KAPITEL 3 / CHAPTER 3 [3]
TECHNOLOGICAL SOLUTIONS FOR COMBATING THE "SUGAR EPIDEMIC": EXPERIENCE IN CONTINUOUS PROCESSING OF RAW MATERIALS FOR LOW GLYCEMIC INDEX FLAKES

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Introduction

The Concept of the "Sugar Epidemic"

In recent decades, the global prevalence of type 2 diabetes, metabolic syndrome, and obesity has surged at an alarming rate, leading to the widespread adoption of the term "sugar epidemic." According to the World Health Organization (WHO), the number of individuals diagnosed with type 2 diabetes has quadrupled since 1980, with current estimates exceeding 422 million cases worldwide [1].

One of the primary contributors to this phenomenon is excessive consumption of foods with a high glycemic index (GI), which triggers sharp fluctuations in blood glucose levels and fosters insulin resistance. High-GI foods cause rapid spikes in blood sugar, prompting the pancreas to release substantial amounts of insulin. Over time, this strain depletes pancreatic β-cells, ultimately increasing the risk of type 2 diabetes and associated metabolic disorders [2].

Moreover, diets rich in refined carbohydrates and sugar are strongly linked to obesity, as they provide only transient satiety while promoting excessive caloric intake. Research indicates that high-GI diets elevate the risk of cardiovascular disease by 37% and negatively impact cholesterol levels [3].

The modern confectionery industry plays a significant role in the rising consumption of rapidly digestible carbohydrates. Traditional sweets, often composed of white flour, sugar, and trans fats, have a high glycemic index, which disrupts metabolic processes and exacerbates insulin resistance [6].

The Role of Low-GI Foods in Combating the "Sugar Epidemic"

One of the most effective strategies for addressing the "sugar epidemic" is

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replacing high-GI foods with alternatives that have a slower carbohydrate metabolism. This approach is based on reducing the rate of carbohydrate digestion by incorporating alternative ingredients such as dietary fiber, proteins, and resistant starches [4].

- Dietary fiber, found in oats, whole grains, and legumes, slows starch breakdown and promotes a gradual increase in blood glucose levels. Studies have shown that consuming 30 grams of fiber daily can reduce the risk of diabetes by 40% [5].
- Proteins, both plant- and animal-based, enhance insulin sensitivity and slow glucose absorption in the intestines. For example, incorporating nut or legume flour into baked goods can lower their GI by 20–30%.
- Resistant starches and low-glycemic carbohydrates, present in chickpea and lentil flour, amaranth, and quinoa, have minimal impact on blood sugar levels while promoting prolonged satiety [5].

Beyond their health benefits, low-GI foods hold significant market potential. The global health food industry is expanding by 7–10% annually, with rising demand for low-glycemic confectionery driven by increasing rates of diabetes, obesity, and cardiovascular diseases [4].

Thus, integrating low-GI food production technologies can significantly mitigate the adverse effects of the "sugar epidemic" and serve as a crucial tool in addressing metabolic disorders.

3.1. Review of Scientific Advances

Lowering the glycemic index (GI) of foods has become a key focus in the development of modern food technologies. Traditional grain and legume-based products often have a high GI, which can lead to sharp fluctuations in blood glucose levels, thereby increasing the risk of type 2 diabetes, obesity, and cardiovascular diseases.

One of the most effective strategies for regulating GI involves technological processing of raw materials, which alters the structure of starch, fiber, and other carbohydrate components. In particular, acidic and alkaline soaking has been shown to promote the formation of resistant starch (RS), which helps reduce the body's glycemic response.

3.1.1. Technological Processing of Raw Materials for Lowering GI

The Impact of Alkaline and Acidic Soaking on Carbohydrate Structure

Alkaline Soaking (Nixtamalization and Other Methods)

Alkaline treatment of grains is among the most effective techniques for modifying their structure. Studies indicate that soaking grains in an alkaline solution (e.g., $Ca(OH)_2$, NaOH, KOH) facilitates:

- Amylopectin degradation, which slows down starch breakdown [6].
- Increased resistant starch (RS) formation, making it less digestible in the small intestine while allowing fermentation in the colon, thus benefiting gut microbiota [7].
- A 15–30% reduction in glycemic response, as demonstrated in experiments on nixtamalized cereals [8].

