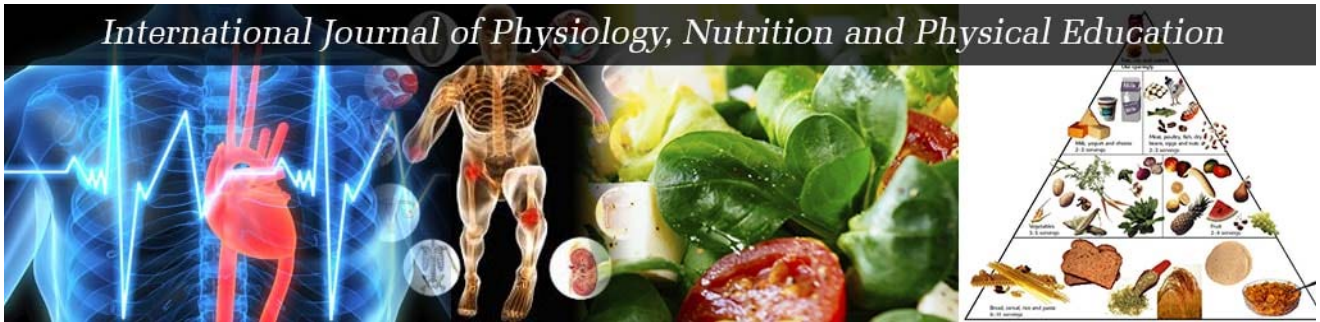

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Digestion and metabolism of carbohydrates

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Abstract
Carbohydrates are the single most abundant and economic sources of food energy in the human diet, constituting 40–80% of total energy intake in different populations. Carbohydrates are classified according to their degree of poly-merization into sugars, oligosaccharides, and polysaccharides – the last consisting of starches with different degrees of resistance to digestion – and dietary fibers or nonstarch polysaccharides. Glycemic carbohydrates are digested (hydrolyzed by enzymes) to sugars (monosaccharides) in the small bowel and absorbed and metabolized.
Nonglycemic carbohydrates are fermented in varying degrees to short-chain fatty acids (SCFAs), carbon dioxide, hydrogen, and methane in the large bowel. Absorbed SCFAs are metabolized in colonic epithelial, hepatic, and muscle cells. For optimum function of the nervous system and other cells, blood glucose concentrations are tightly controlled by a group of hormones (insulin in the absorptive phase; glucagon, epine-phrine, and cortisol in the postabsorptive phase), utilizing several possible metabolic pathways for glucose anabolism and catabolism. Intakes of optimum amounts of different types of carbohydrates are associated with good health through effects on energy balance, digestive functions, blood glucose control, and other risk factors for several chronic diseases

Keywords: Metabolism, digestion, nutrition

Introduction
Carbohydrates in foods, Carbohydrates are one of the four major classes of biomolecules and play several important roles in all life forms, including: sources of metabolic fuels and energy stores structural components of cell walls in plants and of the exoskeleton of arthropods parts of RNA and DNA in which ribose and deoxyribose, respectively, are linked by N-glycosidic bonds to purine and pyrimidine bases integral features of many proteins and lipids (glycoproteins and glycolipids), especially in cell membranes where they are essential for cell-cell recognition and molecular targeting. Carbohydrates are very diverse molecules that can be classified by their molecular size (degree of poly-merization or DP) into sugars (DP 1-2), oligosac-charides (DP 3-9), and polysaccharides The physicochemical properties of carbohydrates and their fates within the body are also influenced by their monosaccharide composition and the type of linkage between sugar residues. Examples of food carbohy-drates and an overview of their digestive fates are given in. From birth, carbohydrate provides a large part of the energy in human diets, with approximately 40% of the energy in mature breast milk being supplied as lactose. After weaning, carbohydrates are the largest source (40-80%) of the energy in many human diets, with most of this derived from plant material except when milk or milk products containing lactose are consumed.

Nonglycemic carbohydrates
Carbohydrates that are not absorbed in the small intestine enter the large bowel, where they are par-tially or completely broken down by bacteria in the colon by a process called fermentation. McCance and Lawrence in 1929 were the first to classify carbohy-drates as “available” and “unavailable.” They realized that not all carbohydrates provide “carbohydrates for metabolism” to the body. They called these carbohy-drates “unavailable.” This was a very useful concept because it drew attention to the fact that some carbo-hydrate is not digested and absorbed in the small intestine, but rather reaches the large bowel where it is fermented. However, it is now realized that it is misleading to talk of carbohydrate as unavailable because some indigestible carbohydrate can provide the body with energy through fermentation in the

colon. Thus, "unavailable carbohydrates" are not really unavailable. For this reason, it has been suggested by the Food and Agriculture Organization (FAO 1998) of the United Nations and World Health Organization that the term "nonglycemic carbohy-drates" is more appropriate.

Nature of carbohydrates that enter the colon

Carbohydrates that enter the colon can be classified either physiologically or chemically. Neither of these classifications is entirely satisfactory because it is difficult to measure the physiologically indigestible car-bohydrate and this varies in different people. Further, the chemical structure of carbohydrates does not always predict their physiological behavior.

