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Investigation of Nutritional and Functional Properties of Resistant Starch in Food Industry: A Review

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***Abstract* - Dietary starches are important sources of energy for many human societies and it is clear that they can also make quite specific contributions to health. Resistant starch (RS) is recently recognized source of fiber and is classified as a fiber component with partial or complete fermentation in the colon, producing various beneficial effects on health. RS also offers an exciting new potential as a food ingredient. Resistant starch (RS) refers to the portion of starch and starch products that resist digestion as they pass through the gastrointestinal tract. The potential physiological benefits of resistant starch, along with its functional properties, provide a means to increase total dietary fiber in the diet through popular foods. Apart from the potential health benefits of resistant starch, another positive advantage is its lower impact on the sensory properties of food compared with traditional sources of fiber, as whole grains, fruits or bran. By formulating foods with resistant starch, product developers and nutritionists can encourage consumers to increase their fiber intake with a variety of palatable, high quality foods that are healthy as well. In this review, we discuss about resistant starch from both its potential health benefits and functional properties in food industry. This research will create a market potential for a range of new health based food to maintain optimal human health.**

***Keywords*- Functionality, healthy, resistant starch, food industry**

I. INTRODUCTION

The increase in consumer demand for high quality food products have led to a growth in the use of new technologies and ingredients. Several factors influence changes in consumer demand, including: health concerns (cholesterol, cancer, obesity, etc.),changes in demographic characteristics (ethnics, population ageing, etc.) [1], the need for convenience, changes in distribution systems and price. As a result of these changes, interest in new products, particularly convenience oriented products prepared using new technologies [2-3], high pressures, etc., has dramatically increased in recent years. The food industry offers quality and convenience to a wide spectrum of consumers including single households, working couples, the ageing population, and others [4, 5]. To develop these types of products, one must evaluate consumer perceptions, the most important quality aspects being that they taste good, appear healthy and have nutritional value [6]. Also Pérez-Alvarez (2008) describe that any functional food must be safety, healthy and tasty [4].

Recently, eating habits have been changed in the developed countries. Instead of the consumption of the traditional, natural foods, the refined foods that are easy to be digested and contain high calories are consumed every day. Besides the sedimentary lifestyle, the changes of the eating habits led to the spread of obesity worldwide. Obesity puts people at risk for hypertension, dyslipidemia, diabetes mellitus type 2, heart disease, and many other chronic disorders.

Diet rich in dietary fiber is considered to be generally low in saturated fat and have several other health benefits; therefore, many national authorities have long recommended greater consumption of grain and fiber-rich products to control weight. The consumption of dietary fibers seems to be a promising solution according to their definition (AACC report): Dietary fibers are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fibers promote beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation.

Dietary fiber (DF) can be defined from different points of views, including legal, technological, chemical, nutritional and functional. Hipsley defined fiber in 1953 [7] but, dietary fiber is not an entity, but a collective term for a complex mixture of substances with different chemical and physical properties, which exert different types of physiological effects. Dietary fiber was first defined as non-digestible components of plants that make up the plant cell wall: cellulose, hemicelluloses (both non-starch polysaccharides) and lignin. The Commission of The European Communities (2008) defines 'fiber' as carbohydrate polymers with three or more monomeric units, which are neither digested nor absorbed in the small intestine.[8]

In a report of a Joint FAO/WHO Expert Consultation, resistant starch is defined as dietary fiber as well Resistant starch that escapes digestion in the human small intestine appears to have a unique combination of physiological and functional properties compared to traditional types of fiber. Namely, the consumption of high amount of resistant starches may improve glucose and lipid metabolism, can reduce the risk of diabetes mellitus type 2, coronary, and heart diseases as well as colorectal cancer and other gastrointestinal disorders. Additionally, commercial resistant starches have desirable physicochemical properties making it useful in a variety of foods. Moreover, resistant starches do not influence the sensory properties of starch-based products (bread, pasta, cookies, pudding, yoghurt etc.) significantly.

The demand for the application of resistant starch as a functional ingredient is growing, thus, the analysis of its structural, thermal, rheological, and digestibility properties have great importance. Moreover, the understanding of the relationship between structural characteristics and functional as well as nutritional properties of resistant starches can help food producers in optimizing industrial applications.

The aim of this paper is to review selected topics related to resistant starch and examine all aspects from both its potential health benefits (similar to soluble fiber) and functional properties.

II. GENERALLY ABOUT THE STARCH MOLECULE

Starch is the dominant carbohydrate reserve material of higher plants, being found in leaf chloroplasts and in the amyloplasts of storage organs such as seeds and tubers. Biosynthesis of starch granules takes place primarily in the amyloplasts, it is the major source of carbohydrate in the human diet [9]. Starch granules vary in shape (spherical, oval, polygonal, disk, elongated and kidney shapes), in size (1 μm-100 μm in diameter), in size distribution (uni- or bimodal), in association of individual (simple) or granule clusters (compound) and in composition (α-glucan, lipid, moisture, protein and mineral content).chemically, Starch granules are composed of two types of *alpha*-glucan, amylose and amylopectin, which represent approximately 98-99 % of the dry weight. The ratio of the two polysaccharides varies according to the botanical origin of the starch; normal starches contain 70-80 % amylopectin and 20-30 % amylose [10, 11].

Amylose and amylopectin have different structures and properties; however, both molecules are composed of a number of monosaccharides (glucose) linked together with *alpha*-1, 4 and/or *alpha*-1-6 linkages. Amylose is a mainly linear polymer consisting of long chains of *alpha*-1, 4-linked glucose units. Its molecular weight is approximately 1*105-1*106, it has a degree of polymerisation (DP) by number (DPn) of 324-4920 with around 9-20 branch points equivalent to 3-11 chains per molecule [12, 13]. On the basis of X-ray diffraction studies, the presence of A-type and B-type amylose is indicated. The structural elements of B-type are double helices, which are packed in an antiparallel, hexagonal mode. The central channel surrounded by 6 double helices is filled with water (36 H_2O/unit cell). A-Type is very similar to B-type, except that the central channel is occupied by another double helix, making the packing closer. In this type, only 8 molecules of water per unit cell are inserted between the double helices. Generally, most cereal starches give the so-called A-type pattern; some tuber starches (*e.g.* potato) and cereal starches rich in amylose yield the B-type pattern, while legume starches generally give a C-type pattern(mix of A and B), and V-type(semi crystalline form) occurs in swollen granules [1]. These types depend partly on the chain length making up the amylopectin lattice, the density of packing within the granules, and the presence of water [14]. In general, digestible starches are broken down (hydrolyzed) by the enzymes a-amylases, glucoamylase and sucrase–isomaltase in the small intestine to yield free glucose that is then absorbed [15]. However, not all starch in the diet is digested and absorbed in the small intestine [9].

III. RESISTANT STARCH (RS)

For nutritional purposes, starch can be classified into three categories by the Englyst test [16, 17], depending on their rate and extent of digestion; these include rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS). The main enzymes, which take part in starch hydrolysis, are amylases and amyloglucosidases resulting glucose, maltose and dextrins liberation during the digestion [18].

RDS is the fraction of starch granules that cause a rapid increase in blood glucose concentration after ingestion of carbohydrates. This fraction of starch *in vitro* is defined as the amount of starch digested in the first 20 min of a standard digestion reaction mixture [17]. Although RDS is defined by experimental analysis of digestion *in vitro*, the rate of starch conversion to sugar follows similar kinetics in the human digestive system [19]. RDS means mainly amorphous starch fractions that occur in high amounts in freshly cooked or baked starchy foods (bread, potatoes). [18].

SDS is the fraction of starch that is digested slowly but completely in the human small intestine [19]. SDS is defined as the starch that is digested after the RDS but in no longer than 120 min under standard conditions of substrate and enzyme concentration [17]. The potential health benefits of SDS *in vivo* include stable glucose metabolism, diabetes management, mental performance, and satiety [20]. Mostly physically inaccessible amorphous starches, raw starches with A-type or C-type crystalline pattern and B-type starches either in granule form or retrograded form belong to this type.