Nixtamalization has traditionally been used for corn processing; however, research by Simsek et al. (2014) explored its application to wheat, sorghum, and rice. Findings revealed that this treatment enhances the nutritional value of grains while reducing their GI by slowing carbohydrate metabolism [9].

Acidic Soaking (Organic Acids – Acetic, Citric, and Lactic Acids)

Organic acids such as acetic, citric, and lactic acids are widely utilized in the food industry due to their ability to:

- Slow starch breakdown, reducing postprandial glucose spikes [10].
- Increase resistant starch content, which helps lower blood sugar levels after meals [11].
- Modify the physicochemical properties of dough, as confirmed in studies on wheat and rye flour [12].

A study by Ostman et al. (2005) found that consuming acetic acid alongside bread

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reduced blood glucose levels by 25–35%. This effect is attributed to the acid's ability to slow gastric emptying and inhibit amylase activity, thereby delaying starch digestion [13].

3.1.2. The Impact of Technological Processing on GI

Numerous studies have identified several key patterns:

1. Acidic and alkaline soaking significantly alters starch structure, making it less accessible to digestive enzymes.
2. The higher the resistant starch content in a product, the lower its GI.
3. Alkaline processing (nixtamalization) and the use of organic acids can reduce the GI of grain-based foods by 10–30%, depending on processing conditions.

Experimental research has demonstrated the following outcomes:

- White wheat bread typically has a GI of 70–75, whereas bread made with acetic acid or sourdough fermentation exhibits a GI of 55–60 [13].
- Acid-treated oats (soaked for 12 hours) show a 10–20% reduction in GI [14].
- Wheat processed with $Ca(OH)_2$ (alkaline treatment) demonstrates a 15–25% decrease in GI [9].

Thus, technological processing of raw materials offers promising opportunities for developing low-GI products, which can be effectively utilized in the production of functional foods.

3.2. Technology for Producing Low-GI Flakes

The development of food products with a low glycemic index (GI) is a key focus of modern food technology. One promising approach involves producing functional flakes made from wheat, chickpeas, and lentils, using specialized pre-processing techniques that modify starch and fiber structure to lower GI.

3.2.1. Production Process: From Raw Materials to Final Product

Selection of Grain and Legume Crops

To produce low-GI flakes, grains and legumes rich in fiber, protein, and resistant starch are selected. The most suitable ingredients include:

- Wheat – Contains significant amounts of protein and fiber, and after acid or alkaline treatment, forms more resistant starch structures [16].
- Chickpeas – Naturally have a low GI (30–35) and contain a high proportion of slow-digesting carbohydrates and fermentation-resistant proteins, which contribute to gradual glucose release [17].
- Lentils – Provide resistant starch and complex carbohydrates, which help reduce postprandial glycemia [18].

Production Stages

1. Raw Material Preparation
   - Cleaning and milling of grains and legumes.
   - Removal of phytic acid to enhance mineral bioavailability.
2. Technological Processing (Soaking)
   - Immersion in acidic (acetic, citric) or alkaline ($Ca(OH)_2$) solutions.
3. Flake Formation
   - Pressing the mixture into thin flakes.
   - Drying to stabilize texture and enhance crispiness.
4. Drying
   - Low-temperature drying (up to 80°C) to preserve nutritional value.

3.2.2. Justification for Using a Continuous Cooker for Soaking

To enhance quality and efficiency, a continuous cooker—an automated system for controlled soaking of grains and legumes—is utilized.

Key Advantages of the Continuous Cooker:

- Uniform raw material processing – Ensures consistent starch structure modification.
- Optimization of the acid-alkaline environment – pH regulation helps reduce the

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glycemic response of the final product.

- Temperature control (50–70°C) – Promotes the formation of resistant starch without compromising fiber integrity.

