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Development of Low-Glycemic-Index Rice Using Novel Processing Techniques

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Rice (*Oryza sativa* L.) is a staple carbohydrate for over half of the world. It is, however, clear that the increasing world and high Glycemic Index (GI) and high rate of starch digestion of highly polished white rice are epidemiologically related to the increasing prevalence of type 2 diabetes mellitus (T2DM) and metabolic syndrome. Even though genetic breeding of high-amylose varieties is one of the opportunities to decrease GI, it tends to influence sensory and textural properties that consumers are seeking. This has resulted in the invention of post-harvest innovative processing techniques as a scientific necessity. The physicochemical processes of starch modification, that is, conversion of fast digestible starch to resistant starch (RS) by using advanced interventions such as Heat-Moisture Treatment (HMT), High Hydrostatic Pressure (HHP) and enzymatic debranching. These technologies have the potential to be useful interventions to the metabolic impacts of this ubiquitous staple by modulating the thermodynamic and structural properties of the rice endosperm to provide feasible solutions to the idea of stealth health.

Keywords: Glycemic Index, Heat-Moisture Treatment, High Hydrostatic Pressure,

Introduction

In the past, yield and caloric density have been more of a concern to the food security of the world. The milling and polishing of rice processing is done to remove the germ and lipid-rich bran to increase shelf life and palatability. Only remains then the endosperm: a highly concentrated mass of starch granules, bound back in a protein meshwork. While cooking, the starch present in white rice is completely gelatinised. The amylopectin is highly branched, allowing rapid degradation by the salivary and the pancreatic α-amylase, and follow-on degradation by α-glucosidase in the small intestine. This leads to the quick rise of the glucose level in the blood. The foods are classified according to the **Glycemic Index (GI),** where glucose is used as the reference point (GI = 100). The majority of the commercial types of white rice have a high GI (between 70 and 85). The prolonged use of high-GI diets worsens insulin resistance and overloads the pancreatic β-cells.

Scientifically, it is accepted that the rice glycemic index is high and also needs to be reduced. Focusing on altering the physical chemistry of the grain by the food scientists and engineers, rather than doing anything to alter the existing cultural eating habits that are established. The scope is to enrich the proportion with Slowly Digestible Starch (SDS) and Resistant Starch (RS) without necessarily changing the physical appearance or cooking and making characteristics of the grain.

Chemistry of Rice Starch and Digestibility

Rice starch is a blend of two D-glucan polymers:

- Amylose: A fairly straight polymer of D-glucose units that are connected by α (1,4)-glycosidic bonds. It is a helical structure with a tightly packed nature.
- Amylopectin: A macromolecule in the amylopectin that is highly branched because of the presence of α (1,4) backbone and common α (1,6) branch. It is amorphous, bulkier and larger.

Hydrothermal cooking causes the absorption and subsequent swelling of starch granules under the influence of water and the breakdown in hydrogen bonds under the influence of heat, resulting in gelatinisation and leaching of amylose. This transition is marked by onset (T_o), peak (T_p), and conclusion (T_c) temperatures and enthalpy change (Delta H), which is usually determined in DSC.

Upon cooling, starch chains reassociate (retrogradation) amylose crystallises rapidly, and amylopectin more slowly. Such crystal networks are also enzyme resistant, leading to the production of Type 3 resistant starch (RS3).

Table 1: Classification of Resistant Starch (RS)

Type	Description	Source / Formation Method	Digestibility Profile
RS1	Physically inaccessible starch	Whole or partially milled grains, seeds	Resists digestion due to intact cell walls.
RS2	Native, ungelatinized granular starch	Raw potatoes, green bananas	B-type or C-type polymorphs resist enzymatic binding.
RS3	Retrograded starch	Cooked and cooled rice, pasta	Formed via thermodynamic recrystallisation after gelatinisation.
RS4	Chemically modified starch	Cross-linked or etherified starches	Artificial bonds prevent enzyme recognition.
RS5	Amylose-lipid complexes	Lipid-fortified extruded grains	Hydrophobic interactions form V-type crystalline complexes.