RS: The fraction of starch that escapes digestion in the small intestine, and cannot be digested within 120 min, is defined as **RS** [19]. The term of "resistant starch" derives from Englyst et al. (1982) [21]. Later, it has been defined formally by the European Flair Concerted Action on Resistant Starch (EURESTA) as the starch or products of starch degradation that escapes digestion in the human small intestine of healthy individuals and may be completely or partially fermented in the large intestine as a substrate for the colonic microflora acting as a prebiotic material [22]. Many studies have shown that RS is a linear molecule of a-1,4-D-glucan, essentially derived from the retrograded Amylose fraction, and has a relatively low molecular weight (1.2 _ 105 Da) [23].

Resistant starch may not be digested for four reasons:

(i) This compact molecular structure limits the accessibility of digestive enzymes, various amylases, and explains the resistant nature of raw starch granules [24]. The starch may not be physically bioaccessible to the digestive enzymes such as in grains, seeds or tubers.

(ii) The starch granules themselves are structured in a way which prevents the digestive enzymes from breaking them down (e.g. raw potatoes, unripe bananas and high-amylose maize starch) [15].

(iii) Starch granules are disrupted by heating in an excess of water in a process commonly known as gelatinization, which renders the molecules fully accessible to digestive enzymes. Some sort of hydrated cooking operation is typical in the preparation of starchy foods for consumption, rendering the starch rapidly digestible [24]. However, if these starch gels are then cooled, they form starch crystals that are resistant to enzymes digestion. This form of 'retrograded' starch is found in small quantities (approximately5%) in foods such as ''corn-flakes'' or cooked and cooled potatoes, as used in a potato salad.

(iv) Selected starches that have been chemically modified by etherisation, esterisation or cross-bonding, cannot be broken down by digestive enzymes [25].

The physical properties of resistant starch, particularly its low water-holding capacity, make it a functional ingredient that provides good handling and improves texture in the final product [26]. By careful control of the processing conditions employed, for example, the moisture content, pH, temperature, duration of heating, repeated heating–cooling cycles, etc., the content of RS may reach as much as 30%. RS is shown to improve eating qualities because of its increased expansion, enhanced crispiness, and reduced oil ''pickup'' in deep-fat-fried foods, contrary to the traditional dietary fiber, which imparts a gritty texture and strong flavor [23].

In comparison with traditional fibers, such as whole grains, bran or fruit fibers [1], RS possesses the advantage of affecting the sensory properties of the final products less, which is very positive for consumer acceptability. Resistant starch provides many technological properties, such as better appearance, texture, and mouth feel than conventional fibers [27]. A wide range of foods has been enriched with RS including bread, cakes, muffins, pasta and battered foods [28].

IV. RESISTANT STARCH AS A COMPONENT OF DIETRY FIBER

Generally, dietary fiber refers especially to non-starch polysaccharides, resistant oligosaccharides and analogous carbohydrates. It also includes resistant starch [29].Traditionally, in the UK, the definition of dietary fiber includes only non-starch polysaccharides and lignin, and does not include RS [29]. However, currently, naturally occurring resistant starch (such as found in whole grains, legumes, cooked and chilled pasta, potatoes and rice, unripe bananas) is considered dietary fiber, while resistant starches added to foods for health benefits are classified as functional fiber under the AACC (American Association of Cereal Chemists, 2000) and NAS (National Academy of Sciences, 2002) definition (16).

The increased awareness of consumers concerning the relationship between food, lifestyle and health has been one of the reasons for the popularity of food rich in fiber, so resistant starch (RS) has gained importance as a new source of dietary fiber [30]. The general behavior of RS is physiologically similar to that of soluble, fermentable fiber, like guar gum. The most common results include increased fecal bulk and lower colonic pH [31]. Additional observations suggest that resistant starch, such as soluble fiber, has a positive impact on colonic health by increasing the crypt cell production rate, or decreasing colonic epithelial atrophy in comparison with non-fiber diets. There are indications that resistant starch, like guar, a soluble fiber, influences tumorigenesis, and reduces serum cholesterol and triglycerides. Overall, since resistant starch behaves physiologically as a fiber, it should be retained in the total dietary fiber assay [24]. The recent increased interest in RS is related to its effects in the gastrointestinal tract, which in many ways are similar to these of dietary fiber. Like soluble fiber, RS is a substrate for the colonic microbiota, forming metabolites including short-chain fatty acids (SCFA), i.e. mainly acetic, propionic and butyric acid. Butyric acid is largely metabolised by the colonocyte, and is the most import energy source for the cell (32). RS consumption has also been related to reduce postprandial glycemic and insulinemic responses, which may have beneficial implications in the management of diabetes [33]. Therefore, there is wide justification for assuming that RS behaves physiologically like fiber [14].

RS is not a cell wall component but is nutritionally more similar to NSP than to digestible starch. Of late, RS has been considered a new ingredient for creating fiber-rich foods, although one of the problems of including RS is that it does not have all the properties of soluble and insoluble fiber together [29].Several studies have attempted to quantify the dietary intake of resistant starch in different populations. Worldwide, the dietary intake of resistant starch varies considerably. It is estimated that resistant starch intake in developing countries with high starch consumption rates ranges from approximately 30–40 g/day [34]. Intakes in the EU are thought to be from 3 to 6 g/day [35], and 5–7 g/day in Australia [34]. It should be noted that intakes of resistant starch in Australia are likely to be higher than in Europe, because of the commercial availability of top-selling breads, baked goods and cereals that contain ingredients high in resistant starch. Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) has recommended that the total intake of resistant starch should be around 20 g a day based on a study by Baghurst et al. (2001)[34] for good health. However, compared with current resistant starch intake rates in the UK population and elsewhere, to achieve intakes at this level would require substantial dietary changes and, indeed, may only be reached by the consumption of foods containing resistant starches as a food ingredient, rather than in the natural form. However, resistant starch could make a valuable contribution to dietary fiber intakes, as it is fermented slowly in the large bowel and is therefore tolerated better than other soluble fibers [25].

V. TYPES OF RESISTANT STARCH

Resistant starch has been classified into four general subtypes (Table I) called RS1, RS2, RS3 and RS4 [36; 17; 3; 15; 14].

RS1: It has a compact molecular structure which limits the accessibility of digestive enzymes. This starch is entrapped within whole or partly milled grains or seeds and tubers [3; 24]. It is measured chemically as the difference between the glucose released by the enzyme digestion of a homogenized food sample and that released from a non-homogenized sample. RS1 is heat stable in most normal cooking operations, which enables its use as an ingredient in a wide variety of conventional foods [14].

RS2: RS2 are native, uncooked granules of starch, such as raw potato, banana and high amylose maize starches, whose crystallinity makes them poorly susceptible to hydrolysis. They are protected from digestion by the conformation or structure of the starch granule. This compact structure (tightly packed in a radial pattern and is relatively dehydrated) limits the accessibility of digestive enzymes, and accounts for the resistant nature of RS2. A particular type of RS2 is unique as it retains its structure and resistance even during the processing and preparation of many foods; this RS2 is called high amylose maize starch. RS2 is measured chemically as the difference between the glucose released by the enzyme digestion of a boiled homogenized food sample and that from an unboiled, nonhomogenized food sample [3; 15; 14].

RS3: RS3 refers to non-granular starch-derived materials that resist digestion. Starch granules are disrupted by heating in an excess of water in a process commonly known as gelatinisation, which renders the molecules fully accessible to digestive enzymes. However, if these starch gels are then cooled (retrogradation), they form starch crystals that are resistant to enzymes digestion. It may be formed in cooked foods that are kept at low or room temperature. Therefore, most moisture heat-treated foods contain some RS3. It is found in small quantities (approximately 5%) in foods such as corn-flakes or cooked and cooled potatoes. RS3 can be divided into two subtypes: RS3a (IIIa) containing crystalline amylopectin and RS3b (IIIb) having a partially crystallized amylose network [37]. It is measured chemically as the fraction, which resists both dispersion by boiling and enzyme digestion. RS3 is of particular interest, because of its thermal stability. This allows it to be stable in most normal cooking operations, and enables its use as an ingredient in a wide variety of conventional foods. Food processing, which involves heat and moisture, in most cases destroys RS1 and RS2 but may form RS3 [3; 24; 14].

