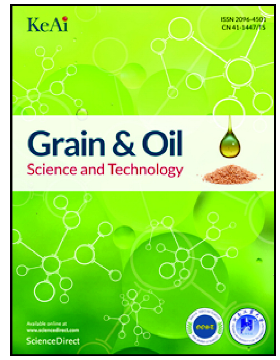
Journal Pre-proof



Natural and modified food hydrocolloids as gluten replacement in baked foods: Functional benefits

Emmanuel Anyachukwu Irondi, Yunus Temitayo Imam, Emmanuel Oladipo Ajani, Emmanuel Oladeji Alamu

PII: S2590-2598(23)00030-4

DOI: https://doi.org/10.1016/j.gaost.2023.10.001

Reference: GAOST 99

To appear in: *Grain & Oil Science and Technology*

Received date: 6 July 2023

Revised date: 10 October 2023

Accepted date: 12 October 2023

Please cite this article as: E.A. Irondi, Y.T. Imam, E.O. Ajani, et al., Natural and modified food hydrocolloids as gluten replacement in baked foods: Functional benefits, *Grain & Oil Science and Technology* (2023), https://doi.org/10.1016/j.gaost.2023.10.001

Natural and modified food hydrocolloids as gluten replacement in baked foods: Functional benefits

Emmanuel Anyachukwu Irondi[1,*], Yunus Temitayo Imam[1], Emmanuel Oladipo Ajani[1], Emmanuel Oladeji Alamu[2,3]

[1]Department of Biochemistry, Kwara State University, Malete, PMB 1530, Ilorin, Nigeria

[2]Food and Nutrition Sciences Laboratory, International Institute of Tropical Agriculture, PMB 5320, Oyo Road, Ibadan, Oyo State, Nigeria

[3]Food and Nutrition Sciences Laboratory, International Institute of Tropical Agriculture, Southern Africa, Research and Administration Hub (SARAH) Campus PO Box 310142, Chelstone, Lusaka 10101, Zambia

*Corresponding author: emmanuel.irondi@kwasu.edu.ng

Abstract

Gluten, the protein responsible for the superior viscoelastic properties of refined wheat flour dough over gluten-free cereals, causes celiac disease in people susceptible to gluten-allergy. Moreover, the sustainability of using wheat flour in baked foods is threatened by its high cost, especially in countries that depend on imported wheat for their bakery industry. Research has shown that hydrocolloids serve as gluten replacements in baked foods, in response to these challenges. Food hydrocolloids are a class of high-molecular weight polysaccharides and proteins, which serve as functional ingredients in the food industry that modify the foods' rheological and textural properties. They function as stabilizers, viscosity modifiers, gelling agents, water binders, fibres, and inhibitors of ice crystal in foods. Further, food hydrocolloids have also been reported to possess health-promoting properties, such as lowering of postprandial blood glucose and plasma cholesterol concentrations, colon cancer prevention, and modulation of intestinal transit and satiety. They are obtained from plants, animals or microorganisms, and can be used in their natural or modified forms. The aim of this paper is to review the functional benefits of natural and modified hydrocolloids as gluten replacements in baked foods, emphasizing their physicochemical, nutraceutical, and sensorial importance. The application effects of food hydrocolloids as gluten substitutes in gluten-free baked products' quality were discussed. Also, some practical approaches to improve the quality of gluten-free baked products, in response to an increasing consumers' demand and the rising cost of refined wheat flour were highlighted.

Keywords: Food hydrocolloids; Baked food; Functional importance; Gluten-free food; Nutraceutical benefits; Sensory quality

1. Introduction

The rising incidence of celiac disease, the cost of refined wheat flour, and consumers' quest for health-promoting foods have necessitated the food industry's development of gluten-free (GF) products [1, 2]. Celiac disease is a life-long immunoglobulin E-mediated enteropathy caused by consuming gluten-containing foods in genetically susceptible people [3, 4]. The only known effective treatment for celiac disease is a strict life-long abstinence from gluten-containing foods [5]. On the other hand, GF products are considered safe for celiac disease patients [6]. In formulating GF products, different ingredients, such as food hydrocolloids (FHs), which mimic the viscoelastic quality of gluten, are employed as gluten substitutes. The Codex Alimentarius Commission [7] defined GF product as "food products containing less than 20 mg/kg gluten". GF products were initially intended for consumers suffering from gluten-associated disorders such as celiac disease, wheat allergies, non-celiac gluten sensitivity, gluten ataxia, and exercise-induced anaphylaxis [8]. However, with the rising cost of wheat, the incidence of other nutrition-related non-communicable diseases, and consumers' demand for healthy foods, GF foods are now widely embraced [1, 9]. Nevertheless, the production of high-quality GF-baked products poses a significant challenge to the food industry, due to the absence of gluten, which confers some unique visco-elastic properties to the dough [3]. To overcome this challenge, diverse ingredients such as flours of GF cereals, and additives that can mimic the visco-elastic properties of the gluten, such as hydrocolloids are employed in the development of GF products [3, 10].

Food hydrocolloids, also called gums, are a class of high-molecular weight polysaccharides and proteins, which serve as functional ingredients in the food industry that modify the foods' rheological and textural properties. They function as stabilizers, viscosity modifiers, gelling agents, water binders, fibres, and inhibitors of ice crystal in foods [3, 10–12]. Examples of FHs used to replace gluten in baked foods include agar, acacia, locust bean gum, guar gum, pectin, tara, xanthan gum and carboxymethylcellulose. These FHs have diverse effects on the GF-baked products' quality, depending on several factors, such as the FH's charge, molecular weight, and concentration. For instance, Horstmann et al. [12] incorporated six different hydrocolloids, namely guar gum, locust bean gum, hydroxypropylmethylcellulose, pectin, xanthan gum, and sodium alginate, under optimized condition, as gluten replacement in potato starch-based GF bread. The authors observed an increase the bread volume due to the addition of negatively charged FH, such as pectin and sodium alginate. They suggested that these negatively charged FHs produce repulsive forces with the potato starch's negatively charged phosphate groups, slowing down the starch granules' pasting and gelatinization. This effect lowers starch viscosity, leading to a higher bread volume as a result of high gas cell expansion. On the other hand, high-molecular-weight FHs with a neutral charge, such as locust bean and guar gums, do not produce such repelling forces. To explain the smaller bread volume observed with the addition of these neutrally-charged high-molecular weight FHs, the authors [12] postulated that many hydrogen bonds were formed with leached amylose, resulting in high viscosity values. Consequently, the dough elasticity was lowered by these high values of viscosity, limiting gas cell expansion with a concomitant smaller bread volume.

The use of FHs as gluten replacement in food systems also confers some health-promoting properties, such as lowering of postprandial blood glucose and plasma cholesterol concentrations, colon cancer prevention, and modulation of intestinal transit and satiety, to the food [1, 11, 13]. These benefits become necessary considering the increasing cases of nutrition-related non-communicable diseases, occasioned by nutrition transition among other factors [14, 15]. Nutrition transition explains the shift from natural foods to highly processed and energy-dense foods [14, 16].

From the foregoing, this paper aimed to present a review on the functional benefits of natural and modified FHs as gluten replacements in baked products, emphasizing the physicochemical, nutraceutical, and sensorial importance.

2. Cereal flours in baked foods: wheat versus GF cereals

Refined wheat flour is the gold standard for producing baked products such as bread and biscuits. However, these foods are typically energy-dense, with low levels of essential nutrients and health-promoting bioactive ingredients [1, 9]. This is because refined flour is produced by milling only the starchy endosperm, after removing the bran, with its high deposition of phytochemicals, and the germ. The functional superiority of refined wheat flour over GF cereals' flours in baked foods is attributed to gluten [1, 9]. However, in addition to causing celiac disease in susceptible individuals, the sustainability of using refined wheat for baking is challenged by its high cost in countries that depend on wheat importation for their bakery industry. According to a recent report by Qu [17], the price of wheat skyrocketed by 31% due to COVID-19-related factors, such as increased demand, high costs of shipping, and port disruptions. The economic burden posed by the high cost of wheat has been compounded recently as a result of the Ukraine-Russian war, as Ukraine is a major wheat exporter, accounting for about 12% of global wheat exports [18].

In an effort to produce GF products with health-promoting properties, several studies have focused on formulating baked products with the flour of GF cereals [1, 19–21]. Some GF cereals that have been used for this purpose include sorghum (*Sorghum bicolor* (L.) Moench), maize (*Zea mays* L.), rice (*Oryza sativa* L.), millets, teff, and some pseudocereals, such as amaranth, quinoa, and buckwheat [8, 22]. Some other studies also reported oats as a GF cereal [23–25], but the Codex Alimentarius described them as a gluten-containing cereal [26]. The flours of these GF cereals are either used alone or as a composite for the formulation of GF-baked products [22]. Nevertheless, the production of high-quality GF products from these GF cereals poses a big challenge to the food industry, due to the absence of gluten [3]. It is well-known that the proteins in the flours of these GF cereals cannot form a network and therefore, do not meet the baking quality requirements [27]. Consequently, their GF products are characterized by a dense and dry structure, low volume, poor mouth feel and flavour, and high crumb hardness, with an overall low quality [28].