3.3. Research Objectives and Description of the Continuous Cooker

Modern food technologies are increasingly focused on developing products with a controlled glycemic index (GI), a crucial factor in combating type 2 diabetes, obesity, and metabolic disorders. One promising approach involves the use of a continuous cooker (Figure 1), which enables precise control over the acidic or alkaline soaking process for grains and legumes.

The development and implementation of this method offer several advantages:

- Optimization of carbohydrate structural modifications in raw materials to lower GI.
- Controlled processing environment for precise regulation of acid-alkaline balance.
- Enhanced production efficiency and scalability of the technology.

Figure 1. General view of the raw material soaking system.

The system consists of dry ingredient feeders, dosing units for raw materials and soaking agents (alkali or acid) (Figure 2). Once dosed, the mixture is directed into a high-speed mixer before entering the continuous cooker (Figure 3).

Figure 2. Raw material and ingredient dosing system.

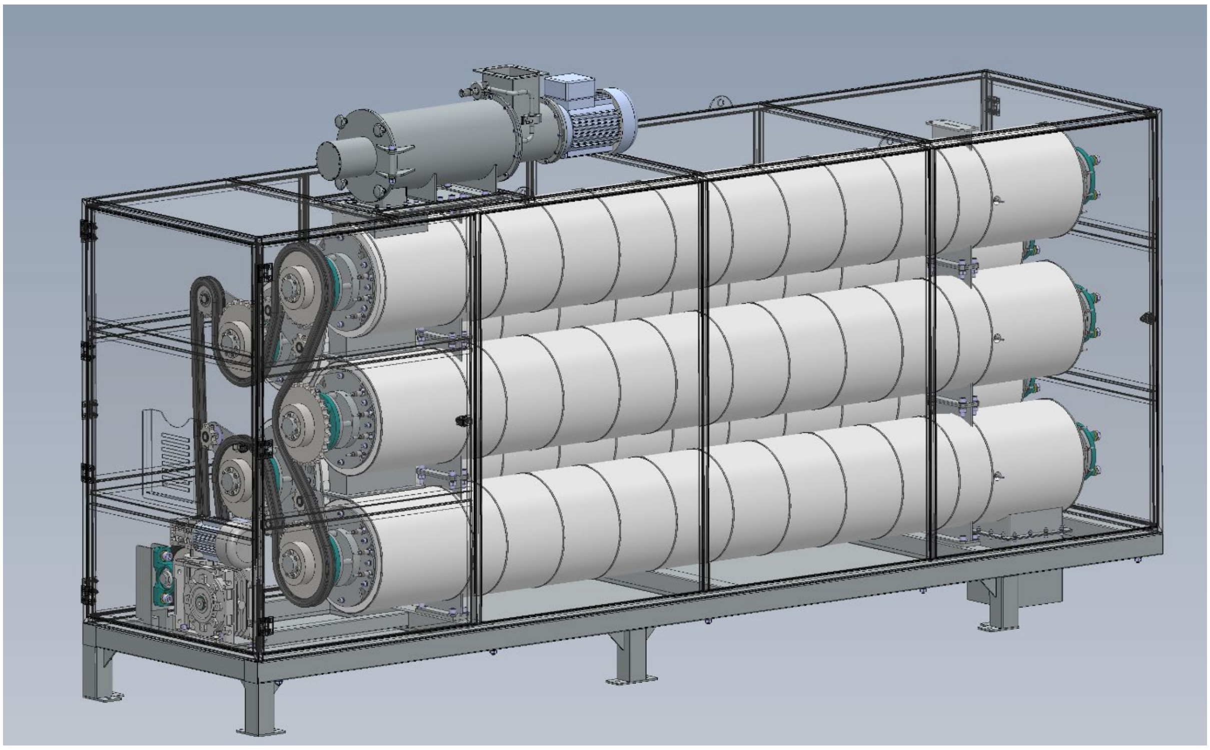

Figure 3. Continuous Cooker – General View.

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The continuous cooker consists of dosing units, a high-speed mixer, mixing chambers, heating elements, and an automation and control system. The mixing mechanism is designed in the form of a spiral (Figure 4). The heating zones allow for precise temperature and mixing time regulation.

