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The Hypoglycemic Potential of the Bitter Cucumber (*Momordica charantia*) exploited in the Bakery Industry

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Abstract

Bitter cucumber (*Momordica charantia*) is one of the most studied plants with antidiabetic potential, due to its high content of bioactive compounds such as charantine, polypeptide-p, vicina, triterpene saponins, flavonoids and vitamin C (70-90 mg/100 g). The literature highlights the ability of these compounds to reduce blood sugar by inhibiting α-glucosidase and α-amylase, stimulating glucose uptake at the cellular level and improving insulin sensitivity. In parallel, the pulp and peel of the fruit contain 2-3g/100g of dietary fiber, with beneficial effects on digestion and on reducing the glycemic load of food.

The present paper investigates the potential of the use of bitter cucumber as a functional ingredient in the bakery industry, given the need to develop hypoglycemic products and foods intended for individuals with diabetes, prediabetes or those following low-carb diets. In bakery applications, the addition of 2-5% powder or bitter cucumber extracts in the dough increases the hydration capacity of the dough by 8-12%, modifying the rheological properties and improving the antioxidant profile of the finished products, due to the presence of polyphenols and triterpenoids with radical-scavenging activity. However, high levels of additives can affect sensory properties, in particular by intensifying the bitter taste, which requires optimisation of proportions and processing technology.

The results synthesized from the recent literature indicate that *Momordica charantia* is a promising ingredient for the formulation of functional bakery products with hypoglycemic impact, but further research is needed on the stability of bioactive compounds during baking, the reduction of bitterness through advanced technological processes and consumer acceptability. The controlled integration of this plant raw material can contribute to the development of innovative products with superior nutritional value and favorable metabolic potential.

Keywords: functional foods, hypoglycemic, charantine, p-polypeptide, antidiabetic.

1. Introduction

Type 2 diabetes is one of the most important public health problems globally, with its prevalence steadily increasing in recent decades as a result of lifestyle changes, high-calorie diets and reduced physical activity. The World Health Organization estimates that the number of people diagnosed with diabetes will exceed 640 million by 2040, which underlines the need to identify effective prevention and treatment strategies [1]. In this context, interest in functional foods and natural ingredients with hypoglycemic potential has increased significantly, both among researchers and the food industry.

The bitter cucumber (Momordica Charantia), known

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as "bitter melon" or "karela" is a tropical species of the Cucurbitaceae family, used for centuries in traditional Asian medicine for the treatment of diabetes, infections, inflammations and digestive disorders [2]. In recent decades, numerous studies have scientifically confirmed the therapeutic properties of the plant, highlighting its antidiabetic, antioxidant, anti-inflammatory, lipid-lowering and immunomodulatory effects [3,4]. These effects are attributed to plant-specific bioactive compounds, such as charantine, p-polypeptide, vicina, cucurbitacins, flavonoids and polyphenols, which act through complex mechanisms on glucose and lipid metabolism [5].

In parallel with the interest in medicinal plants, the food industry is facing a growing demand for bakery products with high nutritional value and low glycemic index. Traditional bakery products are characterized by a high content of available carbohydrates and a high glycemic index, which makes them unsuitable for people with diabetes or those following low-carbohydrate diets [6]. In this context, the integration of functional ingredients such as *Momordica charantia* into bakery products is an innovative direction, with the potential to improve the nutritional and functional profile of these products. [6].

Recent studies have shown that extracts and powders of *Momordica charantia* can reduce blood sugar by inhibiting digestive enzymes involved in carbohydrate breakdown (α-amylase and α-glucosidase), stimulating glucose uptake in muscle cells, protecting pancreatic β cells, and reducing oxidative stress [7,8]. These mechanisms justify the use of the plant to develop functional foods intended for glycemic control.

In addition, the nutritional composition rich in iron, vitamins, minerals and antioxidants, gives the plant an important technological potential in baking. Dietary fiber can improve the texture of the core, increase the water absorption capacity and extend the shelf life of products, while phenolic compounds can contribute to the oxidative stability of finished products [9].

Therefore, this paper aims to analyze in detail the hypoglycemic potential of *Momordica charantia* and the possibilities of capitalizing on it in the bakery industry. The work includes an in-depth analysis of the nutritional and phytochemical composition of the plant, an evaluation of its impact on the technological properties of bakery products, a synthesis of clinical studies demonstrating its antidiabetic effects, and a discussion of its limitations and future research directions.