3. The role of gluten in baked foods

Gluten is the main structure-forming protein present in wheat, barley and rye, which confers viscoelastic properties to dough and allow gas produced from yeast fermentation to be retained and oven-rise during baking [27, 29]. It also modulates the final baked products' appearance and crumb structure [28]. Gliadins and glutenin are the two types of gluten. The former is a monomeric protein whereas, the latter is polymeric protein. Gluten's primary role in baking is to confer a viscoelastic property to the dough, which is majorly achieved by the action of gliadins [30]. However, it has also been documented that the gluten network is formed in the presence of water and under mechanical work by the combined action of gliadin and glutenin proteins of wheat [26].

Gluten is also responsible for proofing baked products, such as bread loaves, and improving the quality of baked products [31]. During the baking process, refined wheat flour, with its gluten, is hydrated, leading to the formation of a viscous mass. This confers the viscosity, structure, mixing tolerance, dough, and the ability to hold gas during leavening [32]. Through the structure formed, gluten can also to enclose flour components, such as fibres and starch granules [33]. Thus, gluten's absence negatively impacts the dough's rheology and the final product's quality, as GF doughs are characterized by a reduced elasticity and cohesiveness relative to wheat dough [34]. It is a well-documented that the colour, texture, alveoli structure, and crumb of baked products depend mainly on the presence and strength of gluten [5, 35].

4. Food hydrocolloids as gluten replacement in GF baked foods

Hydrocolloids are class of polysaccharides (water-soluble, food or modified) or protein with variable chemical structures, which are responsible for their functional features, ability to form gel when dispersed in water, and applications in the food industry [36–38]. Many functions (Figure 1) have been attributed to FHs as gluten replacers in the food industry, either alone or in conjunction with other components of the food. These include, thickening, gelling, emulsifying, dispersing, and stabilizing functions [39]. Apart from their use as gluten substitute, they can also be used as food additives to improve food attributes, such as shelf-life and flavor [37, 40]. Due to the diverse functions of hydrocolloids in food systems, Seisun & Zalesny [41] recently described them as "essential and critical ingredients in food". The inclusion of FHs is the easiest approach to increase the level of dietary fiber in GF products.

The major FHs are alginates, agar, acacia, cassia tora, gelatin, carrageenan, gellan, locust bean gum, guar gum, pectin, tara, starches, xanthan, carboxymethylcellulose (CMC), methyl cellulose/hydroxypropylmethyl cellulose (MC/HPMC), and microcrystalline cellulose (MCC). In addition to these major FHs, karaya, tragacanth, konjac, pullulan, tamarind, and scleroglucan are some less common FHs [41]. There are several reports on the use of these FHs as gluten substitutes, including xanthan gum, guar gum, hydroxypropylmethyl cellulose (HPMC) [5, 42], carrageenan, agar, and alginate [43]. The exact intrinsic mechanisms underlying the interactions between FHs with other food constituents, and between different FHs, are still not fully understood [44, 45]. However, Naji-Tabasi & Mohebbi [46] pointed out that FHs facilitate starch granules' cohesion, enabling the production of GF-baked products, such as bread. Some FHs and their application in GF-baked products formulation are depicted in Figure 2.

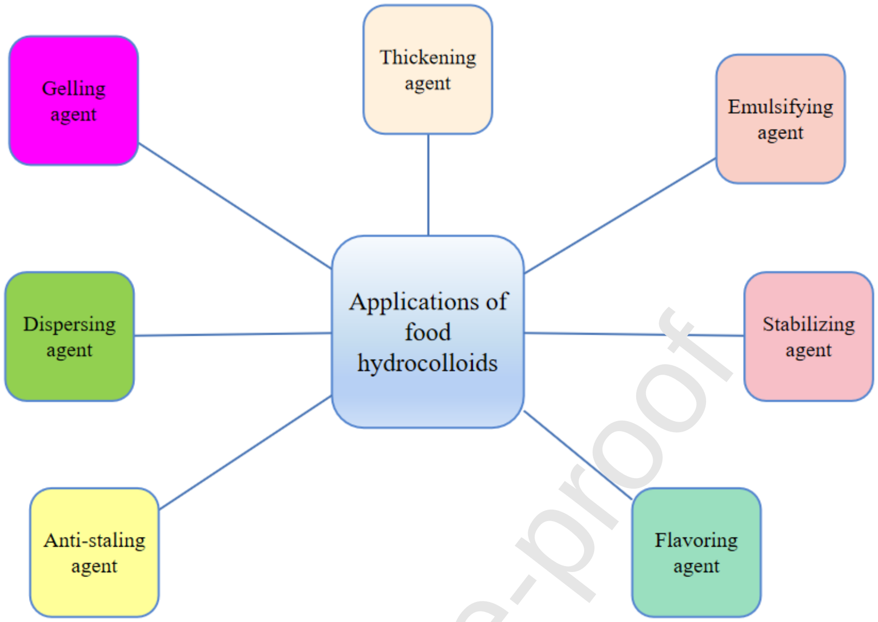


Fig.1 Functions of food hydrocolloids

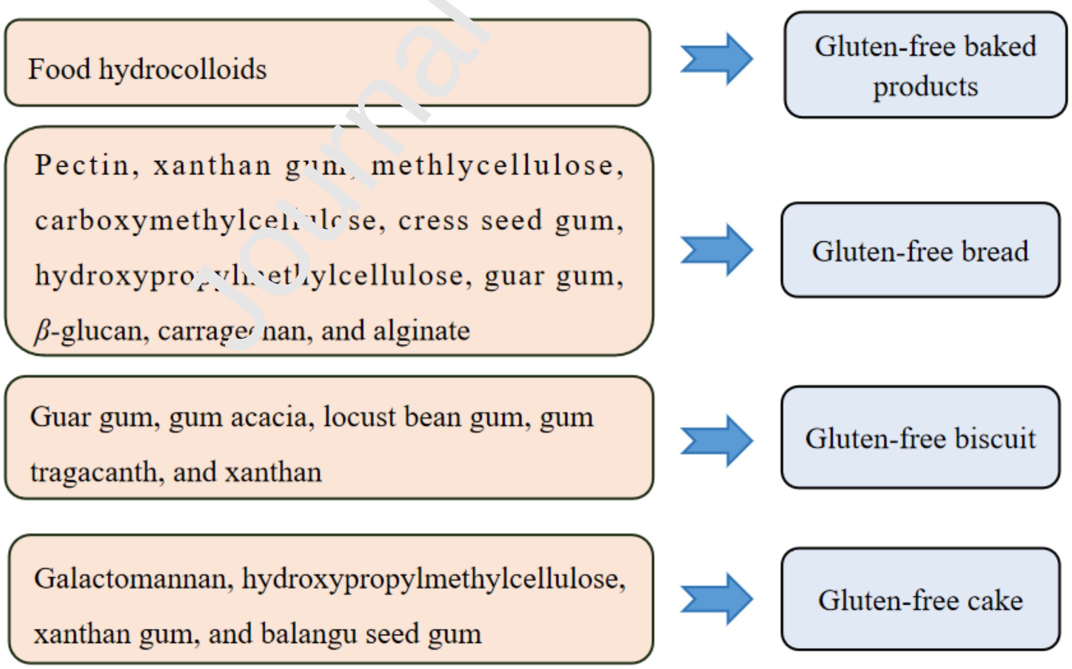


Fig. 2. Some food hydrocolloids and their application in GF-baked products formulation

4.1. Natural food hydrocolloids used in GF-baked foods

Natural FHs have been greatly utilized in the food industry to increase the functionality of food products like confectionery, beverages, meat and poultry, sauces and dressings [47]. The classification of natural FHs is based on their chemical structures, behaviors and origins [27]. The different sources of natural FHs include, microbial (e.g. xanthan gum), plant (e.g. starch, pectin, locust bean gum and carrageenan) and animal (e.g. chitosan) [48]. Depending on the source, they are classified into different types, including microbial gums, seed gums, exudate gums, seaweeds gums, mucilage gums, tuber gum, etc [49]. However, plant materials are the major and less expensive sources of natural FHs [47, 50]. Some plant sources of natural FHs, their gum type, major polysaccharide constituent and functions are presented in Table 1 [1, 21, 35, 46, 50–85].

