

Development of Controlled-Release Functional Foods for Targeted Gastrointestinal Nutrient Delivery

Gunjan¹, Shivam Gupta² and Ranjana Pande³

¹Department of Life Sciences, Sharda School of Bio-Science & Technology, Sharda University, Greater Noida, Uttar Pradesh, INDIA

²Department of Life Sciences, Sharda School of Bio-Science & Technology, Sharda University, Greater Noida, Uttar Pradesh, INDIA

³Department of Life Sciences, Sharda School of Bio-Science & Technology, Sharda University, Greater Noida, Uttar Pradesh, INDIA

³Corresponding Author: ranjanapande@gmail.com



www.jrasb.com || Vol. 5 No. 3 (2026): June Issue

Received: 19-05-2026

Revised: 22-06-2026

Accepted: 27-06-2026

ABSTRACT

Nutrition bars are popular among people because they are easy to carry and consume but most of the bars available in the market are made with a uniform internal mixture. They do not have any distinct layers, due to this homogeneous structure or nutrients such as carbohydrates, proteins and fat begins digesting at the same time after consumption. This often leads to sudden increase in blood sugar levels, and a quick decline in energy. As a result consumers may experience early hunger and fatigue.

This concept of self-regulating digestion and the manner in which the framework of the food can adjust the rate by which nutrients reach the gut is the concept the product builds around. Rather than those conventional encapsulation tricks or artificial coatings, this bar depends on the variations of the behavior of proteins in acid and fat- matrix characteristics to schedule when nutrients are released.

The prototype consists of three different layers each developed for a specific digestive phase.

This approach of time program nutrition represents a structural strategy rather than a pharmaceutical intervention here naturally occurring physiochemical properties are utilized to achieve control digestion instead of synthetic agents or chemical coating such a design makes the concept feasible for food production while maintaining functional benefits.

Keywords- Layered nutrition bar, Time-programmed nutrition, Satiety enhancement, Sustained energy release, Multi-layer food systems.

I. INTRODUCTION

Recently, there is an observed trend of the increased popularity of convenient and functional foods caused by accelerated lifestyles and heightened health awareness among people. Nutrition bars, namely protein and energy bars, have become one of the most demanded dietary items due to their convenience, easy consumption, and compact source of essential nutrients. In addition, nutrition bars are widely used by sportsmen and people who are in need of fast meal replacement or additional sources of energy.

Problem Statement: Limitations of Conventional Nutrition Bars

Traditional nutrition bars cannot be considered completely effective due to multiple factors.

- most commercially available nutrition bars are composed of a single mixture of carbohydrates, proteins, and fats that leads to simultaneous release of these nutrients. As a consequence, these products cause fast blood glucose increase followed by its quick fall, which results in fatigue and early hunger.

- such products do not contain any means to control the digestion rate or regulate the absorption time of nutrients.

As a result, a growing number of studies are focused on the creation of functional foods capable of providing controlled and targeted delivery of nutrients. One of the innovative approaches implies a design of the so-called self-regulating food whose structure defines the speed and the sequence of nutrients release without the use of any mechanical devices and chemicals. Self-regulation of digestion can be achieved through different strategies related to solubility, gel formation, and fat-based architecture of food.

Objective of the study

The current project involves the development of self-regulated nutrition bar capable of providing a time-released function. It should be noted that the proposed nutritional bar is going to represent a multi-layer product that is going to disintegrate under certain conditions of the digestion process and provide controlled release of nutrients. Such a product will help consume energy, feel satiated, and prevent fatigue.

II. CONCEPTS UTILIZED

• Self-regulated digestion

Self-regulated digestion refers to the complex, automatic physiological mechanisms within the gastrointestinal (GI) tract—coordinated by neural and endocrine systems—that break down food, extract nutrients, and regulate the rate of digestion based on food composition and volume.