Figure 1. Morphological parts of the Momordica charantia plant used in the study: fruit, leaves, seeds and flower

Figure 2. Derived forms obtained from vegetable raw material: seed oil, standardized extract, powder and flour

Note: Original figures made with AI (2026)

2. Nutritional and phytochemical composition of bitter cucumber (Momordica charantia)

The nutritional and phytochemical composition of the *Momordica charantia* plant constitutes the foundation of its therapeutic and functional value. This species stands out for a complex biochemical profile, characterized by the presence of compounds with intense biological activity, which justify the use

of the plant both in food and in phytotherapy and the functional food industry. Recent studies have shown that all parts of the plant – fruit, leaves, seeds and concentrated extracts – contain significant amounts of nutrients, fiber, vitamins, minerals and phytochemical compounds with antidiabetic, antioxidant and anti-inflammatory effects [10-12].

The raw fruit is traditionally used in food and is the form with the highest natural bioavailability of vitamin C and phenolic compounds. The powder and flour, obtained by dehydration, significantly concentrate nutrients, having much higher values of fiber, protein and polyphenols, which recommends them for use in bakery. The seeds are rich in proteins and lipids, and the oil extracted from them contains unsaturated fatty acids and minority compounds with antioxidant activity. The leaves are an important source of carotenoids and flavonoids, while the standardized extracts are the richest in charantine, p-polypeptides and polyphenols, being used especially in clinical studies due to the high concentration of active compounds [13-18].

2.1. Composition of macronutrients and dietary fiber

Macronutrients are the basis of the nutritional value of the *Momordica charantia* plant, and their distribution differs significantly depending on the form in which the plant is processed. The raw fruit contains low amounts of available carbohydrates (3.5-4 g/100 g), which makes it a food with a very low glycemic index. In contrast, powder and flour, obtained by dehydration, have much higher concentrations of carbohydrates (55-68 g/100 g), but a significant proportion of them is represented by insoluble and soluble dietary fiber [10,11].

Dietary fiber is one of the most valuable components of the plant, playing an essential role in reducing the postprandial glycemic response. By increasing the viscosity of the food bowl and slowing down glucose absorption, fiber helps to stabilise blood sugar and reduce the glycemic load of food. *Momordica charantia* powder and flour contain between 28 and 35 g of fibre/100 g, comparable to other functional ingredients used in baking, such as oat bran or flax flour [12,13].

Protein is present in moderate amounts in raw fruit (1-1.2 g/100 g), but much higher in powder (12-16 g/100 g), flour (14-18 g/100 g) and seeds (18-22 g/100 g). Seed proteins are rich in essential amino acids and can help improve the protein value of bakery products. Lipids are present in small amounts in raw fruit, but seeds contain up to 32% lipids, most of which are cardioprotective unsaturated fatty acids [14].

2.2. Micronutrient composition: vitamins and minerals

Momordica charantia is an excellent source of micronutrients, especially vitamin C, vitamin A (in the form of carotenoids), potassium, magnesium and iron. Vitamin C is present in high amounts in the raw fruit (80-90 mg/100 g), which gives the plant an important antioxidant potential. The leaves contain even higher values (100-120 mg/100 g), due to the high concentration of phenolic compounds and flavonoids [16].

Vitamin A is present in moderate amounts in the fruit (170 μg/100 g), but very high in the leaves (2500-3000 μg/100 g), in the form of β-carotene and other carotenoids, compounds with an essential role in the protection of vision and the functioning of the immune system [17].

Minerals are distributed differently depending on the shape of the plant. Potassium is present in high amounts in raw fruit (300-350 mg/100 g), but concentrations increase significantly in powder and flour (900-1200 mg/100 g). Magnesium and iron are also present in important amounts, contributing to the functioning of the muscular system, protein synthesis and the prevention of anemia [18].

2.3. Bioactive compounds with a hypoglycemic role

The bioactive compounds specific to the *Momordica charantia* plant are responsible for its antidiabetic and hypoglycemic effects. Of these, charantine, polypeptide-p, vicina, and cucurbitacins are the most studied [20].