RS4: describes a group of starches that have been chemically modified (conversion, substitution, or cross-linking) and include starches which have been etherized, esterified or cross-bonded with chemicals in such a manner as to decrease their digestibility. RS4 may be further subdivided into four subcategories according to their solubility in water and the experimental methods by which they can be analyzed. The level of resistance depends on the starch base and the modification reaction In addition to the structural factors mentioned above whereby the chemical structure of starch can influence the amount of RS present, other factors intrinsic to starchy foods can affect a-amylase activity and therefore starch breakdown. These include the formation of amylose–lipid complexes, the presence of native a-amylase inhibitors and also non-starch polysaccharides, all of which can directly affect a-amylase activity. Extrinsic additives, e.g. phosphorus, may also bind to starch, making it more or less susceptible to degradation. In addition, physiological factors can affect the amount of RS in a food. Increased chewing decreases particle size (smaller particles being more easily digested in the gut), while intra-individual variations in transit time and biological factors (e.g. menstrual cycle) also affect the digestibility of starch. At present, it is not known how RS4 is affected by digestion in vivo [3; 15; 14]

Table I

Types of resistant starch, their resistance to digestion in small intestine and food sources. [29, 25, 14, 15]

Type of starch	Description	Digestion in small intestine	Resistance reduced by	Food sources
RS1	Physically inaccessible to digestion by entrapment in a non-digestible matrix	matrix Slow rate; partial degree Totally digested If properly Milled	Milling, chewing	Whole or partly milled grains and seeds, legumes, pasta
RS2	Ungelatinized resistant granules with type B crystallinity, slowly hydrolyzed by α-amylase	Very slow rate; little degree Totally digested when freshly cooked	Food processing and cooking	Raw potatoes, green bananas, some legumes, high amylose starches
RS3	Retrograded starch formed when starch containing foods are cooked and cooled	Slow rate; partial degree Reversible digestion: digestibility improved by reheating	Processing conditions	Cooked and cooled potatoes, bread, corn flakes, food products with prolonged and/or repeated moist heat treatment
RS4	Selected chemically-modified resistant starches and industrially processed food ingredients	Selected chemically-modified resistant starches and industrially processed food	Less susceptible to digestibility in vitro	Some fiber: drinks, foods in which modified starches have been used (certain breads)

From a commercial point of view, there are resistant starch products derived from high-amylose corn starch, including Hi maize® whole grain corn flour (RS1 and RS2), Hi-maize®260 corn starch (RS2), and Novelose®330 (RS3) resistant starch. Recently, Mermelstein et al (2009) [38] reported that there is a fifth type of soluble polysaccharide called ‘‘resistant maltodextrins”. They are derived from starch that is processed to purposefully rearrange starch molecules to render them soluble and resistant to digestion. Two commercial resistant maltodextrins are Nutriose and Fibersol.

VI. FOOD SOURCES OF RESISTANT STARCH

Factors that determine whether starch is resistant to digestion include the physical form of grains or seeds in which starch is located, particularly if these are whole or partially disrupted, size and type of starch granules, associations between starch and other dietary components, and cooking and food processing, especially cooking and cooling [39]. The digestibility of starch in rice and wheat is increased by milling to flour (14).As a food ingredient, RS has a lower calorific (8 kJ/g) value compared with fully digestible starch (15 kJ/g); however, it can be incorporated into a wide range of mainstream food products such as baked products without affecting the processing properties or the overall appearance and taste of the product [40].Unripe banana is considered the RS-richest non-processed food. Several studies have suggested that consumption of unripe bananas confers beneficial effects for human health, a fact often associated with its high resistant starch (RS) content, which ranges between 47% and 57%. Recently, the preparation of unripe banana flour was described, with 73.4% total starch content, 17.5% RS content and a dietary fiber level of 14.5%. Although banana represents dietary fiber, it is important to keep in mind that, when the unripe fruit is cooked, its native RS is rendered digestible [41]. As a percentage of total starch, potato starch has the highest RS concentration and corn starch has the lowest. Raw potato starch contain 75% RS as a percentage of Total Starch (TS). Starches from tubers such as potatoes tend to exhibit B-type crystallinity patterns that are highly resistant to digestion. Amylo maize contains mostly amylose, which has been shown to lower not only digestibility but also blood insulin and glucose values in humans [42].Whole grains are rich sources of fermentable carbohydrates including dietary fiber, resistant starch and oligosaccharides [39]. Fiber provided by the whole grain includes a substantial resistant starch component, as well as varying amounts of soluble and fermentable fibers, depending on the whole grain source [25].

RS concentrations are low for the flour group as a whole. Cereal flours display an A-type crystalline pattern, which is more readily hydrolyzed than raw cereals that are not as highly processed as flours. Therefore, cereal flours contain more RDS and SDS than RS. The nutrient profile of cereal grains and their corresponding flours vary considerably. Grain flours are made up primarily of two components: protein and starch. Cereal grains, in contrast, contain the pericarp, aleurone layers and germ portions of the grain that provide lipid and fiber, Cereal grains are processed and milled to flours, thereby altering the chemical composition of the flour compared with the cereal grain. The RS concentrations are five times higher in the cereal grains than in the flours [42].

Prepared grain products contain moderate levels of RS (mean 9.6% as a percentage of TS). Starch in foods like spaghetti is more slowly digested because of the densely packed starch in the food [42]. Legumes are known for their high content of both soluble and insoluble dietary fiber. Pulse grains are high in RS and retain their functionality even after cooking [40]. Legume starches have higher amylose levels than cereal and pseudo cereal starches [43]. Legumes have high TDF and RS concentrations (mean 36.5% and 24.7%, respectively). RS concentrations generally constituted the highest proportion of the starch fractions of legumes. Leguminous starches display a C-type pattern of crystallinity. This type of starch is more resistant to hydrolysis than that with an A-type crystallinity pattern and helps explain why legumes have high amounts of RS. Another possible reason for the higher RS concentrations in legumes could be the relationship between starch and protein. When red kidney beans are pre incubated with pepsin, there is an increase in their susceptibility to amylolytic attack [42].Cooked legumes are prone to retrograde more quickly, thereby lowering the process of digestion. Processed legumes contain significant amount of RS3. The digestibility of legume starch is much lower than that of cereal starch. The higher content of amylose in legumes, which probably leads to a higher RS content, may account for their low digestibility. High amylose cereal starch has been shown to be digested at a significantly lower rate [33].

There is a very high diversity of the content of resistant starch in seeds of leguminous plants (from 80% to only a few percent). Nevertheless, is very important influence processing on part resistant starch. Hydrothermal processing can cause an increase or reduction in the fraction of resistant starch (depending on the parameters of processing and varieties of legumes) [44].

Wheat bran starch isolated from commercial wheat brans using a wet-milling process was shown to have unique properties compared to commercial wheat endosperm starch. Starch recovery was 90% and the starch fraction contained a low level of protein (0.15%). The more resistant starch content and lower retrogradation rate are properties that present an opportunity to make wheat bran starch a new functional ingredient for the food industry [3]

VII. HEALTH PROPERTIES OF RESISTANT STARCHES

RS has received much attention for both its potential health benefits and functional properties (14). Resistant starch is one of the most abundant dietary sources of non-digestible carbohydrates (15) and could be as important as NSP (non-starch polysaccharides) in promoting large bowel health and preventing bowel inflammatory diseases (IBD) and colorectalcancer (CRC) [45] but has a smaller impact on lipid and glucose metabolism [15].