• Time-release functionality

Time-release functionality in nutrition refers to strategies designed to control the rate at which nutrients are released, digested, and absorbed by the body, ensuring a sustained supply rather than a rapid spike. This concept encompasses both nutrient-delivery technologies in supplements (such as sustained-release tablets) and dietary patterns (such as time-restricted eating) that align intake with the body's circadian rhythms to optimize metabolism.

In nutrition bars involves formulating ingredients to release energy and nutrients at different rates—often combining fast-acting carbohydrates for immediate energy with sustained-release proteins or fiber to provide a steady supply of nutrients over several hours. This approach helps manage blood sugar levels, supports sustained energy for athletes, and enhances satiety.

III. PRODUCT CONCEPT OVERVIEW

The nutrition bar is engineer to deliver new trends in a time program manner. Its innovative structure she has a sequential release of nutrients that aling with the physiological digestive needs of the body. Instead of

a homogeneous mixture the bar will be divided into 3 different layers.

Layer 1: Immediate Energy Layer

The first layer of the nutrition bar is design for Rapid energy providing and immediate energy boost to the consumer it's composition and sure quick digestion and absorption within the intake initial phase of digestion.

- **Components:** Glucose, sucrose, maltodextrin, fruit sugars.
- **Characteristics:** High water solubility, allowing for rapid breakdown.
- **Digestion Time:** 0–15 minutes post-ingestion.
- **Function:** Provides quick and readily available energy to the body, ideal for immediate energy requirements.

The presence of glucose in the bar deliver instant energy it also prevents crystallization of so close in the caramel as glucose clogs molecule from arranging into crystals by acting as an interfering agent. In substitution of glucose syrup and invert sugar can also be used.

Layer 2: Sustained Energy & Satiety Layer

The second layer of bar is engineer to provide sustain energy and promote satiety. This is achieved through a specific combination of proteins and fibres that form a stable gel matrix.

- **Components:** Casein protein/plant protein, oats, soluble fiber (Psyllium husk).
- **Characteristics:** Forms a protein-fibre gel matrix, which slows down digestion.
- **Digestion Time:** 30–60 minutes post-ingestion.
- **Function:** Facilitates controlled glucose release, preventing crashes, and enhances satiety for a prolonged period.

Plant protein is preferred as its easier to digest and contains no lactose which makes it better for lactose intolerant. Whey lacks fiber, plant proteins often provide fiber, iron, and antioxidant benefits. While whey can create a very dense or chewy texture, plant proteins allow for different textures and, offer an earthy, versatile ingredient profile for varying flavors.

Addition of oats helps form a solid layer it prevention bar from Breaking and makes it easier to press into mould. Without the addition of oats the bar becomes Chalky in taste which is not preferable. It gives after bite and reduces dryness as oats have a great water holding capacity.

Psyllium husk commonly known as [isabgol] absorbs water and forms a gel like Matrix helping hold the ingredients together and prevents the bar from Breaking. It also have a high water holding it is rich insoluble fibers good for gut help and adds functional value to the nutrition bar.

Layer 3: Delayed Functional Layer

The innermost and most slowly digesting layer is designed for delayed nutrient release, contributing to long-term energy and fatigue prevention. Its

hydrophobic nature ensures a prolonged breakdown process.

- **Components:** Nut butter, vegetable fat, essential minerals
- **Characteristics:** Composed of a hydrophobic fat matrix, resistant to rapid enzymatic breakdown.
- **Digestion Time:** 90+ minutes post-ingestion, ensuring a sustained release.
- **Function:** Delays the availability of nutrients, contributing to prolonged energy and effectively preventing fatigue.

It consist of nut butter which is a healthy source of fats and provides adequate amount of protein it improve the palatability of the bar.

The bar was enclosed in an chocolate outer layer it acts as a protective layer, reduces moisture loss/gain and improves the shelf life. It also helps the bar hold its shape and gives a smooth melting feel in mouth.