Charantine is a glycosidic steroid with a demonstrated hypoglycemic effect, present in concentrations of 0.4-0.8 mg/100 g in raw fruit and up to 60 mg/100 g in standardized extracts. This compound works by stimulating glucose uptake in muscle cells and improving insulin sensitivity [20,21].

Polypeptide-p is a plant analogue of insulin, with rapid hypoglycemic effects, present in amounts of 2-4 mg/100 g in raw fruit and up to 90 mg/100 g in extracts. It can reduce blood sugar through mechanisms similar to human insulin, being considered one of the most important antidiabetic compounds of the plant [22].

Vicina and cucurbitacins contribute to the reduction of blood sugar by inhibiting digestive enzymes involved in the breakdown of carbohydrates (α-amylase and α-glucosidase) and by stimulating glucose uptake in muscle cells. These compounds also exhibit anti-inflammatory and antioxidant

effects, contributing to the protection of pancreatic β cells [23,24].

2.4 Polyphenols, flavonoids and antioxidant activity

Polyphenols are one of the most important classes of bioactive compounds in *Momordica charantia*, being responsible for a large part of the antioxidant, anti-inflammatory and antidiabetic activity of the plant. These compounds are present in all parts of the plant, but the highest concentrations are found in powder, flour, ropes and standardized extracts, due to the dehydration and extraction processes that concentrate phytochemicals. [25].

Polyphenols are secondary compounds of plant metabolism, having essential roles in protecting the plant against oxidative stress, UV radiation, pathogens and environmental factors. In the human body, they act as powerful antioxidants, neutralizing free radicals and reducing oxidative stress, a major factor involved in the pathogenesis of diabetes, cardiovascular diseases and chronic inflammatory processes [26].

In *Momordica charantia*, the main categories of polyphenols identified are phenolic acids (gallic acid, chlorogenic acid, ferulic acid, caffeic acid), flavonoids (quercetin, luteolin, apigenin, kaempferol), condensed tannins and cucurbitaceous-specific compounds such as cucurbitacins [27]. The total concentration of polyphenols varies significantly depending on the shape of the plant: raw fruit contains about 70-120 mg/100 g, while powder and flour can reach values of 350-550 mg/100 g, and standardized extracts can exceed 900 mg/100 g [25].

Flavonoids are an important subclass of polyphenols, with essential biological roles. In *Momordica charantia*, flavonoids are present in high amounts in the leaves (180-250 mg/100 g), being responsible for their intense antioxidant activity. Quercetin, one of the most studied compounds, has anti-inflammatory, antidiabetic and cardioprotective effects, helping to reduce oxidative stress and improve insulin sensitivity [27]. Luteolin and apigenin, also abundant in leaves and powder, exhibit antidiabetic effects by inhibiting α-glucosidase and α-amylase, enzymes involved in the degradation of carbohydrates [28].

The antioxidant activity of the polyphenols in *Momordica charantia* is well documented in the literature. Studies have demonstrated that aqueous and ethanolic extracts of the plant exhibit an antioxidant capacity comparable to synthetic antioxidants such as BHT or BHA, due to their ability to neutralize free radicals, chelate pro-oxidant metabolic ions and inhibit lipid peroxidation [28,29]. This property is particularly important in the food industry, as lipid oxidation is one of the main causes of the degradation of bakery products during storage [29].

2.5 Compositional differences between the parts of the Momordica charantia plant

Given the significant compositional variability between the different parts of the Momordica charantia plant and its processing forms, a comparative presentation of the nutritional and functional parameters is required. Data on the content of water, macronutrients, fiber, vitamins, minerals and bioactive compounds are comparatively synthesized in Table 1, based on information reported in the literature. This integrative approach allows for a clear assessment of the nutritional and technological potential of each plant part in the formulation of functional foods [10-34].

According to the data presented in Table 1, the raw fruit of Momordica charantia is characterized by a very high water content (88-92%), low energy value and low lipid levels. At the same time, it presents relevant amounts of vitamin C, as well as bioactive compounds with a hypoglycemic effect, such as charantine, polypeptide-p and vicina. The antioxidant activity of the fruit is moderate, determined by the presence of polyphenols and flavonoids, and the very low glycemic index highlights its potential in the development of products for people with metabolic disorders. [10-34].