A number of physiological effects have been ascribed to RS, which have been proved to be beneficial for health [14]. The physiological properties of resistant starch (and hence the potential health benefit) can vary widely depending on the study design and differences in the source, type and dose of resistant starch consumed [7; 15]. It is possible that modern processing and food consumption practices have led to lower RS consumption, which could contribute to the rise in serious large bowel disease in affluent countries. This offers opportunities for the development of new cereal cultivars and starch-based ingredients for food products that can improve public health. These products can also be applied clinically [45].RS acts largely through its large bowel bacterial fermentation products which are, in adults, short-chain fatty acids (SCFA) [45] but interest is increasing in its prebiotic potential.

There is also increasing interest in using RS to lower the energy value and available carbohydrate content of foods. RS can also be used to enhance the fiber content of foods and is under investigation regarding its potential to accelerate the onset of satiation and to lower the glycemic response The potential of RS to enhance colonic health, and to act as a vehicle to increase the total dietary fiber content of foodstuffs, particularly those which are low in energy and/or in total carbohydrate content [3] (Table II).

A) HYPOGLYCEMIC EFFECTS

The GI of starchy foods may depend upon various factors such as the amylose/amylopectin ratio, the native environment of the starch granule, gelatinization of starch, water content and baking temperature of the processed foods. Thus, the factors affecting the GI values are in accordance with those of RS formation. With glucose as reference, reported GI values range from about 10 for starch from legumes to close to 100 in certain potato or rice products and breakfast cereals [29]. Thus foods containing RS reduce the rate of digestion. The slow digestion of RS has implications for its use in controlled glucose release applications [14] and therefore, a lowered insulin response and greater access to the use of stored fat can be expected [15]. This is clearly important for diabetes and has led to major changes in dietary recommendations for diabetics [46]. The metabolism of RS occurs 5–7 h after consumption, in contrast to normally cooked starch, which is digested almost immediately.Digestion over a 5–7 h period reduces postprandial glycemia and insulinemia and has the potential for increasing the period of satiety [47; 48].

There have been a number of studies on the effects of different forms and doses of RS on glucose and insulin responses but the data are contradictory [29]. In a study on humans, Reader et al. (1997)[48] reported that the consumption of RS3 resulted in lower serum glucose and insulin levels than obtained with other carbohydrates. The study also showed that food containing RS decreased postprandial blood glucose and might play a role in providing improved metabolic control in type II diabetes. From a human study, using a commercial RS3 ingredient (CrystaLean_), the maximum blood glucose level was found to be significantly lower than that of other carbohydrates (simple sugars, oligosaccharides, and common starch). Higher glycemic index values have been reported in humans consuming potatoes and cornflakes – foods that contain significant amounts of retrograded starch [49]. In general, positive effects were usually observed shortly (within the first2–8 h) after heavy meal [50]. An RS3-containing bar decreased postprandial blood glucose and could play a role in providing improved metabolic control in type II diabetes (non-insulin dependent) [14]. RS must contribute at least 14% of total starch intake in order to confer any benefits to glycemic or insulinaemic responses [51; 52; 50].More recently, a study showed that RS reduces levels of glucose dependent insulino tropic polypeptide m-RNA along the jejunum and ileum in both normal and type 2 diabetes rats [53].

Chemically-modified starches (RS4) have also been found to generate different glucose responses. The effect of two test meals containing 1–2% acetylated potato starch and beta cyclodextrin enriched potato starch (2–3%), respectively, was studied in humans and only the latter was found to lower body glucose levels. This may be due to the more distal absorption of beta cyclodextrin in the intestine or to delayed gastric emptying [47].

As RS has a low glycemic response, adding it as an ingredient to foods will help lower the overall GL value of the food (particularly if it is replacing existing readily absorbed forms of carbohydrate). RS is likely to become an increasingly attractive ingredient to many food manufacturers (particularly those of breads and cakes or similar products which traditionally may have had higher GI values) [3].

B) RS AS A PREBIOTIC AGENT

Prebiotics are non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one or more bacteria (probiotics) in the gastrointestinal tract and thereby exert a health-promoting effect [54; 55]. Typical of prebiotics are inulin and oligofructose, both naturally present in a number of fruits and vegetables (e.g. bananas, chicory, Jerusalem artichokes, onions, garlic and leeks, and wheat), and other resistant oligosaccharides such as inulin-type fructans [7]. Various experimental studies on pigs and humans have revealed a time-dependent shift in fecal and large bowel SCFA profiles, suggesting the possible interaction of RS with the ingested bacteria [3]. Since RS almost entirely passes the small intestine, it can behave as a substrate for growth of the probiotic microorganisms. *In vitro* studies have shown that RS-supplemented diet may significantly increase populations of *Lactobacilli*, *Bifidobacteria*, *Staphylococci* and S*treptococci*, decrease the *Enterobacteria* population, and alter microbial enzyme metabolism in the colon [56].

C) PREVENTION OF COLONIC CANCER

There is evidence that butyrate may reduce the risk of malignant changes in cells. Population studies in the cecum of rats fed RS preparations have shown that increase in fecal bulking and lower fecal pH, as well as greater production of SCFA, is associated with the decreased incidence of colon cancer, which have been suggested to resemble the effects of soluble dietary fiber [57; 33].

Dietary fiber and resistant starch, as they ferment in the large bowel, produce high levels of butyric acid or its salts [29] as in vitro experiments with human fecal inocula have shown [14]. Champet al (2003) [58] also demonstrated a specific role for resistant starch in the stimulation of bacteria able to produce butyric acid. As butyrate is one of the main energy substrates for large intestinal epithelial cells and inhibits the malignant transformation of such cells in vitro; this makes easily fermentable RS fractions especially interesting in preventing colonic cancer [36]. As observedin the various studies, the butyrates can have an inhibitory effect on the growth and proliferation of tumor cells in vitro by arresting one of the phase of cell cycle (G1) [29].Bingham et al (2003) [59] showed that in populations with a low to average intake of dietary fiber, the doubling of dietary fiber intake could reduce the risk of colorectal cancer by up to 40%. In contrast, there was no relationship between dietary NSP and large bowel cancer [29]. However, when RS was combined with an insoluble dietary fiber, such as wheat bran, much higher SCFA levels, in particular of butyrate was observed in the feces [60]. In rats, when RS was combined with a soluble fiber as Psyllium (Plantagoovata), the site of RS fermentation was pushed more distally. As the distal colon is the site where most tumors arise, it may be of additional benefit for cancer protection if fermentation is further enhanced within the distal colon. Psyllium (Plantago ovata) may be a good candidate to spare and deliver starch to the distal colon [61].More recently, Liu and Xu (2008)[62] showed that RS dose-dependently suppressed the formation of colonic aberrant crypt foci (ACF) only when it was present during the promotion phase to a genotoxic carcinogen in the middle and distal colon, suggesting that administration of RS may retard growth and/or the development of neoplastic lesions in the colon. Therefore, colon tumorigenesis may be highly sensitive to dietary intervention. Adults with preneoplastic lesions in their colon may therefore benefit from dietary RS. This suggests the usefulness of RS as a preventive agent for individuals at high risk for colon cancer development [3].

D) HYPOCHOLESTEROLEMIC EFFECTS

RS appears to particularly affect lipid metabolism, as seen from studies in rats, where reductions in a number of measures of lipid metabolism have been observed. These include total lipids, total cholesterol, low density lipoproteins (LDL), high density lipoproteins (HDL), very low density lipoproteins (VLDL), intermediate density lipoproteins (IDL), triglycerides and triglyceride-rich lipoproteins [15]. Hypocholesterolemic effects of RS have been widely demonstrated. In rats, RS diets (25% raw potato) markedly raised the cecal size and the cecal pool of short-chain fatty acids (SCFA), as well as SCFA absorption and lowered plasma cholesterol and triglyceride levels. Also, there was a lower concentration of cholesterol in all lipoprotein fractions, especially the HDL1 and a decreased concentration of triglycerides in the triglyceriderich lipoprotein fraction [14].