Table 1. Some plant sources of natural food hydrocolloids, gum type, major polysaccharide constituent and functions

Plant	Gum type	Major polysaccharide constituent/Function	Reference
Sweet detar (*Detarium microcarpum*)	Seed gum	Xyloglucan/thickening and stabilizing agent	[1, 51–53]
Bean pod (*Brachystegia eurycoma*)	Seed gum	Xyloglucan/thickening and stabilizing agent	[50–52]
Mahogany (*Afzelia africana*)	Seed gum	Xyloglucan/thickening and stabilizing agent	[51–53]
Fenugreek (*Trigonella foenum-graecum* L.)	Seed gum	Galactomannan/thickening, stabilizing, emulsifying and geling agent	[54–56]
Flaxseed (*Linum usitatiissimum*)	Seed gum	Arabinoxylan/Water binding agent	[54, 56]
Cress (*Lepidium sativum*)	Seed gum	Galactomannan/Thickening and stabilizing agent	[46, 57–59]
Locust bean or carob tree (*Ceratonia siliqua*)	Seed gum	Galactomannan/thickening, stabilizing, emulsifying and geling agent	[55, 56, 60, 61]
Balangu (*Lallemantia royleana*)	Seed gum	Arabinogalactan/stabilizing and thickening agent	[62, 63]
Basil (*Ocimum bacilicum*)	Seed gum	Glucomannan and xylan/thickening, stabilizing and emulsifying agent	[64, 65]
Butternut squash (*Cucurbita moschata*) seed	Seed gum	Mannose, glucose, and galactose (galactomannan)/thickening, stabilizing and emulsifying agent	[66, 67]
Charota (*Cassia tora*)	Seed gum	Galactomannan/viscous-enhancing and water-binding agent	[56, 68]
Guar (*Cyamposis tetragonolobus*)	Seed gum	Galactomannan/thickening, stabilizing, emulsifying and geling agent	[55, 56, 69]
Okra (*Abelmoschus esculentus*	Mucilage	Pectin/thickening and stabilizing agent	[54, 70]

L.)	gum		
Psyllium (*Plantago psyllium*)	Mucilage gum	Arabinoxylan/thickening and gelling agent	[21, 71, 72]
Mustard (*Brassica juncea* L.) seed	Mucilage gum	Pectic polysaccharides/ thickening, stabilizing and texturizing agent	[73–75]
Tamarind (*Tamarindus indica* L.)	Mucilage gum	Xyloglucan/thickening, gelling, stabilizing, and binding agent	[53, 55, 56, 76]
Acacia (*Acacia nilotica* Linn. and *Acacia senegal*)	Exudate gum	Arabinogalactan/binding agent	[77–79]
Tragacanth (*Astragalus gummifer*)	Exudate gum	Arabinogalactan/stabilizing, thickening and emulsifying agent	[80–82]
Karaya (*Sterculia* species)	Exudate gum	Rhamnogalacturonans/stabilizing, thickening and emulsifying agent	[68, 83]
Konjac (*Amorphophallus konjac*)	Tuber gum	Glucomannan/thickening, stabilizing and gelling agent	[35, 55]
Salep (*Orchis anatolica*)	Tuber gum	Glucomannan/thickening, stabilizing and gelling agent	[84, 85]

Due to their availability and affordability, natural FHs were considered a cheaper alternative to replace gluten than modified FHs [50]. In this context, some studies have reported their use as gluten replacement in baked products. Souler et al. [86] reported using xanthan gum to formulate a GF biscuit from a rice-chickpea flour blend. Naji-Tabasi & Mohebbi [46] also baked GF bread with a composite of rice flour, corn flour, and corn starch added with cress seed gum and xanthan gum at 1% (*W*/*W*) level. In a study reported by Irondi et al. [50], GF bread was baked with whole pearl millet flour blended with *Brachystegia eurycoma* flour. In a related study, Irondi et al. [1] produced GF bread from sweet detar (*Detarium microcarpum*) and whole pearl millet flour. Filipcev et al. [10] also reported the use of psyllium in buckwheat/carob GF bread. Psyllium was also reportedly used with chickpea for the formulation of GF bread by Santos et al. [21] alongside with cassava starch and rice flour. Okra powder, which was reported to contain mucilage, mainly pectin [87] has also been used for baking GF bread [88]. There have also been reports on the use of natural FHs of animal origin in baking. Lieke et al. [89] and Marina et al. [90] reported that whey protein was used for GF bread. A combination of different natural FHs (guar gum, gum acacia, gum tragacanth, and xanthan) added to buckwheat flour was also used in baking a GF biscuit Maninder et al. [91]. Furthermore, GF cake based on fava bean was baked by Ejet et al. [92] using galactomannan and xanthan gum. In a similar report, an infant biscuit was produced from rice-chickpea flour by incorporating locust bean and xanthan gum [93].

4.2. Modified food hydrocolloids used in GF-baked foods

Modified food hydrocolloids are another form of FHs used as gluten substitutes in GF-baked foods. They are produced either through natural hydrocolloid derivatization and selective chemical modification [94] or by physical and enzymatic treatments [41]. The most commonly used modified FHs include methylcellulose (MC), carboxymethylcellulose (CMC), hydroxypropyl methylcellulose (HPMC) and hydroxyethyl cellulose (HEC) [95]. They are cellulose derivatives (cellulose ethers) obtained via chemical modification [48, 95]. Among these modified FHs, HPMC is the most used and has been credited to be the most favourable hydrocolloid in GF bread production [34]. It is produced by reacting both methylchloride and propylene oxide with alkali cellulose [96].

Some factors, such as cost [97], manufacturing process [98], and supply and demand [51], limit the use of modified FHs in the baking process. However, like natural FHs, many researchers have applied modified FHs as gluten substitute in baked products. Recently, Tabrizi et al. [99] used HPMC in baking GF bread. Furthermore, Sadeghnia et al. [100] used CMC to produce GF bread. In another study, sodium-CMC was blended with whole pearl millet flour at two proportions (1.5% and 3% basis) to produced GF bread [1, 50]. HPMC and CMC were used by Baldino et al. [101] to bake rice and buckwheat GF bread. Some other studies which reported the use of modified FHs for baking products include Hager & Arendt [102], Ronda et al. [103], Liu et al. [104], and Belorio & Gómez [105].

5. Functional benefits of natural and modified hydrocolloids in GF-baked foods

The functional benefits, including physicochemical, nutraceutical, and sensorial importance, of natural and modified hydrocolloids in GF-baked foods (Figure 3) are presented in the following sections.

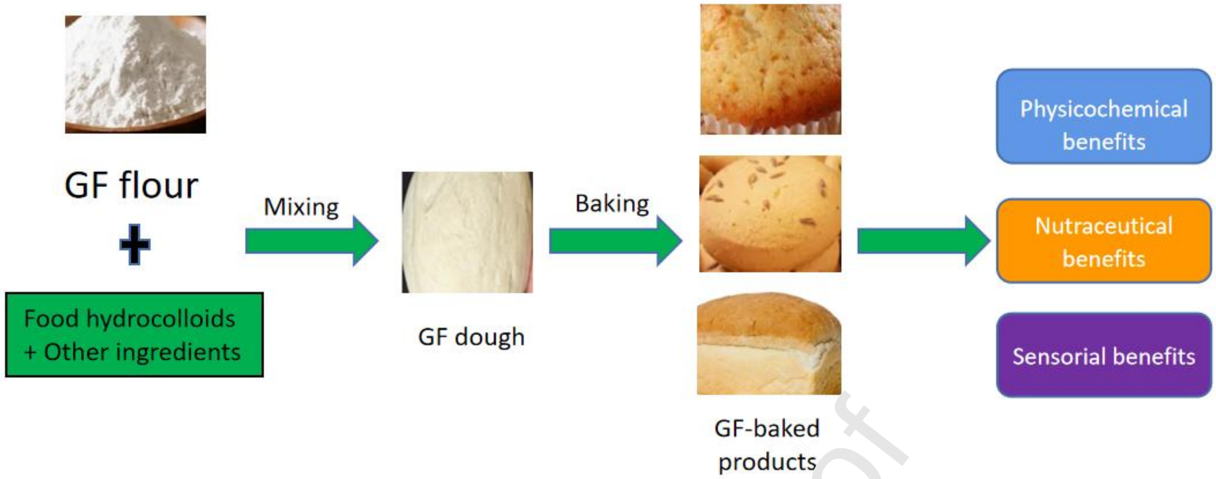


Fig. 3. Gluten-free baked products formulation and functional benefit

5.1. *Physicochemical importance of natural and modified hydrocolloids in GF-baked foods*

The use of FHs (natural and modified) in baked GF products has been reported to be of physicochemical importance in products. The FHs, by mimicking the viscoelastic properties of gluten, affect the physicochemical properties of GF flours and their products such as bread [1, 50], cake [92], and biscuit [106]. The addition of *Brachystegia eurycoma* and *Detarium microcarpum* flour (underutilized legume sources of hydrocolloids) in pearl millets flour was reported to improve the physicochemical and pasting properties of the resulting GF flour [1, 50]. FHs increase dough stability by increasing viscosity, coalescence and flocculation [107]. Also, the potential of FHs to increase viscosity has made it to be credited with the potential to improve dough development, gas retention and quality of GF bread [108].