Table 2: Factors Affecting GI of Rice

Factor	Mechanism	Effect on GI
Amylose content	Slower digestion	↓ GI
Amylopectin content	Rapid digestion	↑ GI
Processing (parboiling, milling)	Alters starch structure	Variable
Cooking & storage	Retrogradation	↓ GI
Dietary fibre & lipids	Delay digestion	↓ GI

Novel Processing Techniques for GI Reduction

The general aim of new rice processing is to physically or biochemically reorganise the native starch matrix to enhance the production of RS3 and RS5, hence reduced the total GI.

1. Parboiling

Paddy soaking → Steaming → Drying → Milling

Mechanism

- Starch gelatinisation
- Formation of **amylose-lipid complexes**
- Increased **retrograded starch**

These changes reduce starch digestibility and lower GI.

Evidence

- GI reduced to ~53.9 in parboiled rice

- Pressure parboiling reduced GI by ~30% compared to raw rice

Effect of Parboiling Severity

Processing Type	**GI Value**
Non-parboiled	~55
Traditional parboiled	~46
Pressure parboiled	~39

2. Heat-Moisture Treatment (HMT) and Annealing (ANN)

The most extensively studied physical modification method is hydrothermal treatments. Physical techniques are very popular hydrothermal processes which can improve the movement of the molecules in the starch grains through the use of heat.

- **Heat-Moisture Treatment (HMT):** Formation of compact crystalline structure of amylose and amylopectin due to the stress reorganisation that occurs with low moisture (10-30%) and high temperature (90-120ºC).
- **Annealing (ANN):** It is less susceptible to enzyme digestion because the crystalline order is formed by low temperatures (under gelatinization) in high moisture (>60%). High Hydrostatic Processing (HHP). High Hydrostatic Pressure (HHP) is a non-thermal treatment that subjects rice to 100-600 MPa in liquid, and the pressure is evenly distributed throughout the food structure.

Features

- Uses high pressure instead of heat
- Modifies starch crystallinity

At pressures above 400 MPa, starch granules can be exposed to water, which can separate hydrogen bonds (non-covalent interactions) but not glycosidic bonds. It results in gelatinization at room temperature due to pressure.

3. Germination (Pre-soaking Sprouting)

Paddy soaking → Germination (24–72 h) → Drying → Milling → Cooking

Mechanism

- Activation of enzymes
- Increase in bioactive compounds
- Modification of starch structure

Germination + parboiling significantly lowers GI without affecting taste.

4. Enzymatic Debranching and Controlled Retrogradation

High specificity in lowering rice GI is provided through biochemical methods of enzyme modification of amylopectin. Branch-cleaving enzymes such as **isoamylase** and **pullulanase** break α(1,6) glycosidic bonds at the end of the branches, transforming branched amylopectin to linear chains that are more prone to retrogradation and to form RS3.

5. Extrusion Cooking

Extrusion is the process of forcing a dough of rice flour through a die that has a shape and is subjected to high shear, pressure and temperature. Although mainly applied to snacks, new extrusion profiles are being employed to manufacture so-called **reconstructed** or **fortified** rice kernels.

At this stage of the melt, the functional ingredients that reduce GI may be incorporated into the matrix:

- **Dietary Fibers:** Soluble fibers (such as guar gum or oat and β-glucan) can be added. They raise the viscosity of human gut digesta, retarding the emptying of the stomach and glucose uptake.
- **Polyphenols:** Plant extracts that contain polyphenols in abundance can be extruded with the rice. The enzymes inhibited by polyphenols like e.g., such as α-amylase and α-glucosidase, are competitively inhibited in nature.

6. Chemical and Enzymatic Modification

- Use of organic acids (e.g., citric acid)
- Enzyme treatments

These methods promote resistant starch formation and reduce GI.

Physicochemical and Sensory Impacts

The main challenge in the creation of low-GI processed rice is collateral effects on sensory characteristics. The main criteria of rice as judged by consumers are visual appeal, scent and texture in terms of the degree of hardness and stickiness.