The results of feeding trials on rats using RS from Adzuki bean starch (AS) and Tebou bean starch (TS) suggested that AS and TS has a serum cholesterol-lowering function due to enhanced levels of hepatic SR-B1 (scavenger receptor class B1) and cholesterol 7alpha-hydroxylase mRNA [63]. The bean starches lowered the levels of serum total cholesterol and VLDL + IDL +LDL cholesterol, increased the cecal concentration of short-chain fatty acids (in particular the butyric acid concentration), and increased fecal neutral sterol excretion. From studies on hamsters fed diets containing cassava starch extruded with 9.9% oat fiber or cassava starch extruded with 9.7% RS, hypocholesterolemic properties of both were demonstrated suggesting their potential for use in foods to improve cardiovascular health [64].

According to several studies, RS ingestion may decrease the serum cholesterol level in rats fed a cholesterol-free diet [65; 66]. Some earlier studies in humans reported the beneficial effect of RS on fasting plasma triglyceride and cholesterol levels. However, some other studies indicate that RS consumption does not affect the measures of total cholesterol in humans. Therefore it is evident that more research is needed to help us better understand the effects of RS on lipid metabolism in humans [15].

E) INHIBITION OF FAT ACCUMULATION

A number of authors have examined the potential of RS to modify fat oxidation [15] and various studies [15;29] have examined its potential as satiety agent and also an ingredient by weight management [67], although the results are still not conclusive. It is proposed that eating a diet rich in RS may increase the mobilization and use of fat stores as a direct result of a reduction in insulin secretion [72]. Studies to date in humans would indicate that diets rich in RS do not affect total energy expenditure, carbohydrate oxidation or fat oxidation [68; 69; 70; 71]. In another study on human volunteers, breads rich in RS imparted greater satiety than white breads between 70 and 120 min after eating (D73). Anderson, et al (2002)[74] reported that high-RS meals caused less satiety than low-RS meals 1-h post ingestion. Higgins et al. (2004)[75] examined the relationship between the RS content of a meal and postprandial fat oxidation, finding that replacing 5.4% of total dietary carbohydrates with RS could significantly increase postprandial lipid oxidation and probably reduce fat accumulation in the long term. Keenan et al. (2006)[76] reported that the use of resistant starch in the diet as a bioactive functional food component is a natural, endogenous way to increase gut hormones that are effective in reducing energy intake, so may be an effective natural approach to the treatment of obesity.

F) REDUCTION OF GALL STONE FORMATION

Digestible starch contributes to gall stone formation through a greater secretion of insulin, and insulin in turn leads to the stimulation of cholesterol synthesis, so RS reduces the incidence of gallstones. Gallstones are less frequent in southern India where whole grains are consumed rather than flour, as in northern India. The dietary intake of RS is 2- to 4-fold lower in the United States, Europe, and Australia, compared with populations consuming high-starch diets, such as in India and China, which may be reflected in the difference in the number of gallstone cases in the latter countries [3].

G) ABSORPTION OF MINERALS

Resistant starch enhances the ileal absorption of a number of minerals in rats and humans. Lopez et al. (2001) [77] and Younes et al. (1995) [78] reported an increased absorption of calcium, magnesium, zinc, iron and copper in rats fed RS-rich diets. In humans, these effects appear to be limited to calcium [79; 80;82]. RS could have a positive effect on intestinal calcium and iron absorption. A study to compare the apparent intestinal absorption of calcium, phosphorus, iron, and zinc in the presence of either resistant or digestible starch showed that a meal containing 16.4% RS resulted in a greater apparent absorption of calcium and iron compared with completely digestible starch [61].

For a balanced view of the effect on RS on health, it is important to note that the consumption of high amounts of RS may have some negative effects on gastrointestinal performance. These include bloating, borborygmi (noise due to gas movement in the intestine), flatulence, colic and watery feces. Overall, the benefits of RS consumption are considered to outweigh any gastrointestinal discomfort [56].

VIII. FOOD TECHNOLOGICAL AND NUTRITIONAL APPLICATIONS OF RESISTANT STARCH

Resistant starch has a great interest to product developers and nutritionists for two reasons, the first being the above-mentioned potential physiological benefits and the second the unique functional properties, yielding high quality products not attainable otherwise with traditional insoluble fibers [81; 26]. Historically, fiber-containing foods have been coarser, denser and sometimes less palatable than refined, processed foods. The use of resistant starches as food ingredients typically does not change the taste or significantly change the texture, but may improve sensory properties compared with many of the traditionally used fibers, such as brans and gums [14]. RS has desirable physicochemical properties [83] such as swelling, viscosity increase, gel formation and water-binding capacity, making it useful in a variety of foods. RS has a small particle size, white appearance, bland flavor and also provides good handling in processing and crispness, expansion, and improved texture in the final product [14].Its low water-holding capacity, make it a functional ingredient that provides good handling and provides and improves texture in the final product [81].RS shows improved crispness and expansion in certain products and better mouth feel, color, and flavor than can be obtained with some traditional, insoluble fibers [14]. This greatly increases the likelihood that consumers will accept these foods and hence increase their dietary fiber intake [17]. These properties make it possible to use most resistant starches to replace flour on a 1-for-1 basis without significantly affecting dough handling or rheology. RS not only fortifies fiber but also imparts special characteristics not otherwise attainable in high-fiber foods [33].They may also be used to provide fiber in some commercially available low-carbohydrate foods marketed for those following low-carbohydrate dieting regimens [15]. There are also potential uses in fermented foods, such as dry-cured sausages.

The processing conditions can affect the resistant content of starch by influencing its gelatinisation and retrogradation [84[. Augustinet al (2008) [85] describe that it is possible to make a physically functional RS ingredient by the application of physical processes to starch suspension. Technically, it is possible to increase the RS content in foods by modifying the processing conditions such as pH, heating temperature and time, number of heating and cooling cycles, freezing, and drying [14]. The substitution of 3% milk solids in yoghurts (12% total solids) with heated, sheared and microfluidised starch suspensions increased the viscosity and decreased syneresis of yoghurts but the incorporation of starch that had only been heated and sheared without microfluidisation did not. Unlike natural sources of RS (e.g. legumes, potatoes, bananas), commercially manufactured resistant starches are not affected by processing and storage conditions. For example, the amount of RS2 in green bananas decreases with increasing ripeness, while a commercial form of RS2, Hi-maize, does not present these difficulties[15].

The food manufacture may be thought of as enhancement of the proportion of the starch that test as RS. The reason for including an ingredient high in RS is to combine physical functionality, processing stability and nutritional functionality. The physical functionality of RS is required for the physical characteristics of the food, such as texture, water-holding capacity. The processing stability of RS is important in order to preserve the nutritional functionality of the RS-containing ingredients. The nutritional functionality of the RS-containing ingredients can involve both resistance to digestion in the small intestine and resistance to fermentation in the colon. Eventually, we should be able to produce starch materials with the desired rate and extent of digestion (in terms of mean population responses) and (for any RS that might be present) a desired rate of hydrolysis and fermentation in the colon. In any starch material, the constituent molecules will have a range of susceptibility to amylolytic activity in vitro. For a starch or starch-containing ingredient, it is possible to alter this range by judicious selection of processing conditions to increase the proportion of RS. The starch material will also have a range of thermal stabilities before and after processing, which may or may not reflect the range of susceptibility to hydrolysis [84] The industrial applications of RS mainly involve the preparation of moisture-free food products [81]. Bakery products such as bread, muffins, and breakfast cereals can be prepared by using RS as a source of fiber. The amount of RS used to replace flour depends on the particular starch being used, the application, the desired fiber level, and, in some cases, the desired structure–function claims.