In the study of Malhotra et al. [109], HPMC inclusion limited bread crumb's water loss, diffusion, starch and protein macromolecules interactions. It also reduced the staling kinetics of the GF bread during storage. Other studies have also shown that FHs are vital in formulating GF-baked products during dough formation, battering, baking or in the final products. Other functional importance include modifying dough behaviour, improving the internal structure, increasing the porosity and reducing strength and extension of the 3D network of the baked product [101]. They also increase water absorption of GF dough and products [110–112], which may be due to the hydroxyl groups in FHs structures [113]. However, some studies affirmed that adding FHs increased the hardness of GF products. In this regard, Shahzad et al. [114] concluded that both commercial and non-conventional FHs (xanthan gum, gum Arabic, fenugreek, cress seed, okra, and flaxseed) caused an increase in the hardness of GF cookies made from Turkish bean and sorghum flours. In addition, two other studies [115, 116] demonstrated that the inclusion of guar and xanthan gums in millet flour, and xanthan gum in GF flour brought about an increased hardness. The increased hardness of the GF product due to FHs addition has been ascribed to the hydrocolloids' propensity to bind substantial free water [114]. Gul et al. [116] attributed the increased hardness of GF product arising from xanthan gum inclusion to the "extremely branched structure of the xanthan" that enables it to interact easily with other constituents to form associations. Furthermore, Shahzad et al. [114] demonstrated that the addition of non-conventional (fenugreek, cress seed, okra, flaxseed) and commercial (xanthan gum) FHs resulted in a decrease in the pasting temperature of Turkish bean flour-based and sorghum flour-based blends. In the same study, they deduced that the water activity, moisture, and fibre contents of GF cookies made from the hydrocolloid substituted blends increased.

Some studies have also reported that adding FHs decreases the specific volume of GF-baked products, such as cookies, cakes, and breads. Ostermann-Porcel et al. [117] documented that the specific volume of GF cookies decreased as the okara flour substitution level increased. In another study, Yildiz & Dogan [118] reported a decrease in the specific volume of GF cake formulated with a blend of chestnut flour and potato starch. This decrease in specific volume has been attributed to the capacity of fibres to influence gas retention and structure, thereby hampering the dough [119]. Furthermore, addition of xanthan gum resulted in a decrease in the volume of GF bread [102] and GF flat bread [120]. This decrease in the GF breads was ascribed to the xanthan gum's thickening effect, leading to a reduction in gases diffusion in air cells when baking, thereby disrupting the expansion of gas [121].

Further, hydrocolloids' anti-staling effects on GF-baked products have been reported. Filipcev and his colleagues [10] affirmed that psyllium inclusion displayed an effective anti-staling effect on GF bread formulated with buckwheat and carob flour composite. In a related study, the addition of psyllium husk powder at 2.86%, 7.14%, and 17.14% levels in rice flour-based GF bread formulations resulted in a delay in bread staling [13]. The researchers observed that 17.14% psyllium husk powder incorporation caused longest bread staling delay and improved the bread structure. Also, Wronkowska et al. [122] reported a delayed staling of GF bread, when buckwheat was supplemented with commercial corn starch, potato starch and pectin. This delay in staling was ascribed to the formation of complexes between the emulsifiers and amylose, thereby limiting the swelling leaching and subsequent retrogradation of starch [122]. The anti-staling effects of hydrocolloids are related to their water-retaining capacity, limiting water redistribution within starchy matrices [123]. For instance, some researchers affirmed that the effects of psyllium on the quality of GF bread depend on the level of water, psyllium-water interaction, as well as its strong complexes-forming capacity with proteins in the system via ionic and non-ionic bonding. Thus, the GF bread dough strength and crumb texture are affected [10, 124, 125].

5.2. Nutraceutical benefits of natural and modified food hydrocolloids in GF-baked foods

Besides their physicochemical importance, FHs confer nutraceutical/health-promoting properties to GF-baked food [126]. These health-promoting properties include immune regulation, weight management, lowering postprandial blood glucose and plasma cholesterol concentrations, colon cancer prevention, and cardiovascular disease prevention. Other health benefits associated with FHs are insulinaemic and glycemic control in type 2 diabetes, osteoporosis risk reduction, and modulation of intestinal transit and satiety [1, 11, 13, 38, 127]. These nutraceutical benefits of FHs have been attributed mainly to their chemical composition [11]. Irondi et al. [1] showed that the inclusion of sweet detar flour (a natural hydrocolloid source) at 1.5% level in whole pearl millets GF flour led to a stronger inhibition of starch-digesting enzymes (α-amylase and α-glucosidase) activity of the blend, relative to the native (pearl millets) flour. Further, Liu et al. [112] demonstrated that HPMC, CMC, xanthan gum, and apple pectin addition significantly decreased the level of rapidly digestible starch and the estimated glycemic index of potato flour-based GF bread relative to control bread. Hydrocolloids' ability to reduce GF products' glycemic index has been ascribed to their tendency to form a layer surrounding starch granules, thereby decelerating their hydrolysis by starch-hydrolyzing enzymes (α-amylase and α-glucosidase). Consequently, this diminishes the level of absorbable monosaccharides [112, 128].

The nutraceutical benefits of FHs in GF-baked products are not limited to the above reports, as their addition also affects other health-promoting properties of the GF products. The work of Shahzad et al. [114] affirmed that the inclusion of cress seed gum led to a higher antioxidant activity in GF cookies made from Turkish bean and sorghum flours. Similarly, a novel GF bread comprising corn starch, pectin, and potato starch, enriched with flaxseed oil cake extract was reported to have an improved antioxidant capacity than the control [129]. Furthermore, Mishra et al. [130] by using psyllium gum in baking GF bread reported that psyllium gum, due to its bulking effect, rendered laxative effect. This can help in alleviating osteoporosis risk, render bowel function [131], prevent colon cancer, coronary heart diseases, type 2 diabetes [19], as well as constipation.

FHs serve as a source of dietary fibre in GF products [96]. In this regard, a recent report by Ronie et al. [2] indicated that Bario rice (red-pigmented) flour-based GF bread containing 30% potato starch had a higher fibre level than the counterpart wheat bread. The high level of dietary fibre and their role as prebiotics in GF-baked products promote a healthy gastrointestinal tract. The intake of certain FHs could enhance the growth of health-promoting bacteria such as lactobacillus and bifido, thereby regulating the intestinal bacterial flora composition. The concomitant increase in the fermentative activity of these intestinal bacterial flora and the production of short-chain fatty acid [132] could facilitate their associated cell proliferation, angiogenesis, and apoptosis-modulatory effects [38].

5.3. Sensorial importance of natural and modified hydrocolloids in GF-baked foods

By modifying their rheological characteristics, FHs impart the sensory qualities of baked products [38]. Furthermore, the interaction between protein and sugar during baking results in the Maillard reaction and its products formation, with an attendant colour change [119]. Hence, achieving a desirable sensorial acceptability remains a big challenge when developing GF-baked products [133]. However, despite consumers' preference for refined wheat products [9], their acceptance of GF products made from GF cereals has been linked to the health benefits associated with GF products [1]. In this context, the effect of FHs on the sensory qualities of baked products has been reported by several studies. Thejasri et al. [106] investigated the sensory characteristics of GF biscuit formulated with foxtail millet (*Setaria italica*) and quinoa (*Chenopodium quinoa* Willd.) incorporated with guar and xanthan gums. They concluded that adding guar and xanthan gums at 1% significantly improved the sensorial attributes of both foxtail millet and quinoa biscuits [106]. In a related study, Kaur et al. [134] reported that adding xanthan gum to buckwheat flour biscuits significantly improved the biscuits' colour, texture, taste, and overall acceptability. Further, adding galactomann and xanthan gum enhanced the sensory qualities of fava (*Phaseolus lunatus*) bean-based GF cakes [92]. *Detarium microcarpum* and *Brachystegia eurycoma* flours were also reported to improve the sensory attributes of whole pearl millets-based GF bread [1, 50].

The sensory qualities of a GF bread formulated by substituting rice flour for sweet potato flour and using 2% CMC were comparable to those without the addition CMC [135]. In another study, the partial replacement of 6% each of rice flour and starch with amaranth in rice flour: corn starch and rice flour: tapioca-based flat bread improved the colour of the bread [136]. Further, Shahzad et al. [114] investigated the influence of some non-conventional (fenugreek, cress seed, okra, flaxseed) and commercial (xanthan gum and gum Arabic) hydrocolloids on the sensory qualities of GF cookies made from Turkish beans and sorghum. They demonstrated that cookies containing okra and gum Arabic at a 5% substitution level had a similar acceptability score as the control (plain flour of Turkish beans and sorghum). A GF bread made from Bario rice (red-pigmented) added with potato starch in the proportions of 70% and 30% for rice flour and potato starch, respectively, was adjudged to have high sensory scores in colour, flavour, texture, and overall acceptability [2].