This project was successfully implemented in a food production facility in India, demonstrating significant advantages in efficiency and processing control.

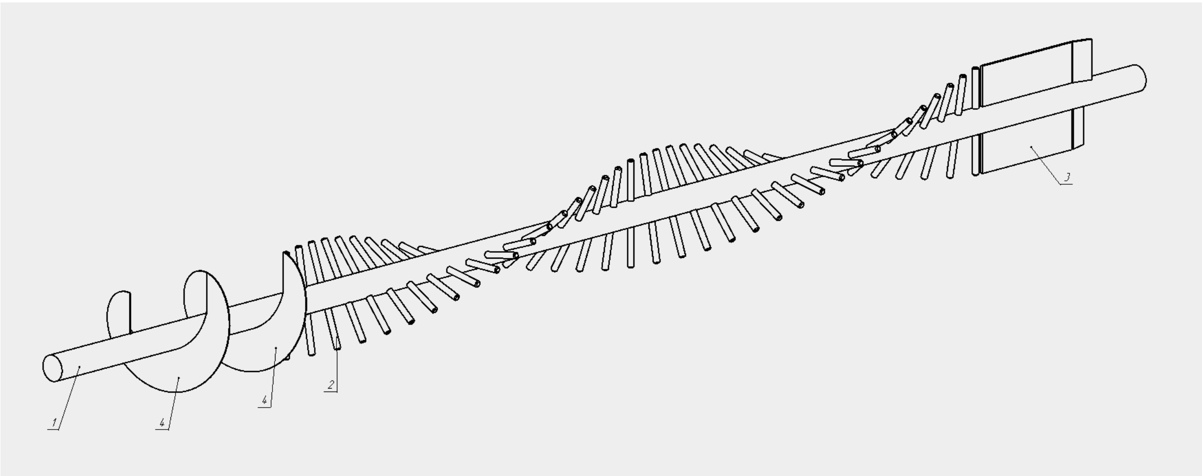

Figure 4. General view of the mixing mechanism.

3.3.1. Development of a New Raw Material Processing Method

Using a Continuous Cooker for Soaking

Traditional grain soaking methods rely on periodic immersion in a solution, which presents several drawbacks, including uneven processing, high water and energy consumption, and limited process control.

The continuous cooker overcomes these challenges by ensuring:

- Automated regulation of key processing parameters (temperature, pH, soaking duration).
- Even distribution of acids or alkalis throughout the raw material flow.
- Flexible settings for different types of grains and legumes.

This technology enables precise control over:

- Solution penetration depth into grains and legumes.
- Soaking duration, which influences starch structure modification.
- Formation of resistant starch, which slows carbohydrate metabolism and reduces

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the GI of the final product.

Controlled Regulation of Acid-Alkaline Balance

One of the most critical factors in GI modification is maintaining precise pH control during processing. Depending on the reagents used, different effects can be achieved:

- Acidic soaking (acetic, citric, lactic acids):
  - Enhances fiber hydration and solubility.
  - Promotes the formation of resistant starch.
  - Slows carbohydrate digestion, reducing GI.
- Alkaline soaking (calcium, sodium, or potassium hydroxide):
  - Used in nixtamalization (e.g., for corn flour production).
  - Breaks down anti-nutritional factors, improving protein and micronutrient bioavailability.
  - Promotes stable glycosidic bonds, slowing starch breakdown.

Automated pH regulation allows for the precise optimization of processing parameters for each type of raw material, making this technology highly adaptable across various food production industries.

3.3.2. Advantages of the Method Over Traditional Approaches

Higher Processing Efficiency

The continuous cooker enables the rapid processing of large volumes of raw materials, significantly reducing production costs.

Key advantages:

- Stable process parameters, ensuring uniform product quality.
- Precise reagent dosing, minimizing raw material loss and excess chemical use.
- Elimination of intermediate drying steps, reducing energy consumption.

Traditional batch-soaking methods require extended processing times (up to 12–24 hours), whereas the continuous cooker shortens this time significantly, ensuring greater process control and efficiency.