The incorporation of RS in baked products, pasta products and beverages imparts improved textural properties and health benefits [86]. A panel rated 40% TDF RS loaf cakes as best for flavor, grittiness moisture perception, and tenderness 24 h after baking. Based on an evaluation by a trained sensory panel of toasted waffles for initial crispness, crispness after3 min, moistness and overall texture, RS waffle showed greater crispness than control or traditional fiber. RS can improve expansion in extruded cereals and snacks. RS may also be used in thickened, opaque health beverages in which insoluble fiber is desired. Insoluble fibers generally require suspension and add opacity to beverages. Compared with insoluble fibers, RS imparts a less gritty mouth feel and masks flavors less [14]. Bread containing 40% TDF RS had greater loaf volume and better cell structure compared with traditional fibers tested [87].

Hydrolyzed starches (those which retain their granular structure and essentially behave like unmodified starches in undergoing gelatinization on heating), which are also referred to as thin boiling starches, are also a form of RS. The advantage of this starch is the high concentration, which can be used as a paste of low viscosity, and its ability to set as a firm gel [88]. Cross linked starches of RS4 type, based on maize, tapioca and potato, have been useful in formulations needing pulpy texture, smoothness, flow ability, low pH storage, and high temperature storage [14]. Baixauli et al (2008)[26] studied the instrumental texture characteristics of muffins with added resistant starch and noted that its addition produced a softer texture: the samples were less hard, elastic and cohesive, reflecting a more tender structure; these effects were more evident at higher concentrations of resistant starch. Arimi et al (2008)[89] have successfully replaced most or all of the fat in imitation cheese with resistant starch without adversely affecting meltability or hardness and conferring the well-established benefit of resistant starch as a functional fiber. In addition, low-fat, starch-containing imitation cheese has been demonstrated to have the potential to expand during microwave heating. Since this type of imitation cheese expands on microwave heating, it can be presented as a stand-alone snack, pre-expanded or as a home expansion product.

The rheology and microstructure of a control imitation cheese were compared with cheeses containing Novelose240 (N240, native resistant starch) or Novelose330 (N330, retrograded resistant starch), as a source of fiber to replace fat. by Clara Montesinos et al [90]. also, resistant starch are applied in microencapsulation probiotic bacteria because of it is prebiotic Mirzaei et al [91] were investigated on Effect of calcium alginate and resistant starch microencapsulation on the survival rate of Lactobacillus acidophilus La5 and sensory properties in Iranian white brined cheese. They found resistant starch was able to increase the survival rate of L. acidophilus La5 in Iranian white brined cheese after 6 months of storage.

Table II

Health properties of resistant starches (3)

Potential physiological effects	**Conditions where there may be a protective effect**
Control of glycaemic and insulinaemic responses	Diabetes, impaired glucose and insulin responses, the metabolic syndrome
Improved bowel health	Colorectal cancer, ulcerative colitis, inflammatory bowel disease, diverticulitis, constipation
Improved blood lipid profile	Cardiovascular disease, lipid metabolism, the metabolic syndrome
Prebiotic and culture protagonist	Colonic health
Increased satiety and reduced energy intake	Obesity
Increased micronutrient absorption	Enhanced mineral absorption, osteoporosis

IX. CONCLUSION

Fiber consumption has been reduced significantly in western society and is far below the recommended level. The main reason has been the change in life style, which has promoted a significant reduction in fruit, vegetables and legume consumption. With the aim of increasing fiber intake in the diet, many fiber enriched foods have been developed. Resistant starch (RS) is a recently recognized source of fiber and is classified as a fiber component with partial or complete fermentation in the colon, producing various beneficial effects on health. RS also offers an exciting new potential as a food ingredient. As a functional fiber, its fine particles and bland taste make the formulation of a number of food products possible with better consumer acceptability and greater palatability than those made with traditional fibers. Technically, it is possible to increase the RS content in foods by modifying the processing conditions such as pH, heating temperature and time, the number of heating and cooling cycles, freezing, and drying. RS shows improved crispness and expansion in certain products, which have better mouth feel, color and flavor than products produced with traditional insoluble fibers.

X. REFERENCES

[1] Pérez-Alvarez, J. A. (2008a). Overview of meat products as functional foods. In J.Fernández-López & J. A. Pérez-Alvarez (Eds.), Technological strategies for functional meat products development (pp. 1–17). Kerala, India: Transworld Research Network.

[2] Fuentes-Zaragoza, E., Sánchez-Zapata, E., Navarro-Rodriguez de Vera, C., Sendra -Nadal, E., Sayas-Barberá, E., & Fernández-López, J. (2009). Aspectos generales de la aplicación de la tecnología sous-vide a los productos pesqueros. Alimentación,Equipos y Tecnología, 246, 20–23.

[3] Fuentes-Zaragoza, E., Sánchez-Zapata, E., Navarro-Rodriguez de Vera, C., Sendra-Nadal, E., Sayas-Barberá, E., Fernández-López, J. (2010). Aspectos generales de la aplicación de la tecnología sous-vide a los productos cárnicos. Alimentación, Equipos y Tecnología, in press.

[4] Pérez-Alvarez, J. A. (2008b). Los alimentos del bienestar: Alimentación del siglo XXI. IAlimentos, 3, 54.

[5] Fagan, J. D., & Gormley, T. R. (2005). Effect of sous-vide cooking, with freezing, on selected quality parameters of seven fish species in a range of sauces. European Food Research and Technology, 220, 299–304.

[6] Garcia-Segovia, P., Andres-Bello, A., & Martinez-Monzo, J. (2007). Effect of cooking Method on mechanical properties, color and structure of beef muscle (M. pectoralis). Journal of Food Engineering, 80, 813–821.

[7] Buttriss, J. L., & Stokes, C. S. (2008). Dietary fiber and health: An overview. British Nutrition Foundation, Nutrition Bulletin, 33, 186–200.

[8] Commission of the European Communities (2008). Draft commission directive: Amending directive 90/496/EEC. <http://www.food.gov.uk/multimedia/pdfs/consultation/cwd>.

[9] Ratnayake, W. S., & Jackson, D. S. (2008). Thermal behavior of resistant starches RS2, RS 3, and RS 4. Journal of Food Science, 73(5), 356–366.

[10] Jane, J.L. (2009) Structural features of starch granules II. In: BeMiller, J.N. & Whistler, R.L. (ed) Starch Chemistry and Technology (3rd edition), pp 194-227. Academic Press, New York, USA.

[11] Tester, R.F., Karkalas, J. & Qi, X. (2004) Starch – composition, fine structure and architecture – review. Journal of Cereal Science, 39(2):151-165.

[12] Smith, A.M. (2001) The biosynthesis of starch granules. Biomacromolecules, 2:335-341.

[13] Wang, T.L., Bogracheva, T.Y. & Hedley, C.L. (1998) Starch: as simple as A, B, C? Journal of Experiental Botany, 49(320):481-502.

[14] Sajilata, M.G., Singhal, R.S. & Kulkarni, P.R. (2006) Resistant starch – A review. Comprehensive Reviews in Food Science and Food Safety, 5:1-17.