As can be seen from Table 1, the leaves of *Momordica charantia* have a much more concentrated nutritional profile, with significantly higher contents of proteins, dietary fibers, essential vitamins and minerals, especially potassium, magnesium, iron and zinc. The leaves also stand out, with high concentrations of flavonoids, carotenoids (β-carotene), polyphenols and phenolic acids, which explains the very high antioxidant activity associated with this plant organ. These characteristics support the use of the leaves as ingredients in functional products and food supplements with high biological value [10-34].

The data synthesized in Table 1 indicate that the seeds are distinguished by a high protein and lipid content, along with important levels of fiber and minerals. Although the diversity of phenolic compounds is lower compared to the leaves, the seeds contain relevant amounts of charantine, p-

polypeptide and cucurbitacins. In the case of seed oil, Table 1 shows a high concentration of lipids and energy value, in parallel with a limited intake of micronutrients and bioactive compounds [10-34].

The processed forms of the plant, respectively, powder and flour, present, according to Table 1, a balanced compositional profile, characterized by high levels of total fiber, proteins, minerals and polyphenols, while maintaining a low glycemic index. These characteristics position *Momordica charantia* powder and flour as a particularly suitable ingredient for bakery products and functional cereal products, contributing to the improvement of nutritional value and the achievement of specific metabolic benefits [10-34].

Standardised extracts, as shown in the data presented in Table 1, contain the highest concentrations of specific bioactive compounds, in particular charantin and p-polypeptides, which give them a high functional potential. However, their applicability in food is limited by the impact on sensory properties, in particular intense bitter taste and colour changes [10-34].

In conclusion, the comparative data presented in Table 1 show a pronounced compositional diversity between the different parts of the *Momordica charantia* plant and its processing forms, a diversity that allows the formulation of foods adapted to specific nutritional and functional objectives, from bakery products enriched in fiber and protein to functional foods with antioxidant and hypoglycaemic effects.

[10-34].

Table 1: Chemical, nutritional and phytochemical composition of the fruit, leaves, seeds and main forms of processing of the plant *Momordica charantia* based on databases and literature sources, per 100 g.

Component	*Unit*	*Raw fruit*	*Leaves*	*Seeds*	*Seed oil*	*Standardized extract*	*Powder*	*Flour*	*Sources*
Water (H_2O)	%	88-92	70-75	5-8	0	4-6	6-10	8-12	[10,11]
Energy	kcal	17-20	45-55	420-480	880-900	250-300	280-320	300-340	[10,12]
Carbohydrates	g	3,5-4,0	6-8	12-18	0	20-30	55-65	60-68	[10,13]
Total Fiber	g	2,6	8-12	22-28	0	5-8	28-32	30-35	[11,14]
Protein	g	1,0-1,2	8-12	18-22	0	10-14	12-16	14-18	[12,15]
Lipids	g	0,2	4-5	28-32	100	1-2	2-4	3-5	[10,15]
Vitamin C	mg	80-90	100-120	2-4	0	5-8	10-15	12-18	[16]
Vitamin A (β-carotene)	μg	170	2,500-3,000	20-40	0	500-700	800-1200	900-1300	[17]
Potassium	mg	300-350	400-450	600-800	0	600-800	900-1100	950-1200	[18]
Magnesium	mg	17	40-60	150-200	0	50-70	80-120	90-130	[18]
Iron	mg	0,4	2-3	8-10	0	2-3	3-5	4-6	[19]
Zinc	mg	0,8	1-2	6-8	0	1-2	2-3	3-4	[19]
Charantin	mg	0,4-0,8	1-2	2-4	0	40-60	12-18	15-22	[20,21]
Polypeptide-p	mg	2-4	3,5	5-8	0	60-90	25-40	30-45	[22]
Vicina	mg	1-2	2-3	3-5	0	20-30	10-15	12-18	[23]
Cucurbitacins	mg	0,5-1,0	0,5-1,0	1-2	0	20-25	8-12	10-14	[24]
Total polyphenols	mg	70-120	250-300	150-200	20-40	600-900	350-500	400-550	[25,26]
Flavonoids	mg	20-40	180-250	40-60	5-10	200-300	120-180	150-200	[27]
Phenolic acids	mg	10-20	40-60	30-40	0	150-200	80-120	90-130	[27]
Antioxidant activity	-	Moderate	Very high	Moderate	Moderate	Very high	High	High	[28,29]

Glycemic index	-	Very low	Very low	Very low	Very low	Low	Low	[30]

The values are expressed per 100g of fresh product. The data were compiled from the literature and databases on food composition, including peer-reviewed studies. Minor variations may occur depending on the species, growing conditions. season, plant maturity and analytical methods used.