IV. MATERIAL AND METHODS

Procurement of Raw Material

Sugar, Butter, Fresh Cream, Honey, Plant Protein, Rolled Oats, Psyllium Husk, Coffee flavouring, Cocoa Powder, Peanut Butter.

Methodology

1. A caramel sauce was made by the caramelization of sugar, butter and heavy cream with the addition of invert sugar to prevent crystallization.
2. The second layer was prepared by mixing rolled oats powder with plant protein psyllium husk and cocoa powder binded with honey and water. Coffee flavouring was also added.
3. In the third layer peanut butter was mixed with a tiny amount of vegetable fat to ensure a smooth consistency.
4. A mould was coated with chocolate and the layers were arranged
 - First the caramel layer was added and allowed to set for 10 minutes.
 - Then the protein layer was added and again allowed to set for 10 minutes.
 - In the end the final peanut butter layer was added and coated with chocolate again.

The chocolate was allowed to set before de molding.



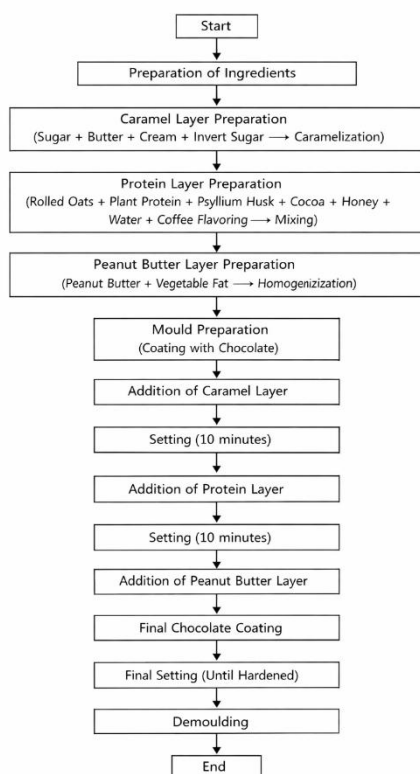
Figure1: Prototype protein bar



Figure 2: Cross-Section of the developed protein bar



Figure 3: Different layers of the bar



V. REVIEW OF LITERATURE

Geeshani Somaratne, Maria J. Ferrua, et.al (2020) reviewed food material properties as determining factors in nutrient release during human gastric digestion. The review explains how the structure and composition of solid foods affect nutrient release in the stomach. It describes key processes like gastric juice diffusion, enzyme action, and mechanical breakdown, and discusses methods used to study them.

Anwesha Sarkar, AtanuSaha, and Alan Mackie (2020) reviewed food structures and oral processing for targeted nutrition. This review discusses how food structure and oral processing affect digestion, nutrient release, and feelings of fullness. It emphasizes the role of microstructure, texture, and chewing in controlling nutrient availability. The study concludes that designing foods with specific structural characteristics can support targeted nutrition, better blood sugar control, and improved appetite regulation.

E. B. Giuntini, A. E. Dan M., F. Hoffmann-Sarda, Sarda F et al. (2022) studied the effects of soluble dietary fibers on glycemic response. They concluded that soluble dietary fibers, especially viscous types like inulin, β -glucan, psyllium, and others, can help reduce post-prandial glycemic response and improve blood glucose control by increasing chyme viscosity, fermentative short-chain fatty acid production, and slowing carbohydrate digestion and absorption. Boukid F. (2020) reviewed plant-based protein bars and their formulation challenges. The review discussed the use of

plant proteins such as pea, soy, and rice protein. It concluded that while plant-based bars are sustainable and health-promoting, issues like texture, flavor, and protein digestibility need optimization.

Santos J. L., Granato D., and Barba F. J. (2021) reviewed functional snack bars enriched with bioactive compounds such as antioxidants, probiotics, and omega-3 fatty acids. They concluded that such bars can help in reducing oxidative stress and improving gut health, but stability of bioactives during processing remains a challenge.