[15] Nugent, A. P. (2005). Health properties of resistant starch. British Nutrition Foundation, Nutrition Bulletin, 30, 27–54.
[16] Berry, C.S. (1986) Resistant starch, formation and measurement of starch that survives exhaustive digestion with amylolytic enzymes during the determination of dietary fiber. Journal of Cereal Science, 4:301-314.
[17] Englyst, H.N., Kingman, S.M. & Cummings, J.H. (1992) Classification and measurement of nutritionally important starch fractions. European Journal of Clinical Nutrition, 46(2):S33-50.
[18] Annison, G. & Topping, D.L. (1994) Nutritional role of resistant starch: chemical structure vs physiological function. Annual Reviews in Nutrition, 14:297-320.
[19] Dona, A.C., Pages, G., Gilbert, R.G. & Kuchel, P.W. (2010) Digestion of starch: In vivo and in vitro kinetic models used to characterise oligosaccharide or glucose release – Review. Carbohydrate Polymers, 80:599-617.
[20] Lehmann, U. & Robin, F. (2007)Slowly digestible starch – its structure and health implications: a review. Trends in Food Science & Technology, 18(7):346-355.
[21] Englyst, H.N., Wiggins, H.S. & Cummings, J.H. (1982) Determination of the non-starch polysaccharides in plant foods by gas-liquid chromatography of constituent sugars as alditol acetates. Analyst, 107:307-318.
[22] Faraj, A., Vasanthan, T. & Hoover, R. (2004) The effect of extrusion cooking on resistant starch formation in waxy and regular barley flours. Food Research International, 37:517-525.
[23] Tharanathan, R. N. (2002). Food-derived carbohydrates: Structural complexity and functional diversity. Critical Reviews in Biotechnology, 22(1), 65–84.
[24] Haralampu, S. G. (2000). Resistant starch: A review of the physical properties and biological impact of RS3. Carbohydrate Polymers, 41, 285–292.
[25] Lunn, J., & Buttriss, J. L. (2007). Carbohydrates and dietary fiber. Nutrition Bulletin, 32, 21–64.
[26] Baixauli, R., Salvador, A., Martinez-Cervera, S., & Fiszman, S. M. (2008). Distinctive sensory features introduced by resistant starch in baked products. Food Science and Technology, 41, 1927–1933.
[27] Charalampopoulos, D., Wang, R., Pandiella, S. S., & Webb, C. (2002). Application of cereals and cereal components in functional foods: A review. International Journal of Food Microbiology, 79, 131–141.
[28] Sanz, T., Salvador, A., & Fiszman, S. M. (2008b). Evaluation of four types of resistant starch in muffin baking performance and relationship with batter rheology.European Food Research & Technology, 227, 813–819.
[29] Sharma, A., Yadav, B. S., & Ritika (2008). Resistant starch: Physiological roles and food applications. Food Reviews International, 24, 193–234.
[30] Sanz, T., Salvador, A., & Fiszman, S. M. (2008b). Evaluation of four types of resistant starch in muffin baking performance and relationship with batter rheology. European Food Research & Technology, 227, 813–819.
[31] Slavin, J., Stewart, M., Timm, D., & Hospattankar, A. (2009). Fermentation patterns and short chain-fatty acid (scfa) profiles of wheat dextrin and other functional fibers. In Proceedings of 4th international dietary fiber conference 2009 (p. 35). International Association for Cereal Science and Technology (ICC), 1–3 July 2009, Vienna, Austria.
[32] Elmstahl, H. L. (2002). Resistant starch content in a selection of starchy foods on thebSwedish market. European Journal of Clinical Nutrition, 56, 500–505.
[33] Tharanathan, R. N., & Mahadevamma, S. (2003). Grain legumes: A boon to human nutrition. Trends in Food Science & Technology, 14, 507–518.
[34] Baghurst, K. I., Baghurst, P. A., & Record, S. J. (2001). Dietary fiber, non starch polysaccharide and resistant starch intakes in Australia. In G. A. Spiller (Ed.). Handbook of dietary fiber in human health (pp. 583–591). Boca Raton, FL: CRC Press.
[35] Dyssler, P., & Hoffmann, D. (1994). Estimation of resistant starch intake in Europe. In N.-G. Asp, J. M. M. van Amelsvoort, & J. G. A. J. Hautvast (Eds.), Proceedings of the concluding plenary

meeting of EURESTA (pp. 84–86). Wageningen, The Netherlands: EURESTA.
[36] Asp, N.G., van Amelsvoort, J.M.M. & Hautvast, J.G.A.J. (1996) Nutritional implications of resistant starch. Nutrition Research Reviews, 9:1-31.
[37] Themeier, H., Hollman, J., Neese, U. & Lindhauer, M.G. (2005) Structural and morphological factors influencing the quantification of resistant starch II in starches of different botanical origin. Carbohydrate Polymers, 61:72-79.
[38] Mermelstein, N. H. (2009). Analyzing for resistant starch. Food Technology, 4, 80–84.
[39] Slavin, J. (2004). Whole grains and human health. Nutrition Research Reviews, 17, 99–110.
[40] Rochfort, S., & Panozzo, J. (2007). Phytochemicals for health, the role of pulses. Journal of Agricultural and Food Chemistry, 55, 7981–7994.
[41] Rodriguez, S. L., Islas, J. J., Agama, E., Tovar, J., & Bello, L. A. (2008). Characterization of a fiber-rich powder prepared by liquefaction of unripe banana flour. Food Chemistry, 107, 1515–1521.
[42] Bednar, G. E., Patil, A. R., Murray, S. M., Grieshop, C. M., Merchen, N. R., & Fahey, G. C. (2001). Starch and fiber fractions in selected food and feed ingredients affect their small intestinal digestibility and fermentability and their large bowel fermentability in vitro in a canine model. The Journal of Nutrition, 131, 276– 286.
[43] Mikulikoa, D., Masar, S., & Kraic, J. (2008). Biodiversity of legume health-promoting starch. Starch, 60, 426–432
[44] Giczewska, A., & Borowska, J. (2003). Nutritional value of broad bean seeds. Part 1: Starch and fiber. Food, 47(2), 95–97.
[45] Topping, D. L., Anthony, M. F., & Bird, F. (2003). Resistant starch as prebiotic and synbiotic: State of the art. Proceedings of the Nutrition Society, 62, 171–176.
[46] Cummings, J. H., Edmond, L. M., & Magee, E. A. (2004). Dietary carbohydrates and health: Do we still need the fiber concept? Clinical Nutrition supplements, 1, 5–17.
[47] Raben, A., Tagliabue, A., Christensen, N. J., Madsn, J., Holst, J. J., & Astrup, A. (1994). Resistant starch: The effect on postprandial glycemia, hormonal response and satiety. American Journal of Clinical Nutrition, 60, 544–551.
[48] Reader, D., Johnson, M. L., Hollander, P., & Franz, M. (1997). Response of resistantstarch in a food bar vs. two commercially available bars in persons with type II diabetes mellitus. Diabetes, 46(1), 254.
[49] Truwell, A. S. (1992). Glycemic index of foods. European Journal of Clinical Nutrition, 46(2), 91–101.
[50] Higgins, J. A., Higbee, D. R., Donahoo, W. T., Brown, I. L., Bell, M. L., & Bessesen, D. H. (2004). Resistant starch consumption promotes lipid oxidation. Nutrition & Metabolism, 1, 8.
[51] Behall, K. M., & Hallfrisch, J. (2002). Plasma glucose and insulin reduction after consumption of breads varying in amylose content. European Journal of Clinical Nutrition, 56, 913–920.
[52] Brown, M. A., Storlien, L. H., & Brown, I. L. (2003). Cooking attenuates the ability of high amylose meals to reduce plasma insulin concentrations in rats. British Journal of Nutrition, 90, 823–827.
[53] Shimada, M., Mochizuki, K., & Goda, T. (2008). Dietary resistant starch reduceslevels of glucose-dependent insulinotropic polypeptide mRNA along the jejunum–ileum in both normal and type 2 diabetics rats. Bioscience, Biotechnology and Biochemistry, 72(8), 2206–2209.
[54] Scholz-Ahrens, E., Ade, P., Marten, B., Weber, P., Timm, W., Yahya, A., et al. (2007).Prebiotics, probiotics, and synbiotics affect mineral absorption, bone mineral content, and bone structure. Journal of Nutrition, 137, 838–846.
[55] Roberfroid, M. B. (2000). Prebiotics and probiotics: Are they functional foods? American Journal of clinical Nutrition, 71(6), 1682–1687.
[56] Perera, A, Meda, V. & Tyler, R.T. (2010) Resistant starch: A review of analytical protocols for determining resistant starch and of factors affecting the resistant starch content of foods. Food Research International, 43:1959-1974.