6. Conclusion and future perspective

Food hydrocolloids have been extensively used as gluten replacement in GF-baked products, targeting consumers susceptible to gluten allergy, due to their capacity to mimic gluten's viscoelastic quality. They are derived from plant, animal, and microbial sources and may be used in natural or modified forms. Food hydrocolloids improve the textural, rheological, dough handling properties, and gas retention of GF dough, extend the shelf-life and enhance the overall quality of GF-baked products. Also, they render nutraceutical benefits such as antioxidant activity, lowering of postprandial blood glucose and plasma cholesterol concentrations, modulation of intestinal transit and satiety, promotion of a healthy gastrointestinal tract by enhancing the growth of health-promoting bacterial and colon cancer prevention.

GF-baked products are believed to be of much lower nutritional quality, as they lack some essential nutrients, such as minerals and vitamins [57]. Therefore, future research can target improving the nutritional quality of GF products, possibly by using the flour of GF legumes, either alone or blended with that of a cereal or pseudo-cereal. The GF products' formulation can also be optimized using a product development software, such as the Design Expert. Furthermore, various forecasts and market reports are of the opinion that the value of FHs in the global FHs market will increase by 50% in the next ten years [47]. This is expected to increase the prices of FHs and GF-baked products, which may be further exacerbated by the high cost of producing modified FHs. Therefore, research efforts can be intensified in exploring the more readily available and affordable natural FHs in the formulation of GF-baked products, to cushion the effect of a possible price rise on the food industry and consumers of GF-baked products.

CRediT Authorship Contribution Statement

Emmanuel Anyachukwu Irondi: Conceptualization, Supervision, Writing – original draft. Yunus Temitayo Imam: Conceptualization, Writing – original draft. Emmanuel Oladipo Ajani: Supervision, Writing – review & editing. Emmanuel Oladeji Alamu: Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare no competing interests.

Acknowledgement

The authors acknowledge the library of Kwara State University, Malete, and the Knowledge Center, International Institute of Tropical Agriculture, Ibadan, for facilitating access to most of the internet resources used in this review paper.

References

[1] E.A. Irondi, Y.T. Imam, E.O. Ajani, Physicochemical, antioxidant and starch-digesting enzymes inhibitory properties of pearl millet and sweet detar gluten-free flour blends, and sensory qualities of their breads, Front. Food Sci. Technol. 2 (2022) 974588. https://doi.org/10.3389/frfst.2022.974588.

[2] M.E. Ronie, H. Mamat, A.H. Abdul Aziz, et al., Proximate compositions, texture, and sensory profiles of gluten-free Bario rice bread supplemented with potato starch, Foods 12 (2023) 1172. https://doi.org/10.3390/foods12061172.

[3] S.A. Mir, M.A. Shah, H.R. Naik, et al., Influence of hydrocolloids on dough handling and technological properties of gluten-free breads, Trends Food Sci. Technol. 51 (2016) 49–57. https://doi.org/10.1016/j.tifs.2016.03.005.

[4] X. Theodoridis, M.G. Grammatikopoulou, A. Petalidou, et al., Dietary management of celiac disease: revisiting the guidelines, Nutr. 66 (2019) 70-77. https://doi.org/10.1016/j.nut.2019.04.008.

[5] C. Lamacchia, A. Camarca, S. Picascia, et al., Cereal-based gluten-free food: how to reconcile nutritional and technological properties of wheat proteins with safety for celiac disease patients, Nutr. 6 (2014) 575–590. https://doi.org/10.3390/nu6020575.

[6] C.M. Rosell, F. Barro, C. Sousa, et al., Cereals for developing gluten-free products and analytical tools for gluten detection, J. Cereal Sci. 59 (2014) 354-364. https://doi.org/10.1016/j.jcs.2013.10.001.

[7] Codex Alimentarius Commission, Draft revised codex standard for foods for special dietary use for persons intolerant to gluten, Joint FAO/WHO Food Standards Programme. Geneva, Switzerland: WHO (2007).

[8] M.A.N. Khairuddin, O. Lasekan, Gluten-free cereal products and beverages: A review of their health benefits in the last five years, Foods 10 (2021) 2523. https://doi.org/10.3390/foods10112523.

[9] O. Parenti, L. Guerrini, B. Zanoni, Techniques and technologies for the breadmaking process with unrefined wheat flours, Trends Food Sci. Technol. 99 (2020) 152-166. https://doi.org/10.1016/j.tifs.2020.02.034.

[10] B. Filipcev, M. Pojic, O. Simurina, et al., Psyllium as an improver in gluten-free breads: effect on volume, crumb texture, moisture binding and staling kinetics, LWT-Food Sci. Technol. 151 (2021) 112156. https://doi.org/10.1016/j.lwt.2021.112156.

[11] M. Manzoor, M. Ahmad, J.D. Bandral, et al., Food hydrocolloids: Functional, nutraceutical and novel applications for delivery of bioactive compounds, Int. J. Biol. Macromol. 165 Part A (2020) 554-567. https://doi.org/10.1016/j.ijbiomac.2020.09.182.

[12] S.W. Horstmann, C. Axel, E.K. Arendt, Water absorption as a prediction tool for the application of hydrocolloids in potato starch-based bread, Food Hydrocolloids 81 (2018), 129-138. https://doi.org/10.1016/j.foodhyd.2018.02.045.

[13] C. Fratelli, F.G. Santos, D.G. Muniz, et al., Psyllium improves the quality and shelf life of gluten-free bread, Foods, 10 (2021) 954. https://doi.org/10.3390/foods10050954.

[14] N.D. Ford, S.A. Patel, K.M.V. Narayan, Obesity in low- and middle-income countries: burden, drivers, and emerging challenges, Annu. Rev. Publ. Health 38 (2017) 145–164.

[15] S. Raj, Influences of the nutrition transition on chronic disease. In: D. Noland, J. Drisko, L. Wagner (eds), Integrative and Functional Medical Nutrition Therapy, Humana, Cham. (2020). https://doi.org/10.1007/978-3-030-30730-1_2.

[16] Md. S. Islam, N.J. Jhily, R. Hasan, et al., Nutritional transition in unindustrialized countries: Causes and consequences on public health, Indian J. Publ. Health Res. Dev. 12 (2021), 342-346.

[17] D. Qu, New scenarios on global food security based on Russia-Ukraine conflict, Food and Agriculture Organization of the United Nations (2022). https://www.fao.org/director-general/news/news-article/en/c/1476480/.

[18] T. Lang, M McKee, The reinvasion of Ukraine threatens global food supplies, BMJ. (2022) 376. http://dx.doi.org/10.1136/bmj.o676.

[19] X.Z. Hu, X.H. Xing, Z.M. Zhang, et al., Antioxidant effects of *Artemis Sphaerocephala* Krasch. gum on Streptozotocin induced Type 2 diabetic rats, Food Hydrocolloids 25 (2011) 207-213.

[20] K.L.F. Pessanha, J.P. de Menezes, A. dos Anjos Silva, et al., Impact of whole millet extruded flour on the physicochemical properties and antihyperglycemic activity of gluten free bread, LWT- Food Sci. Technol. 147 (2021) 111495. https://doi.org/10.1016/j.lwt.2021.111495.

[21] F.G. Santos, E.V. Aguiar, C.M. Rosell, et al., Potential of chickpea and psyllium in gluten-free breadmaking: assessing bread's quality, sensory acceptability, and glycemic and satiety indexes, Food Hydrocolloids 113 (2021) 106487.

[22] E.V. Aguiar, F.G. Santos, A.C.L.S. Centeno, et al., Defining amaranth, buckwheat and quinoa flour levels in gluten-free bread: A simultaneous improvement on physical properties, acceptability and nutrient composition through mixture design, Foods 11 (2022) 848. https://doi.org/10.3390/foods11060848.

[23] D. El Khoury, S. Balfour-Ducharme, I.J. Joye, A review on the gluten-free diet: Technological and nutritional challenges, Nutrients 10 (2018) 1410.

[24] I.S. Cohen, A.S. Day, R. Shaoul, To be oats or not to be? An update on the ongoing debate on oats for patients with celiac disease, Front. Pediatrics 7 (2019) 384. https://doi.org/10.3389/fped.2019.00384.

[25] V. Fajardo, M.P. González, M. Martínez, et al., Updated food composition database for cereal-based gluten free products in Spain: Is reformulation moving on?, Nutrients 12 (2020) 2369.

[26] S. Rai, A. Kaur, C.S. Chopra, Gluten-free products for celiac susceptible people, Front. Nutr. 5 (2018) 116.

[27] F. Salehi, Improvement of gluten-free bread and cake properties using natural hydrocolloids: A review, Food Sci. Nutr. 7 (2019) 3391–3402. https://doi.org/10.1002/fsn3.1245.

[28] A. Zoghi, R.S. Mirmahdi, M. Mohammadi, The role of hydrocolloids in the development of gluten-free cereal-based products for coeliac patients: a review, Int. J. Food Sci. Technol. 56 (2021) 3138-3147. https://doi.org/10.1111/ijfs.14887.