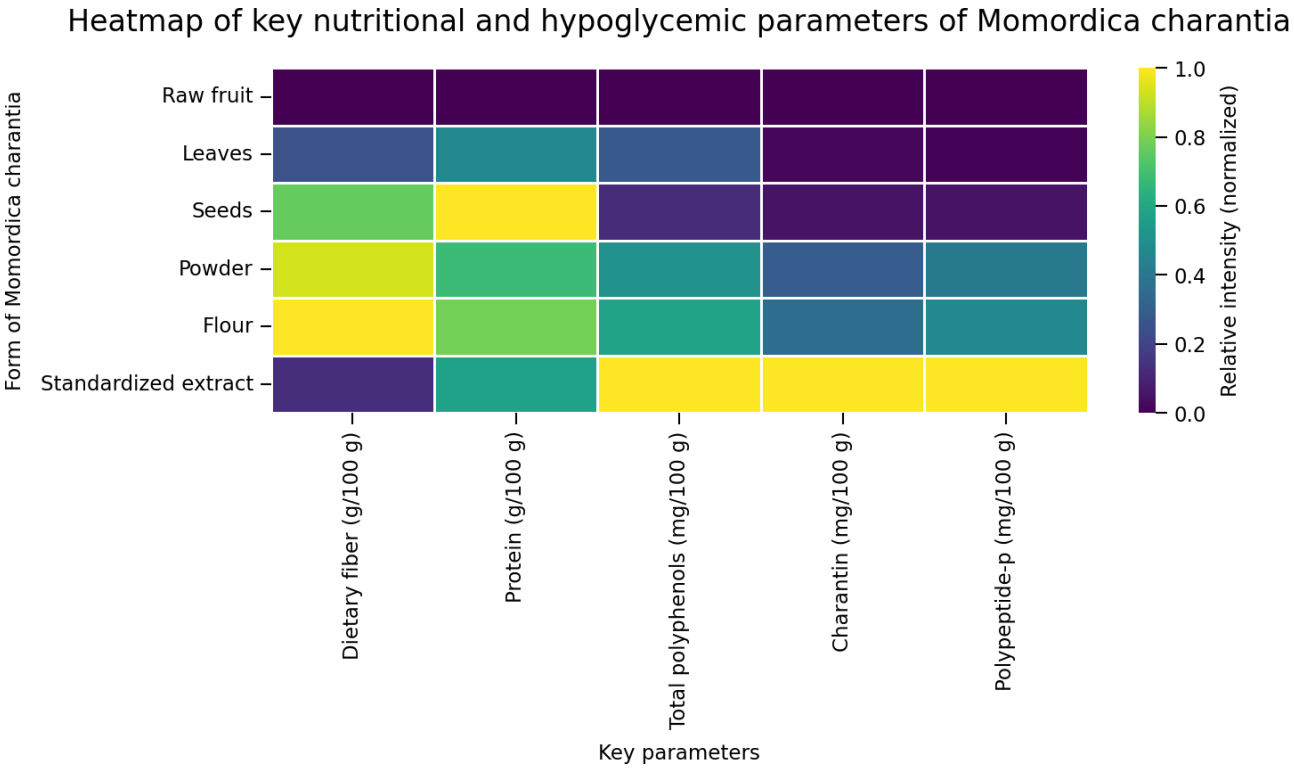

Figure 3. Heatmap of key nutritional and hypoglycemic parameters of *Momordica charantia* plant parts and processed forms.

Note: For graphical purposes, the data in the literature have been expressed as representative and normalized mean values to highlight relative compositional trends rather than absolute quantities.

The representative mean values derived from literary sources were normalized using min-max scaling to allow comparison between parameters expressed in different units. The color intensity reflects the relative abundance of dietary fiber, protein, total polyphenols, charantine and p-polypeptide, highlighting functional differences between plant parts and processed forms relevant for bakery applications.