Kaur A. and Singh N. (2022) studied gluten-free nutritional bars using rice flour, corn, and quinoa. The study found these bars suitable for people with gluten intolerance and Celiac Disease, while maintaining good nutritional and sensory properties.

Rocío Morales-Medina, Stephan Drusch, et.al (2022) reviewed structure, controlled release mechanisms, and health benefits of pectins as an encapsulation material for bioactive food components. This review summarizes current knowledge on how pectin—natural polysaccharides in many fruits—can serve as encapsulation materials for bioactive food ingredients. It discusses their structure, controlled release behaviors, health benefits, and how tailoring pectin structure influences release mechanisms in the gut and potential food applications.

VI. CONCLUSION

This project concludes that self-regulating nutrition bars can be developed with food matrix engineering to regulate the rate nutrients are delivered and subsequently entering the gut, rather than chemical modification or pharmaceutical delivery routes. Designing the bar in 3 intended layers: a burst of energy from (0–15 minutes), meal replacement and satiety (30–60 minutes), functional sustainment before training (>90 mins) focuses on improving digestion behavior so that blood sugar does not spike too quickly, but also reduces early fatigues. This study shows that by using particular physiochemical properties, such as a protein-fiber gel matrix for satiety and specific fat matrices to control long-term energy release, food can be formed to be more in harmony with physiological processes. In the end, this work serves to point out a viable and altogether more possible solution in timed release specialty food products as a function of structural design over typically sterile nutrition bars.

FUTURE SCOPE

- Development of the chocolate coated protein bar shows potential for future scientific and Technology improvements.
- Future Research and focus on improving the formulation using tool such as Response Surface Methodology (RSM) to achieve the perfect balance

between protein content texture and sensory acceptability.

- To understand and improve the interaction between different layers like caramel protein and chocolate water activity and moisture migration can be studied. Controlling these factors is essential to enhance shelf stability and prevent textural defects such as stickiness or hardening during storage.
- To improve consumer acceptability Texture Profile Analysis (TPA) should be performed using instrumental method to evaluate parameter such as hardness cohesiveness and chewiness and to correlate these with sensory valuation data obtain through a 9 point hedonic scale.
- Further studies may include evaluation of sugar crystallization behavior in the caramel layer and the role of interfering agents such as glucose in maintaining an amorphous structure. Additionally the effect of hydrocolloids like psyllium husk on binding, moisture retention, and overall texture stability can be explore.

REFERENCES

- [1] Beale, E. G., Lim, E. H., Yassine, H., Azen, C., & Christopher, C. P. (2019). Delayed-release nutrient (DRN) for appetite control in adults with obesity and type 2 diabetes: A single-dose, randomized, controlled trial. *Diabetes, Obesity and Metabolism*, 21(4), 1013–1018.
- [2] Giuntini, E. B., Sardá, F. A. H., & de Menezes, E. W. (2022). The effects of soluble dietary fibers on glycemic response: An overview and futures perspectives. *Foods*, 11(23), 3934.
- [3] Sarkar, A., Saha, A., & Mackie, A. (2020). Food structures and oral processing: A review of their role in targeted nutrition and health. *Food & Function*, 11(11), 9342–9366.
- [4] Somaratne, G., Ferrua, M. J., Ye, A., Nau, F., Floury, J., Dupont, D., & Singh, J. (2020). Food material properties as determining factors in nutrient release during human gastric digestion: A review. *Critical Reviews in Food Science and Nutrition*, 60(22), 3707–3722.
- [5] Boukid, F. (2020). Plant-based protein bars: A review of challenges and opportunities for improving their nutritional and sensory properties. *Comprehensive Reviews in Food Science and Food Safety*, 19(3), 1251–1271.
- [6] Santos, J. L., Granato, D., & Barba, F. J. (2021). Functional snack bars enriched with bioactive compounds: A review on their nutritional value, health benefits and processing challenges. *Food Research International*, 140, 109867.