[29] A. Houben, A. Hochstotter, T. Becker, Possibilities to increase the quality in gluten free bread production: an overview, Eur. Food Res. Technol. 235 (2012) 195-208. https://doi.org/10.1007/s00217-012-1720-0.

[30] E. Johanan, G. Raquel, O.S. Sergio, et al., Mimicking gluten functionality with β-conglycinin concentrate: evaluation in gluten free yeast-leavened breads, Food Res. Int. 106 (2018) 64–70.

[31] A. Skendi, M. Papageorgiou, T. Varzakas, High protein substitutes for gluten in gluten-free bread, Foods 10 (2021) 1997. https://doi.org/10.3390/foods10091997.

[32] F. Morreale, R. Garzon, C.M. Rosell, Understanding the role of hydrocolloids viscosity and hydration in developing gluten-free bread: A study with hydroxypropylmethylcellulose, Food Hydrocolloids 77 (2017) 629-635. https://doi.org/10.1016/j.foodhyd.2017.11.004.

[33] E. Gallagher, T.R. Gormley, E.K. Arendt, Recent advances in the formulation of gluten-free cereal-based products, Trends Food Sci. Technol. 15 (2004) 143-152.

[34] A. Cappelli, N. Oliva, E. Cini, A Systematic Review of gluten-free dough and bread: dough rheology, bread characteristics, and improvement strategies, Appl. Sci. 10 (2020) 6559. https://doi.org/10.3390/app10186559.

[35] F. Laignier, R.D.C.D.A. Akutsu, B.R.D. Lima, et al., *Amorphophallus konjac*: Sensory profile of this novel alternative flour on gluten-free bread, Foods 11 (2022) 1379. https://doi.org/10.3390/foods11101379.

[36] C.M. Rosell, C. Collar, M. Haros, Assessment of hydrocolloid effects on thermo mechanical properties of wheat using the Mixolab, Food Hydrocolloids 21 (2007) 452-462.

[37] O.P. Nautiyal, Hydrocolloids, modified hydrocolloids as food recipes and formulating agents, J. Food Process. Technol. 2 (2011) 111. https://doi.org/10.4172/2157-7110.1000111.

[38] J.M. Li, S.P. Nie, The functional and nutritional aspects of hydrocolloids in foods, Food Hydrocolloids 53 (2016) 46-61. https://doi.org/10.1016/j.foodhyd.2015.01.035.

[39] X. Yang, A. Li, X. Li, et al., An overview of classifications, properties of food polysaccharides and their links to applications in improving food textures, Trends Food Sci. Technol. 102 (2020) 1–15. https://doi.org/10.1016/j.tifs.2020.05.020.

[40] S. Dipjyoti, B. Suvendu, Hydrocolloids as thickening and gelling agents in food: a critical review, J. Food Sci. Technol. 47 (2010) 587–597. https://doi.org/10.1007/s13197-010-0162-6.

[41] D. Seisun, N. Zalesny, Strides in food texture and hydrocolloids, Food Hydrocolloids 117 (2021) 106575. https://doi.org/10.1016/j.foodhyd.2020.106575.

[42] U. Volta, G. Caio, R. De Giorgio, et al., Non-celiac gluten sensitivity: A work-in-progress entity in the spectrum of wheat-related disorders, Best Pract. Clin. Gastroenterol. 29 (2015) 477–91.

[43] N. Rhein-Knudsen, A.S. Meyer, Chemistry, gelation, and enzymatic modification of seaweed food hydrocolloids, Trends Food Sci. Technol. 109 (2021) 608–621. https://doi.org/10.1016/j.tifs.2021.01.052.

[44] Z. Gao, Y. Fang, Y. Cao, et al., Hydrocolloid-food component interactions, Food Hydrocolloids 68 (2017) 149–156.

[45] W. Lu, K. Nishinari, S. Matsukawa, et al., The future trends of food hydrocolloids, Food Hydrocolloids 103 (2020) 105713. https://doi.org/10.1016/j.foodhyd.2020.105713.

[46] S. Naji-Tabasi, M. Mohebbi, Evaluation of cress seed gum and xanthan gum effect on macrostructure properties of gluten-free bread by image processing, J. Food Meas. Charact. 9 (2015) 110-119. https://doi.org/10.1007/s11694-014-9216-1.

[47] A. Yemenicioğlu, S. Farris, M. Turkyilmaz, et al., Natural hydrocolloids in the food sector - recent applications beyond conventional uses, Int. J. Food Sci. Technol. 55 (2020) 1387–1388. https://doi.org/10.1111/ijfs.14561.

[48] J.J. O'Sullivan, J.A. O'Mahony, Food Ingredients, Ref. Module Food Sci. (2016). https://doi.org/10.1016/b978-0-08-100596-5.03407-7.

[49] S. Barak, D. Mudgil, S. Taneja, Exudate gums: chemistry, properties and food applications – a review, J. Sci. Food Agric. 100 (2020) 2828-2835.

[50] E.A. Irondi, Y.T. Imam, E.O. Ajani, Effect of *Brachystegia eurycoma* flour addition on the physicochemical properties of whole millet flour and the sensory attributes of its gluten-free bread, Acta Universitatis Cibiniensis. Series E: Food Technol. 25 (2021) 43-52. https://doi.org/10.2478/aucft-2021-0004.

[51] L.M. Nwokocha, P.A. Williams, Evaluating the potential of Nigerian plants as a source of industrial hydrocolloids, in: P.A. Williams, G.O. Phillips (Eds), Gums and Stabilisers for the Food Industry, 16th ed., The Royal Society of Chemistry, 2012, pp. 27–44. https://doi.org/10.1039/9781849734554-00027.

[52] A.A. Nwakaudu, M.S. Nwakaudu, C.I. Owuamanam, et al., Effect of carboxymethylcellulose incorporation on the functional, pasting and sensory properties of water yam (D. alata) flour, Eur. J. Food Sci. Technol. 5 (2017) 1-12.

[53] J. Esquena-Moret, A review of xyloglucan: self-aggregation, hydrogel formation, mucoadhesion and uses in medical devices, Macromol 2 (2022) 562-590. https://doi.org/10.3390/macromol2040037.

[54] S.A. Shahzad, S. Hussain, A.A. Mohamed, et al., Effect of hydrocolloid gums on the pasting, thermal, rheological and textural properties of chickpea starch, Foods 8 (2019) 687. https://doi.org/10.3390/foods8120687.

[55] K. Nishinari, M. Takemasa, H. Zhang, et al., 2.19–Storage plant polysaccharides: Xyloglucans, galactomannans, glucomannans, Compr. Glycosci. (2007) 613-652.https://doi.org/10.1016/B978-044451967-2/00146-X.

[56] H. Mirhosseini, B.T. Amid, A review study on chemical composition and molecular structure of newly plant gum exudates and seed gums, Food Res. Int. 46 (2012) 387–398. http://dx.doi.org/10.1016/j.foodres.2011.11.017.

[57] A. Culetu, D.E. Duta, M. Papageorgiou, et al., The role of hydrocolloids in gluten-free bread and pasta; rheology, characteristics, staling and glycemic index, Foods 10 (2021) 3121. https://doi.org/10.3390/foods10123121.

[58] S. Naji, S.M.A. Razavi, Functional and textural characteristics of cress seed (*Lepidium sativum*) gum and xanthan gum: Effect of refrigeration condition, Food Biosci. 5 (2014) 1-8. https://doi.org/10.1016/j.fbio.2013.10.003.

[59] A. Taheri, S.M.A. Razavi, Fabrication of cress seed gum nanoparticles, an anionic polysaccharide, using desolvation technique: an optimization study, BioNanoSci. 5 (2015) 104–116. https://doi.org/10.1007/s12668-015-0169-6.

[60] M. Petitjean, J.R. Isasi, Locust bean gum, a vegetable hydrocolloid with industrial and biopharmaceutical applications, Molecules 27 (2022) 8265. https://doi.org/10.3390/molecules27238265.

[61] K. Nasrallah, S. Khaled, S. El Khatib, et al., Nutritional, biochemical and health properties of Locust beans and its applications in the food industry: a review, J. Food Sci. Technol. (2023). https://doi.org/10.1007/s13197-023-05765-5

[62] F. Salehi, E.S. Amin, S. Pavee, et al., Effect of balangu seed gum on rheological, physical and sensory properties of gluten free rice cake, Food Sci. Nutr. 15 (2018) 61–68.

[63] N. Farhadi, Structural elucidation of a water-soluble polysaccharide isolated from Balangu shirazi (*Lallemantia royleana*) seeds, Food Hydrocolloids. 72 (2017) 263-270. http://dx.doi.org/10.1016/j.foodhyd.2017.05.028.

[64] S.M.A. Razavi, S. Naji-Tabasi, Rheology and texture of basil seed gum: a new hydrocolloid source. In: Advances in Food Rheology and Its Applications (2nd Edition), J. Ahmed, S. Basu, (Editors), Woodhead Publishing, (2023) 413-458. https://doi.org/10.1016/B978-0-12-823983-4.00015-7.