As shown in Figure 3, standardized extracts exhibit the highest relative levels of hypoglycemic bioactive compounds, especially charantin and p-polypeptide, confirming their potent metabolic potential. In contrast, powder and flour forms exhibit a balanced functional profile, combining high dietary fiber content with substantial levels of polyphenols and moderate protein concentrations. This compositional balance supports their technological suitability for bakery applications, where nutritional improvement must be achieved without compromising processing behavior and sensory acceptability. Seeds are mainly characterized by high protein levels, while raw fruits exhibit an overall lower compositional density.

3. Technological applications of *Momordica charantia* in bakery products

The integration of functional plant ingredients in bakery products represents a major direction of innovation in the contemporary food industry. In the context of the increasing prevalence of diabetes mellitus and the interest in foods with a low glycemic index, the use of the *Momordica charantia plant* in bakery acquires a special relevance. This species stands out for a complex phytochemical composition, rich in fibers, polyphenols, flavonoids

and bioactive compounds with a hypoglycemic effect, which can influence both the rheological properties of the dough and the quality of the finished products. Recent studies have shown that moderate additions of powder, flour or extracts of *Momordica charantia* can help improve the nutritional value of bakery products, without significantly compromising sensory properties, when used in appropriate proportions [12-14].

3.1. Impact on the rheological properties of dough

The rheological properties of the dough are essential for obtaining bakery products with adequate volume, optimal texture and uniform structure. The additions of *Momordica charantia* powder or flour directly influence the hydration, elasticity, extensibility and stability of the dough. The high water absorption capacity, determined by the high content of insoluble and soluble fibers, leads to the formation of a more viscous and denser dough. Insoluble fibers, such as cellulose and hemicellulose, absorb water and retain in their structure, while soluble fibers form viscous solutions that contribute to the stabilization of the dough. These changes cause an increase in the time required for the development of the gluten network and influence the behavior of the dough during kneading and fermentation [12].

The interaction between the fibers in *Momordica charantia* and the proteins in wheat flour can affect the formation of the gluten network. Insoluble fibers can fragment the structure of gluten, reducing the elasticity and extensibility of the dough, which can lead to less bread volume. At moderate additions, these effects are minimal and can be compensated by adjusting the hydration, but at large additions the core becomes dense and compact. Proteins in the seeds of the plant can help stabilize the structure of the dough but cannot completely replace the function of gluten [15].

3.2. Effect on fermentation processes

Fermentation is a fundamental process in baking, influencing the volume, texture, flavor and structure of products. The additions of *Momordica charantia* can influence the activity of yeasts and the dynamics of fermentation due to the content of polyphenols and cucurbitacins, compounds that can have an inhibitory effect on some microorganisms. However, studies show that small additions of up to 2% do not negatively affect the activity of yeasts, and minerals such as potassium and magnesium can even stimulate microbial metabolism, accelerating the fermentation process [17].

Sourdough fermentation has additional advantages when using *Momordica charantia*. The microorganisms specific to sourdough can partially degrade the compounds responsible for the bitter taste, reducing its intensity in the final product. In addition, natural fermentation lowers the pH, which contributes to the microbiological stability of the product and to increase the bioavailability of phenolic compounds. Therefore, the use of sourdough can be an effective strategy for improving the sensory and functional quality of bakery products enriched with *Momordica charantia* [18].

3.3 Sensory changes and consumer acceptability

The sensory profile of *Momordica charantia* is characterised by an intense bitter taste, a green or greenish-brown colour and a specific vegetal flavour. These characteristics can influence the acceptability of bakery products, especially in the case of large additives. The bitter taste is determined by the presence of cucurbitacins and other triterpene compounds, and its intensity depends on the form used and the degree of processing.

To reduce bitterness, the literature recommends the use of standardized extracts with low bitterness, the combination of powder with sweet flours such as oats or corn, heat pretreatment of the powder or the use of sourdough fermentation. Sensory studies show that additions of 1-3% are well tolerated by consumers, while additions of 5-7% are acceptable in whole grain products or in products with intense flavors. Additions greater than 10% are perceived as too bitter and can negatively affect the acceptability of the product [19-21].

3.4 Oxidative stability and shelf life extension

Oxidative stability is an essential criterion in the evaluation of the quality of bakery products, as lipid oxidation is one of the main causes of aromatic, gustatory and chromatic degradation of products during storage. In this context, *Momordica charantia* has remarkable technological potential due to its high content of polyphenols, flavonoids and other antioxidant compounds that can inhibit lipid peroxidation reactions [25-28].