A simulated digestion technique was used to investigate the characteristics of starch hydrolysis in uncooked, cooked and extrusion-cooked oat products *in vitro*. The rate and extent of starch hydrolysis were both significantly lower in uncooked rolled oats than in the same material after brief boiling or extrusion cooking. A similar degree of maldigestion *in vivo* would lead to as much as an estimated 68% of oat starch entering the colon. Breath-hydrogen measurements were used to compare the fermentable carbohydrate content of uncooked and briefly boiled rolled oats in human volunteers and to estimate the relative contributions of soluble dietary fiber and undigested starch to the fermented component. Isolated oat gum (beta-glucan) was readily fermented *in vivo* and was apparently the main fermentable component of cooked rolled oats. Uncooked rolled oats gave a higher excess hydrogen production than cooked oats, but the results were variable and the differences not statistically significant. In an additional experiment, lactulose was used as a fermentable reference material to calculate the apparent fermentable carbohydrate content of rolled oats and oat gum. Uncooked rolled oats were estimated to contain a statistically significant quantity of undigested starch, amounting at most to 1.01 +/- 0.40 g (mean +/- SEM) of undigested starch per 50 g of fresh weight. We concluded that starch hydrolysis in oats is limited to some extent by the physical state of the food matrix, but this effect may be greatly overestimated by simulated digestion procedures *in vitro*

Physiological classification of carbohydrates entering the colon

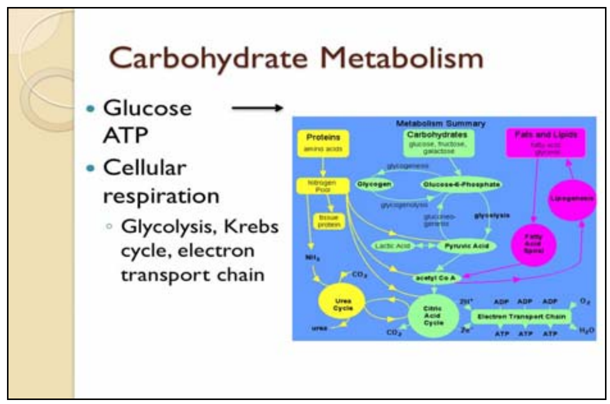
Carbohydrates enter the colon because (1) monosac-charide transporters do not exist in the intestinal mucosa or do not function at a high enough rate; (2) the enzymes needed to digest the carbohydrates are not present in the small intestine; (3) the enzymes are present but cannot gain access to the carbohydrates; or (4) the enzymes do not digest the carbohydrates rapidly enough for them to be completely absorbed. In addition, a small amount of carbohydrate entering the colon consists of carbohydrate residues occurring on mucopolysaccharides (mucus) secreted by the small and large intestinal mucosal cells.

Some carbohydrates are always nonglycemic because the human species lacks the enzymes necessary for their digestion. However, a significant pro-portion (perhaps up to half) of all carbohydrates that escape digestion in the small intestine have a chemical structure which is such that they could potentially be digested or absorbed in the small intestine, but they are variably absorbed for various reasons, examples of which are given below.

First, some monosaccharide's and sugar alcohols are only partially absorbed because of low affinity for intestinal transporters. Xylose is taken up by the glucose transporter, but is only partly absorbed because of a low affinity. Fructose is poorly absorbed on its own, but readily absorbed in the presence of glucose. The surface area of the small intestine avail-able for absorption is reduced by diseases that cause atrophy of the intestinal mucosa, such as tropical sprue or celiac disease, or surgical resection of a portion of the intestine (e.g., for Crohn's disease). An increased rate of intestinal transit (e.g., high osmotic load in the small intestinal lumen from undigested sugars) reduces the time available for absorption to occur.

Second, some individuals have a low or absent intestinal lactase activity; thus, lactose is partly or completely nonabsorbed in these individuals. The availability of pancreatic amylase may be reduced in cystic fibrosis or in individuals whose pancreatic mass has been destroyed by, for example, recurrent pancreatitis.

Third, although starch (amylopectin or amylose) is potentially digested in the small intestine, if it is trapped inside intact cell walls or other plant cell structures, intestinal enzymes may not be able to gain access to it, and therefore it remains undigested. The digestibility of the carbohydrates in banana depends on the degree of ripeness. The starch in green banana is very indigestible, but, as the banana ripens, the starch is converted to digestible sugars.



Conclusion

The Finally, there are many reasons why carbohydrates may not be digested rapidly enough to be completely absorbed. Some forms of retrograded or resistant starch, or foods with a large particle size, are digested so slowly that the time spent in the small intestine is not long enough for their complete digestion. Digestion of these carbohydrates can be altered by factors that affect transit time. The presence of osmotic ally active and unabsorbed molecules (such as unabsorbed sugars) will draw water into the intestine and speed the rate of transit. Substances that increase bulk, such as wheat bran, will have similar effects. Transit rate is slowed in old age and in the presence of viscous fibers. Drugs may increase or decrease the rate of transit. Certain disorders can also affect transit time, such as gastro paresis, a complication of type I diabetes.

The carbohydrate structure and amounts in many foods and ingredients can be manipulated to achieve specific physicochemical properties of benefit for food structure and organoleptic effects and to produce a diverse range of physiological effects. It can be expected that many functional foods of the future will contain such specially selected or modified carbohydrates, but the metabolic and health consequences of these carbohydrates should be examined in more detail before health claims can be justified.

Future research on carbohydrate nutrition should also focus on the physiological and biochemical (metabolic) effects of the SCFAs produced from nonglycemic carbohydrates.

To provide a sound evidence base for recommendations for intakes of specific carbohydrates, the relationships between intakes of different types and quantities of carbohydrate with health and disease, for example during transition of traditional people and consequent lowering of intakes, should be a fruitful area for research.

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