[65] J.P. Osano, S.H. Hosseini-Parvar, L. Matia-Merino, et al., Emulsifying properties of a novel polysaccharide extracted from basil seed (*Ocimum bccilicum* L.): Effect of polysaccharide and protein content, Food Hydrocolloids 37 (2014) 40-48. http://dx.doi.org/10.1016/j.foodhyd.2013.09.008.

[66] S.E. Quintana, E.G. Torregroza-Fuentes, L.A. Zapateiro, Development of dressing-type emulsion with hydrocolloids from butternut squash seed: Effect of additives on emulsion stability, Gels 8 (2022) 209. https://doi.org/10.3390/gels8040209.

[67] S. Orgulloso-Bautista, R. Ortega-Toro, L.A. García Zapateiro, design and application of hydrocolloids from butternut squash (*Cucurbita moschata*) epidermis as a food additive in mayonnaise-type sauces, ACS Omega. 6 (2021) 5499–5508. https://doi.org/10.1021/acsomega.0c05852.

[68] P. Himashree, A.S. Sengar, C.K. Sunil, Food thickening agents: Sources, chemistry, properties and applications-A review, Int. J. Gastro. Food Sci. 27 (2022) 100468. https://doi.org/10.1016/j.ijgfs.2022.100468.

[69] C.T. Herald, Guar gum. in: Food Hydrocolloids, CRC Press, 2020, pp. 171-184..

[70] Y. Wu, N. Eskin, W. Cui, et al., Emulsifying properties of water soluble yellow mustard mucilage: A comparative study with gum Arabic and citrus pectin, Food Hydrocolloids 47 (2015) 191–196.

[71] T.L. Dantas, F.C. Alonso Buriti, E.R. Florentino okra (*Abelmoschus esculentus* L.) as a potential functional food source of mucilage and bioactive compounds with technological applications and health benefits, Plants 10 (2021) 1683. https://doi.org/10.3390/plants10081683.

[72] M.K. Patel, B. Tanna, H. Gupta, et al., Physicochemical, scavenging and anti-proliferative analyses of polysaccharides extracted from psyllium (*Plantago ovata* Forssk) husk and seeds, Int. J. Biol. Macromol. (2019) doi:10.1016/j.ijbiomac.2019.04.062.

[73] L. Yu, G.E.Yakubov, M. Martínez-Sanz, et al., Rheological and structural properties of complex arabinoxylans from *Plantago ovata* seed mucilage under non-gelled conditions, Carbohydr. Polym. 193 (2018) 179–188. https://doi.org/10.1016/j.carbpol.2018.03.096.

[74] E. Alpizar-Reyes, A. Román-Guerrero, R. Gallardo-Rivera, et al., Rheological properties of tamarind (*Tamarindus indica* L.) seed mucilage obtained by spray-drying as a novel source of hydrocolloid, Int. J. Biol. Macromol. 107 (2018) 817-824. https://doi.org/10.1016/j.ijbiomac.2017.09.048.

[75] Y. Wu, D. Hui, N.A.M. Eskin, et al., Water-soluble yellow mustard mucilage: A novel ingredient with potent antioxidant properties, Int. J. Biol. Macromol. 91 (2016) 710–715. http://dx.doi.org/10.1016/j.ijbiomac.2016.05.088

[76] S.W. Cui, M.A.N. Eskin, Y. Wu, et al., Synergisms between yellow mustard mucilage and galactomannans and applications in food products — A mini review, Adv. Colloid Interface Sci. (2006) 128-130, 249–256. https://doi.org/10.1016/j.cis.2006.11.012.

[77] M. Tiwari, A. Panghal, V. Mittal, et al., Bioactive compounds of acacia, health benefits and its utilization in food processing industry: a critical review, Nutr. Food Sci. (2023). https://doi.org/10.1108/NFS-08-2022-0274.

[78] N. Prasad, N. Thombare, S.C. Sharma, et al., Gum arabic–A versatile natural gum: A review on production, processing, properties and applications, Ind. Crops Prod. 187 (2022) 115304. https://doi.org/10.1016/j.indcrop.2022.115304.

[79] F. Thevenet, Acacia Gum (Gum Arabic), in: A. Imeson (Ed.), Food Stabilisers, Thickeners and Gelling Agents, 2010, pp. 11–30. http://dx.doi.org/10.1002/9781444314724.ch2.

[80] Z. Emam-Djomeh, M. Fathi, G. Askari, Gum Tragacanth (*Astragalus gummifer* Labillardiere). Emerging Nat. Hydrocolloids: Rheol. Funct. (2019) 299-326. https://doi.org/10.1002/9781119418511.ch12.

[81] A. Kurt, A. Cengiz, T. Kahyaoglu, The effect of gum tragacanth on the rheological properties of salep based ice cream mix, Carbohydr. Polym. 143 (2016) 116–123. http://dx.doi.org/10.1016/j.carbpol.2016.02.018

[82] M. Nejatian, S. Abbasi, F. Azarikia, Gum tragacanth: structure, characteristics and applications in foods, Int. J. Biol. Macromol. (2020). https://doi.org/10.1016/j.ijbiomac.2020.05.214.

[83] V.T.P. Vinod, R.B. Sashidhar, V.U.M. Sarma, et al., Comparative amino acid and fatty acid compositions of edible gums kondagogu (*Cochlospermum gossypium*) and karaya (*Sterculia urens*), Food Chem. 123 (2010) 57–62. https://doi.org/10.1016/j.foodchem.2010.03.127.

[84] B. Bulut-Solak, L. Alonso-Miravalles, J.A. O'Mahony, Composition, morphology and pasting properties of *Orchis anatolica* tuber gum, Food Hydrocolloids 69 (2017) 483-490. https://doi.org/10.1016/j.foodhyd.2016.12.009.

[85] A. Kurt, Salep glucomannan: Properties and applications, Polysaccharides (2021) 177–203. doi:10.1002/9781119711414.ch9.

[86] B. Soulef, S. Ana, N.Z. Mohammed, et al., Gluten-free biscuits based on composite rice-chickpea flour and xanthan gum, Food Sci. Technol Int. 24 (2018) 607-616.

[87] F.S. Dos Santos, R.M. do Figueiredo, A.J.D.M. Queiroz, et al. Effect of dehydrated method on okra chemical and physical composition, J. Agric. Sci. 11 (2019) 236. https://doi.org/10.5539/jas.v11n5p236.

[88] D. Tufaro, A. Bassoli, C. Cappa, Okra (*Abelmoschus esculentus*) powder production and application in gluten free bread. Effect of particle size, Food Bioprocess. Technol. 15 (2022) 904-914. https://doi.org/10.1007/s11947-022-02784-6.

[89] E.V. Lieke, J.D. Atze, J.H. Rob, et al., Preparation of gluten-free bread using a meso-structured whey protein particle system, J. Cereal Sci. 53 (2011) 355-361.

[90] R.K. Marina, V.H. Raisa, D. Helena, et al., Effect of whey protein and mixed flours on the quality parameters of gluten-free breads, Int. J. Gastro. Food Sci. 24 (2021) 100361.

[91] K. Maninder, S.S. kawaljit, P.A. Amit, et al., Gluten-free biscuits prepared from buckwheat flour by incorporation of various gum: Physicochemical and sensory properties, LWT - Food Sci. Technol. 62 (2015) 628-632.

[92] A.F. Ejet, P.B.S. Albuquerque, G.M.D. Moraes, et al., Influence of hydrocolloid (galactomann and xanthan gum) on the physicochemical and sensory characterization of gluten-free cakes based on fava bean (*Phaseolus lunatus*), Food Funct. 9 (2018) 6369-6379.

[93] B. Soulef, S. Ana, S. Teresa, et al., Optimization of xanthan and locust bean gum in a gluten-free infant biscuit based on rice-chickpea flour using response surface methodology, Food 10 (2020) 12.

[94] J. Milani, G. Maleki, Hydrocolloids in Food Industry, in: B. Valdez (Ed), Food Industrial Processes-Methods and Equipment, IntechOpen, 2012. https://doi.org/10.5772/32358.

[95] A. Yemenicioğlu, S. Farris, M. Turkyilmaz, et al., A review of current and future food applications of natural hydrocolloids, Int. J. Food Sci. Technol. 55 (2019) 1389-1406. https://doi.org/10.1111/ijfs.14363.

[96] J.N. BeMiller, in: Carbohydrate chemistry for food scientists, 2nd ed., St. Paul, Minnesota, USA: *AACC International,* Inc., 2007.

[97] E.I. Ohimain, The prospects and challenges of cassava inclusion in wheat bread policy in Nigeria, Int. J. Sci. Technol. Soc. 2 (2014) 6-17. https://doi.org/10.11648/j.ijsts.20140201.12.