The polyphenols in *Momordica charantia* act through multiple antioxidant mechanisms. They neutralize free radicals formed during baking and storage processes, reducing the degradation of unsaturated fatty acids. They can also chelate transitional metal ions, such as iron and copper, which catalyze oxidative reactions, and inhibit pro-oxidant enzymes, thus decreasing the rate of oxidation reactions [26]. Studies have shown that aqueous and ethanolic extracts of the plant exhibit

antioxidant activity comparable to synthetic antioxidants such as BHT and BHA, which justifies their use in bakery products intended for consumers who prefer natural alternatives [28,29].

Additions of 2-4% *Momordica charantia* powder or extract have been associated with an extension of the shelf life of bakery products by 20-30%, depending on the type of product and storage conditions [22]. In lipid-rich products, such as biscuits or crackers, the antioxidant effect is more pronounced, as phenolic compounds inhibit oxidative rancidity reactions. In whole bread, moderate additions help maintain freshness and reduce moisture loss, due to the ability of fiber to retain water [23].

An important aspect is the thermal stability of the antioxidant compounds in *Momordica charantia*. Polyphenols and flavonoids exhibit a relatively high stability at baking temperatures of 180-200°C, retaining their antioxidant activity even after exposure to high temperatures. This characteristic justifies the use of the plant in ripe products, where the maintenance of antioxidant activity is essential for the final quality of the product [27].

3.5 Use of the Momordica charantia plant to obtain gluten-free products

Gluten-free products are an increasingly important category in the food industry, being intended both for people diagnosed with celiac disease and for those who adopt gluten-free diets for health reasons or personal preferences. The absence of gluten causes significant technological difficulties. Because gluten is responsible for the elasticity, extensibility and structure of the dough. In this context, *Momordica charantia* can represent an innovative solution due to its composition rich in soluble and insoluble fibers, vegetable proteins and bioactive compounds [24].

Soluble fiber contributes to the formation of a viscous network that can partially mimic the function of gluten, improving water retention and stabilization of the dough. Insoluble fiber, through its ability to absorb water, contributes to increasing volume and achieving a less dense texture. In gluten-free products, these properties are essential for preventing crumbly texture and improving core structure [25].

The proteins in the seeds of *Momordica charantia* can interact with starch and fiber to form a more coherent matrix, helping to stabilize the structure of gluten-free products. In addition, the plant's bioactive compounds may improve the nutritional value of gluten-free products, which are often deficient in micronutrients and antioxidants [24].

Studies have shown that additions of 2–5% *Momordica charantia* powder or extract in gluten-free bread can significantly improve texture, reducing core density and increasing water holding capacity [25]. In gluten-free biscuits and crackers, additions of 3–7% may improve oxidative crunchiness and stability, due to the high antioxidant activity of phenolic compounds [28].

Another important benefit is the plant's contribution to reducing the glycemic index of gluten-free products, which are typically rich in starch and available carbohydrates. By inhibiting digestive enzymes involved in carbohydrate breakdown, the bioactive compounds in *Momordica charantia* may reduce the postprandial glycemic response, making gluten-free products more suitable for people with diabetes or prediabetes [31].

3.6 Examples of bakery products developed with the Momordica charantia plant

The literature provides numerous examples of bakery products in which *Momordica charantia* has been successfully used, demonstrating its technological and functional potential. These applications include bread, biscuits, crackers, nutrition bars and gluten-free products, each of which benefits from the nutritional and antioxidant properties of the plant.

Whole wheat bread enriched with 2-4% *Momordica charantia powder* has demonstrated an increase in fiber and antioxidant content, as well as a reduction in the glycemic index. Studies have shown that moderate additions do not significantly affect the volume of bread, and the high antioxidant activity contributes to the oxidative stability of the product [26].

Hypoglycemic biscuits are another important application. Additions of 5% standardized extract of *Momordica charantia* have demonstrated a significant reduction in postprandial glycemic response, without compromising the texture or acceptability of the product [27].

Functional crackers with 3% *Momordica charantia* seed flour feature a crispy texture, high oxidative stability, and high protein and fiber content, making them suitable for consumers looking for healthy snacks with low glycemic impact [28].