Scalability for Industrial Production

The continuous processing system is easily adaptable to large-scale food production, offering multiple benefits:

- Flexible processing settings, allowing optimization for various grains and legumes.
- Compatibility with existing production lines, making it suitable for flakes, baked goods, and confectionery manufacturing.
- Enhanced quality control, with precise regulation of pH, temperature, and soaking duration, ensuring consistent product properties.

Reduction in Costs and Energy Consumption

One of the major benefits of implementing this technology is its economic efficiency. The continuous cooker helps achieve:

- Lower water consumption through a closed-loop reagent recirculation system.
- Minimized raw material losses, thanks to accurate dosing and even soaking.
- Optimized energy use, as heating is applied only to essential processing zones, preventing unnecessary heat loss.

Compared to traditional soaking methods, adopting a continuous cooker results in:

- 15–25% reduction in electricity consumption.
- 20–30% decrease in reagent use.
- 2–3 times shorter production cycles.

This makes the technology not only highly efficient but also environmentally sustainable, aligning with modern trends in the food industry.

Future Research Directions

The proposed continuous soaking technology, utilizing acidic and alkaline treatment, offers significant improvements in food quality, glycemic index reduction, and production efficiency.

Future studies could focus on:

- Optimizing processing parameters to maximize benefits.
- Investigating biochemical changes in grain structures.
- Scaling up the technology for industrial applications.

These advancements could pave the way for the development of new functional food products, particularly beneficial for consumers managing blood glucose levels.

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Conclusions

The development and implementation of technologies to lower the glycemic index (GI) of food products represent a crucial area in modern food science. This study examined the effects of acidic and alkaline soaking of grains and legumes in a continuous cooker on their structural properties, which directly influence the GI of the final product.

Technological processing in a continuous cooker allows for precise control of acid-alkaline balance, soaking duration, and temperature conditions, facilitating the formation of resistant starch and slowing carbohydrate digestion. As a result, this approach enables the production of foods with a more gradual glycemic response, which is essential for the prevention of type 2 diabetes, obesity, and metabolic disorders.

The use of low-GI flakes produced through this technology could play a role in combating the "sugar epidemic." Reducing GI helps regulate blood glucose levels, lower the risk of metabolic diseases, and promote overall consumer health.

This proposed technology has significant potential for application in the production of:

- Confectionery products
- Breakfast cereals
- Bakery items
- Dietary and sports nutrition

Future research could focus on:

- Optimizing processing parameters for enhanced efficiency.
- Investigating the impact of different acid-alkaline environments on raw material structure.
- Expanding industrial applications of this technology.

These advancements could contribute to the creation of new functional food products, supporting the global efforts to improve dietary health and metabolic disease prevention.

Prospects for Further Research

The proposed grain and legume processing technology using a continuous cooker offers extensive opportunities for further research and refinement. Future work could focus on optimizing processing parameters, studying the effects of different acid-alkaline environments on the glycemic index (GI), and implementing the technology in large-scale production.

Optimization of Continuous Cooker Parameters

Enhancing the temperature control system, processing time, and reagent concentrations is crucial for improving efficiency. A key objective is to determine the optimal balance of technological factors to minimize energy consumption while maximizing production efficiency.

Biochemical Studies on Acid-Alkaline Treatment

Further research should investigate how different acid-alkaline environments affect the structural changes in carbohydrates and proteins. Identifying the most effective chemical agents for promoting resistant starch formation and slowing carbohydrate digestion will enable the customization of processing techniques for various grain and legume types.

Industrial Implementation

The next step is to adapt the technology for large-scale food production. This requires:

- Equipment modifications to suit industrial processing needs.
- Development of quality standards to ensure product consistency.
- Economic feasibility analysis to assess the cost-effectiveness of using modified flakes in mass production.
- Consumer demand evaluation to integrate low-GI products into the functional food market effectively.

Conclusion

Future research in this field will contribute to the expansion of healthy, dietary, and functional food options, forming part of a comprehensive strategy to combat the "sugar epidemic" and improve consumer well-being.

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