) have significantly deepened our understanding of digestion and nutrient bioavailability. However, emerging research underscores a crucial factor: the gut microbiota. Each individual hosts a unique ecosystem of trillions of microbes that can metabolize the same food components in remarkably different ways. As a result, metabolic and immune responses to dietary interventions—such as consuming whole fruits versus fruit juice, or raw versus cooked vegetables—can vary greatly between individuals. To the best of our knowledge, most existing research using the gut-on-a-chip model has focused on understanding the physiology of specific organs and their functions under controlled conditions. However, this paper presents a broader perspective, suggesting that the model holds significant potential for application in the field of nutrition. By simulating the dynamic environment of the human gut, the gut-on-a-chip can offer deeper insights into how nutrients are digested, absorbed, and metabolized. It also allows researchers to observe how different dietary components interact with gut microbiota in real time. This could pave the way for more precise, personalized nutritional strategies and a better understanding of diet-related diseases. This reinforces the need for personalized nutrition approaches, where dietary recommendations are tailored to the specific composition and function of an individual's gut microbiome (Conlon & Birth,2014).

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPHELS journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest.

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