[57] Ferguson, L. R., Tasman-Jones, C., Englyst, H., & Harris, P. J. (2000). Comparative effects of three resistant starch preparations on transit time and short-chain fatty acid production in rats. Nutrition & Cancer, 36, 230–237.
[58] Champ, M., Langkilde, A. M., & Brovns, F. (2003). Advances in dietary fiber characterization 1. Definition of dietary fiber, physiological relevance, health benefits and analytical benefits. Nutrition Research Reviews, 16, 71–82.
[59] Bingham, S. A., Day, N. E., & Luben, R. (2003). Dietary fiber in food and protection against colorectal cancer in the European prospective investigation into cancer and nutrition (EPIC): An observational study. The Lancet, 361, 1496–1501.
[60] Leu, R. K., Hu, Y., & Young, G. P. (2002). Effects of resistant starch and nonstarch polysaccharides on colonic luminal environment and genotoxin-induced apoptosis in the rat. Carcinogenesis, 23(5), 713–719.
[61] Morita, T., Kasaoka, S., Hase, K., & Kiriyama, S. (1999). Psyllium shifts the fermentation site of high-amylose cornstarch toward the distal colon and increases fecal butyrate concentration in rats. Journal of Nutrition, 129,2081–2087.
[62] Liu, R., & Xu, G. (2008). Effects of resistant starch on colonic preneoplastic aberrant crypt foci in rats. Food and Chemical Toxicology, 46, 2672–2679.
[63] Han, K. H., Fukushima, M., Kato, T., Kojima, M., Ohba, K., Shimada, K., et al. (2003). Sterol excretions and hepatic mRNA levels in rats. Lipids, 38(9), 919–924.
[64] Martinez-Flores, H. E., Chang, Y. K., Martinez-Bustos, F., & Sgarbierid, V. (2004). Effect of high fiber products on blood lipids and lipoproteins in hamsters. Nutrition research, 24(1), 85–93.
[65] De-Deckere, E. A. M., Kloots, W. J., & Van-Amelsvoort, J. M. M. (1993). Resistant starch decreases serum total cholesterol and triacylglycerol concentrations in rats. Journal of Nutrition, 123, 2142–2151.
[66] Hashimoto, N., Ito, Y., Han, K. H., Shimada, K., Sekikawa, M., Topping, D. L., et al. (2006). Potato pulps lowered the serum cholesterol and triglyceride levels in rats. Journal of Nutritional Science and Vitaminology, 52, 445–450.
[67] Mikušová, L., Šturdík, E., Mošovská, S., Brindzová, L., & Mikulajová, A. (2009). Development of new bakery products with high dietary fiber content and antioxidant activity for obesity prevention. In Proceedings of 4th international dietary fiber conference (p. 185). Vienna, Austria: International association for cereal science and technology (ICC).
[68] Ranganathan, S., Champ, M., Pechard, C., Blanchard, P., Nguyen, M., Colonna, P., et al. (1994). Comparative study of the acute effects of resistant starch and dietary fibers on metabolic indexes in men. American Journal of Clinical Nutrition, 59,879–883.
[69] Tagliabue, A., Raben, A., Heijnen, M. L., Deurenberg, P., Pasquali, E., & Astrup, A. (1995). The effect of raw potato starch on energy expenditure and substrate oxidation. American Journal of Clinical Nutrition, 61, 1070–1075.
[70] Howe, J. C., Rumpler, W. V., & Behall, K. M. (1996). Dietary starch composition and level of energy intake alter nutrient oxidation in 'carbohydrate-sensitive' men. Journal of Nutrition, 126, 2120–2129.
[71] Roben, A., Andersen, K., & Karberg, M. A. (1997). Acetylation of or B- cyclodesetrin addition to potato starch: Beneficial effect on glucose metabolism and appetite sensations. American Journal of Clinical Nutrition,66, 304–314.
[72] Tapsell, L. C. (2004). Diet and metabolic syndrome: Where does resistant starch fit in? Journal of the Association of Analytical Chemists International, 87(3), 756–760.
[73] De Roos, N., Heijnen, M. L., & De Graff, C. (1995). Resistant starch has little effect on appetite, food intake and insulin secretion of healthy young men. European Journal of Clinical Nutrition, 49, 532–541.
[74] Anderson, G. H., Catherine, N. L., & Woodend, D. M. (2002). Inverse association between the effect of carbohydrates on blood glucose and subsequent

short term food intake in young men. American Journal of Clinical Nutrition, 76,1023–1030.
[75] Higgins, J. A., Higbee, D. R., Donahoo, W. T., Brown, I. L., Bell, M. L., & Bessesen, D. H. (2004). Resistant starch consumption promotes lipid oxidation. Nutrition & Metabolism, 1, 8.
[76] Keenan, M. J., Zhou, J., Mccutcheon, K. L., Raggio, A. M., Bateman, H. G., Todd, E., et al. (2006). Effects of resistant starch, a non-digestible fermentable fiber, on reducing body fat. Obesity, 14, 1523–1534.
[77] Lopez, H. W., Levrat-Verny, M. A., Coudray, C., Besson, C., Krespine, V., Messager, A., et al. (2001). Class 2 resistant starches lower plasma and liver lipids and improve mineral retention in rats. Journal of Nutrition, 131, 1283–1289.
[78] Younes, H., Levrat, M. A., Demige, C., & Remesy, C. (1995). Resistant starch is more effective than cholestyramine as a lipid-lowering agent in the rat. Lipids, 30,847–853.
[79] Trinidad, T. P., Wolever, T. M. S., & Thompson, L. U. (1996). Effect of acetate and propionate on calcium absorption from the rectum and distal colon of humans. American Journal of Clinical Nutrition, 63, 574–578.
[80] Canovas, A., & Pérez-Alvarez, J. A. (2006). La fibra dietética: Un ingrediente para el desarrollo de alimentos funcionales. Alimentaria, 370, 65–68.
[81] Yue, P., & Waring, S. (1998). Resistant starch in food applications. Cereal Foods World, 43(9), 690–695.
[82] Coudray, C., Bellanger, J., Castiglia-Delavaud, C., Rémésy, C., Vermorel, M., & Rayssignuier, Y. (1997). Effect of soluble or partly soluble dietary fibers supplementation on absorption and balance of calcium, magnesium, iron and zinc in healthy young men. European Journal of Clinical Nutrition, 51, 375–380.
[83] Fausto, F. D., Kacchi, A. I., & Mehta, D. (1997). Starch products in confectionery. Beverage & Food World, 24(4), 4–16.
[84] Thompson, D. B. (2000). On the non-random nature of amylopectin branching. Carbohydrate Polymers, 43, 223–239.
[85] Augustin, M. A., Sanguansri, P., & Htoon, A. (2008). Functional performance of a resistant starch ingredient modified using a microfluidiser. Innovative Food Science and Emerging Technologies, 9, 224–231.
[86] Premavalli, K. S., Roopa, S., & Bawa, A. S. (2006). Resistant starch – A functional dietary fiber. Indian Food Industry, 25(2), 40–45.
[87] Baghurst, P. A., Baghurst, K. I., & Record, S. J. (1996). Dietary fiber, non-starch polysaccharides and resistant starch – A review. Food Australia, 48(3): 3–35.
[88] Seib, P. A., & Kyungsoo, W. (1999). Food grade starch resistant to a-amylase and method of preparation. US patent 5855,946. January 5, 1999. Manhattan, Kansas: Kansas State Univ Research Foundation.
[89] Arimi, J. M., Duggan, E., O'Riordan, E. D., O'Sullivan, M., & Lyng, J. G. (2008). Microwave expansion of imitation cheese containing resistant starch. Journal of Food Engineering, 88: 254–262.
[90] Montesinos-Herrero, Clara., C. Cottell, David., O'Riordan, E. Dolores., O'Sullivan, Michael.(2006). Partial replacement of fat by functional fiber in imitation cheese: Effects on rheology and microstructure. International Dairy Journal 16 : 910–919.
[91] Mirzaei,H., Pourjafar,H., Homayouni,A. (2012). Effect of calcium alginate and resistant starch microencapsulation on the survival rate of Lactobacillus acidophilus La5 and sensory properties in Iranian white brined cheese. Food Chemistry 132 :1966–1970.