Texture Profile Analysis (TPA): The majority of methods to further raise Resistant Starch also raise the rigidity of the starch matrix.

- **Hardness:** HMT and enzymatic retrogradation make rice harder because of hard crystalline structures limiting hydration during cooking.
- **Stickiness:** The decreased amylopectin leaching or the immobilization reduces the stickiness of low-GI rice.

Sensory Mitigation Strategies

Processing is also optimized to counteract decreased palatability, such as mild ultrasound with shorter HMT can enhance resistant starch without decreasing tenderness. Ahead of drying, hydrocolloid coatings also improve mouthfeel and the retention of moisture during cooking.

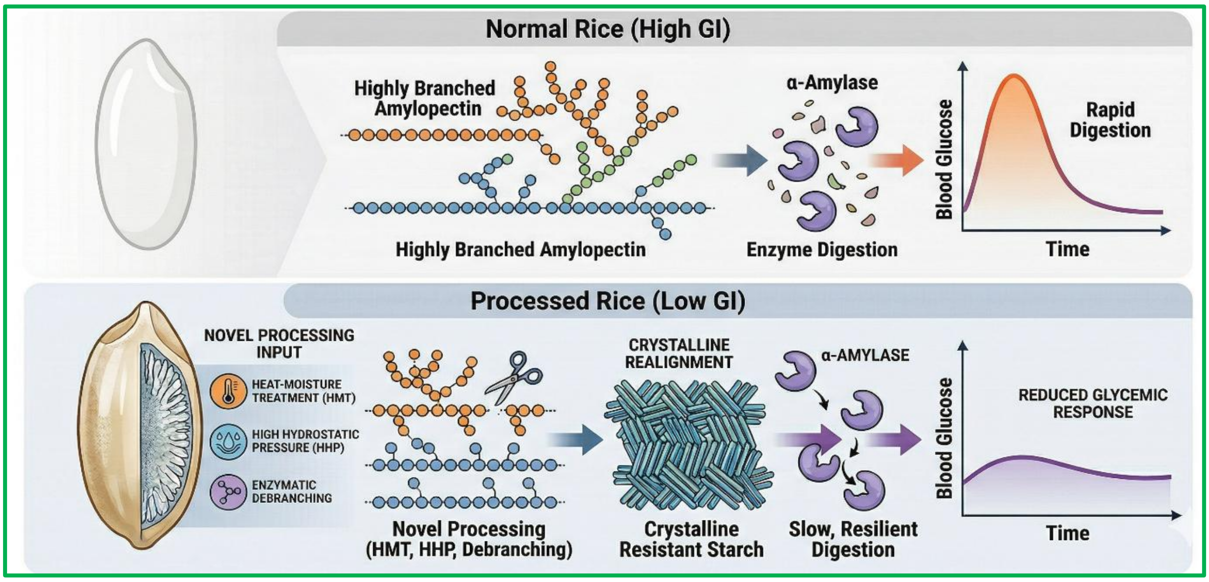

Fig 1: Comparison between Rice Molecular Structure- Normal and Processed Rice

Future Perspectives

1. **Emerging Technologies**
- Nanotechnology-based starch modification
- AI-assisted processing optimization
- Hyperspectral quality control.

1. **Research Directions**
- Combining genetic and processing approaches
- Invention of ready-to-eat LGI rice products.
- Personalized nutrition

Conclusion

Heat-Moisture Treatment, High Hydrostatic Pressure, enzymatic debranching, and advanced extrusion are examples of technologies that are demonstrating the possibility of reorganizing the thermodynamic and molecular properties of starch in a fundamental manner. With the simple transformation of amylopectin into easily digestible forms into highly ordered, resistant crystal forms, scientists are actively creating rice that behaves metabolically like a complex and fiber-rich food. With the development of precision food engineering, stealth health strategies such as processed low-GI rice will become the most important part of global preventive healthcare. It will silently reduce the metabolic load in the global population as grain of tomorrow will have its cultural echo and gastronomic versatility sound.

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