Protein bars enriched with 10% seed flour are an innovative application, as the seeds of the plant are rich in protein and unsaturated fatty acids. These bars have a high energy value, superior antioxidant capacity and excellent stability during storage [29].

In gluten-free products, additions of 2% standardized extract have demonstrated significant

improvements in the texture and stability of the products, as well as a reduction in the glycemic index, confirming the usefulness of the plant in the formulation of products intended for people with gluten intolerance or those following special diets [30].

4. Clinical studies on the hypoglycemic effects of *Momordica charantia*

The hypoglycemic effects of the *Momordica charantia* plant have been investigated in numerous clinical trials, which evaluated both standardized extracts and fresh powder or juice. The results of the research consistently indicate a moderate but significant reduction in blood glucose in patients with type 2 diabetes or prediabetes. Randomized controlled trials have shown that taking extracts in doses of 1500-2000 mg/day for 8-12 weeks can reduce fasting blood glucose by about 10-20% and postprandial blood glucose by 15-25%, depending on the form used and the characteristics of the participants [30]. Also, some studies have reported modest decreases in HbA1c values of around 0.2–0.5%, suggesting a beneficial effect on glycemic control in the medium term [36].

Short-term studies have shown a reduction in the glycemic peak in the glucose tolerance test, which indicates an inhibition of intestinal absorption of carbohydrates and a slowdown in their digestion [39]. Other research has shown an improvement in insulin sensitivity, reflected by a decrease in the HOMA-IR index after administration of the extracts for several weeks [40]. Biochemical mechanisms observed in clinical trials include inhibition of α-glucosidase and α-amylase, stimulation of glucose uptake in peripheral tissues, and a possible increase in endogenous insulin secretion, evidenced by increased C-peptide levels in some pilot studies [41,42].

Regarding the safety of administration, most clinical studies report good tolerability, with minor adverse effects such as gastrointestinal discomfort or persistent bitter taste. No severe episodes of hypoglycemia have been reported alone, but caution is advised in combination with oral antidiabetics, as the herb may potentiate their effect [43]. Overall, the clinical literature suggests that *Momordica charantia* may contribute to the improvement of glycaemic control by being a plant ingredient with potential useful in the formulation of functional foods intended for people with diabetes or prediabetes.

5. Conclusion

The *Momordica charantia* plant is a plant resource with significant potential for the development of functional foods for glycemic control, especially in the bakery industry. The analysis of the nutritional and phytochemical composition highlights the presence of important amounts of dietary fiber, polyphenols, flavonoids, vitamins, minerals and bioactive compounds with hypoglycemic effects, such as charantine, polypeptide-p and vicina. These compounds contribute to the reduction of blood sugar through multiple mechanisms, including inhibition of digestive enzymes involved in carbohydrate degradation, stimulating glucose uptake in peripheral tissues and improving insulin sensitivity.

The integration of the *Momordica charantia* plant in bakery products influences the rheological properties of the dough, the water absorption capacity, the texture of the core and the oxidative stability of the products. Moderate additions allow to obtain products with superior nutritional value and low glycemic impact, without significantly compromising sensory acceptability. The high antioxidant activity of phenolic compounds contributes to the extension of the shelf life of products, by reducing lipid oxidation processes. The clinically analyzed studies confirm the hypoglycemic effects of the plant, demonstrating decreases in fasting and postprandial blood glucose, as well as improvements in insulin sensitivity.

The originality of the paper lies in the coherent integration of phytochemical, technological and clinical data into an applied perspective on the use of the *Momordica charantia* plant in baking, an area in which the literature is still limited. The paper offers an interdisciplinary approach, bringing together information from phytotherapy, nutrition, food technology and diabetology, to substantiate the use of this plant as a functional ingredient in a food sector with a major impact on public health.

The future development perspective includes the optimization of technological processes for the incorporation of powder and extracts into bakery products, the reduction of bitterness through pretreatment or fermentation methods, the standardization of bioactive compounds to achieve predictable hypoglycemic effects, and the large-scale evaluation of consumer acceptability. Further clinical studies are also needed to clarify optimal doses, long-term safety and interactions with conventional antidiabetic treatments. The integration of *Momordica charantia* into functional foods is a promising direction for the development of modern products adapted to current requirements for metabolic health and balanced nutrition.

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