[98] A.A. Adedeji, J. Alakali, P.O. Adewole, et al., Thermophysical properties of *Detarium microcarpum* seed flour, LWT-Food Sci. Technol. 47 (2012) 233–237. https://doi.org/10.1016/j.lwt.2012.01.010.

[99] S.A. Tabrizi, A. Arianfer, Z. Sheikholeslami, Impact of cress seed and basil gum and HPMC on physicochemical and texture properties of gluten free bread, J. Agric. Sci. Technol. 25 (2023) 75-86.

[100] N. Sadeghnia, M.H. Azizi, M. Seyedain Ardebili, et al., Effect of xanthan and CMC on rheological properties of gluten free bread dough, Iran. J. Food Sci. Technol. 13 (2016) 137–148.

[101] N. Baldino, F. Laitano, F.R. Lupi, et al., Effect of HPMC and CMC on rheological behavior at different temperatures of gluten-free bread formulations based on rice and buckwheat flours, Eur. Food Res. Technol. 244 (2018) 1829–1842. https://doi.org/10.1007/s00217-018-3096-2.

[102] A.S. Hager, E.K. Arendt, Influence of hydroxpropyl methylcellulose (HPMC), xanthan gum and their combination on loaf specific volume, crumb hardness and crumb grain characteristics of gluten-free breads based on rice, maize, teff and buckwheat, Food Hydrocolloids 32 (2013) 195–203.

[103] F. Ronda, S. Perez-Quirce, A. Lazaridou, et al., Effect of barley and oat *β*-glucan concentrates on gluten-free rice-based doughs and bread characteristics, Food Hydrocolloids 48 (2015) 197-207.

[104] X. Liu, T. Mu, H. Sun, et al., Effect of ingredients on the quality of gluten-free steamed bread based on potato flour, J. Food Sci. Technol. 56 (2019) 2863–2873.

[105] M. Belorio, M. Gómez, Effect of hydration on gluten-free breads made with hydroxypropyl methylcellulose in comparison with psyllium and xanthan gum, Foods 9 (2020) 1548.

[106] V. Thejasri, T.V. Hymarathi, T. Pradeepa, et al., Sensory, physico-chemical and nutritional properties of glute free biscuit formulated with quinoa (*Chenopodium quinoa* Willd.), foxtail millet (*Setaria italica*) and hydrocolloids, Int. J. Curr. Microbiol. Appl. Sci. 6 (2017) 1710-1721. https://doi.org/10.20546/ijcmas.2017.608.205.

[107] E. Dickinson, Food emulsions and foams: Stabilization by particles, Curr. Opin. Colloid Interface Sci. 15 (2010) 40-49.

[108] V.D. Capriles, J.A.G. Areas, Novel approaches in gluten-free breadmaking: Interface between food science, nutrition, and health, Compr. Rev. Food Sci. Food Saf. 13 (2014) 871-890.

[109] M. Mariotti, M.A. Pagani, M. Lucisano, The role of buckwheat and HPMC on the bread making properties of some commercial gluten-free bread mixture, Food Hydrocolloids 30 (2013) 393-400.

[110] M.J. Correa, M.C. Añón, G.T. Pérez, et al., Effect of modified celluloses on dough rheology and microstructure, Food Res. Int. 43 (2010) 780–787.

[111] R. Moreira, F. Chenlo, M.D. Torres, Effect of chia (*Sativa hispanica* L.) and hydrocolloids on the rheology of gluten-free doughs based on chestnut flour, LWT-Food Sci. Technol. 50 (2013) 160–166.

[112] X. Liu, T. Mu, H. Sun, et al., Influence of different hydrocolloids on dough thermo-mechanical properties and *in vitro* starch digestibility of gluten-free steamed bread based on potato flour, Food Chem. 239 (2018) 1064–1074.

[113] C.M. Rosell, J.A. Rojas, C.B. De Barber, Influence of hydrocolloids on dough rheology and bread quality, Food Hydrocolloids 15 (2001) 75–81.

[114] S.A. Shahzad, S. Hussain, A.A. Mohamed, et al., Gluten-free cookies from sorghum and Turkish beans; effect of some non-conventional and commercial hydrocolloids on their technological and sensory attributes, Food Sci. Technol. Campinas 41 (2021) 15-24. https://doi.org/10.1590/fst.25419.

[115] R. Devisetti, R. Ravi, S. Bhattacharya, Effect of hydrocolloids on quality of proso millet cookie, Food Bioprocess Technol. 8 (2015) 2298-2308. http://dx.doi.org/10.1007/s11947-015-1579-8.

[116] H. Gul, F. Hayit, S. Acun, et al., Improvement of quality characteristics of gluten-free cookies with the addition of xanthan gum, Sciendo 1 (2018) 529-535. http://dx.doi.org/10.2478/alife-2018-0083.

[117] M.V. Ostermann-Porcel, N. Quiroga-Panelo, A.N. Rinaldoni, et al., Incorporation of okra into gluten-free cookies with high quality and nutritional value, J. Food Qual. 2017 (2017) 4071585. https://doi.org/10.1155/2017/4071585.

[118] O. Yildiz, I.S. Dogan, Optimization of gluten-free cake prepared from chestnut flour and transglutaminase: response surface methodology approach, Int. J. Food Eng. 10 (2014) 737–746.

[119] M. Mohammadi, N. Khorshidian, M. Yousefi, et al., Physicochemical, rheological, and sensory properties of gluten-free cookie produced by flour of chestnut, date seed, and modified starch, J. Food Qual. 2022 (2022) 5159084. https://doi.org/10.1155/2022/5159084.

[120] M. Mohammadi, N. Sadeghnia, M.H. Azizi, et al., Development of gluten-free flat bread using hydrocolloids: Xanthan and CMC, J. Ind. Eng. Chem. 20 (2014) 1812–1818.

[121] A. Noorlaila, H. Nor Hasanah, R. Asmeda, et al., The effects of xanthan gum and hydroxypropylmethylcellulose on physical properties of sponge cakes, J. Saudi Soc. Agric. Sci. 19 (2020) 128–135. https://doi.org/10.1016/j.jssas.2018.08.001.

[122] M. Wronkowska, M. Haros, Soral-Smietana, M. Effect of starch substitution by buckwheat flour on gluten-free bread quality, Food Bioprocess Technol. 6 (2013) 1820–1827. https://doi.org/10.1007/s11947-012-0839-0.

[123] N. Sozer, R. Bruins, C. Dietzel, et al., Improvement of shelf-life stability of cakes, J. Food Qual. 34 (2011) 151–162. https://doi.org/10.1111/j.1745-4557.2011.00379.x.

[124] E. Pejcz, R. Spychaj, A. Wojciechowicz-Budzisz, et al., The effect of Plantago seeds and husk on wheat dough and bread functional properties, LWT-Food Sci. Technol. 96 (2018) 371–377. https://doi.org/10.1016/j.lwt.2018.05.060.

[125] F.G. Santos, E.V. Aguiar, A.C.L.S. Centeno, et al., Effect of added psyllium and food enzymes on quality attributes and shelf life of chickpea-based gluten-free bread, LWT-Food Sci. Technol. 134 (2020) 110025. https://doi.org/10.1016/j.lwt.2020.110025.

[126] D.H. Goff, Q. Guo, The role of hydrocolloids in the development of food structure. in: F. Spyropoulos, A. Lazidis, I. Norton (Eds.), Handbook of Food Structure Development, 2019. https://doi.org/10.1039/9781788016155-00001.

[127] D. Bosscher, J. Van Loo, A. Franck, Inulin and oligofructose as functional ingredients to improve bone mineralization, Int. Dairy J. 16 (2006) 1092-1097.

[128] H.J.M. Chung, Q. Liu, S.T. Lim, Texture and *in vitro* digestibility of white rice cooked with hydrocolloids, Cereal Chem. 84 (2007) 246–249.

[129] U. Krupa-Kozak, N. Bączek, V.D. Capriles, et al., Novel gluten-free bread with an extract from flaxseed by-product: The relationship between water replacement level and nutritional value, antioxidant properties, and sensory quality, Molecules 27 (2022) 2690. https://doi.org/10.3390/molecules27092690.

[130] S. Mishra, S. Sinha, K.P. Dey, et al., Synthesis, characterization and applications of polymethylmethacrylate grafted psyllium as flocculant, Carbohydr. Polym. 99 (2014) 462-468.

[131] M.E. Barcenas, C.M. Rosell, Different approaches for improving the quality and extending the shelf life of the partially baked bread: Low temperatures and HPMC addition, J. Food Eng. 72 (2006) 92-99.

[132] C. Viebke, S. Al-Assaf, G.O. Phillips, Food hydrocolloids and health claims, Bioact. Carbohydr. Dietary Fibre 4 (2014) 101-114.

[133] J. Xu, Y. Zhang, W. Wang, et al., Advanced properties of gluten-free cookies, cakes, and crackers: A review, Trends Food Sci. Technol. 103 (2020) 200-213. https://doi.org/10.1016/j.tifs.2020.07.017.

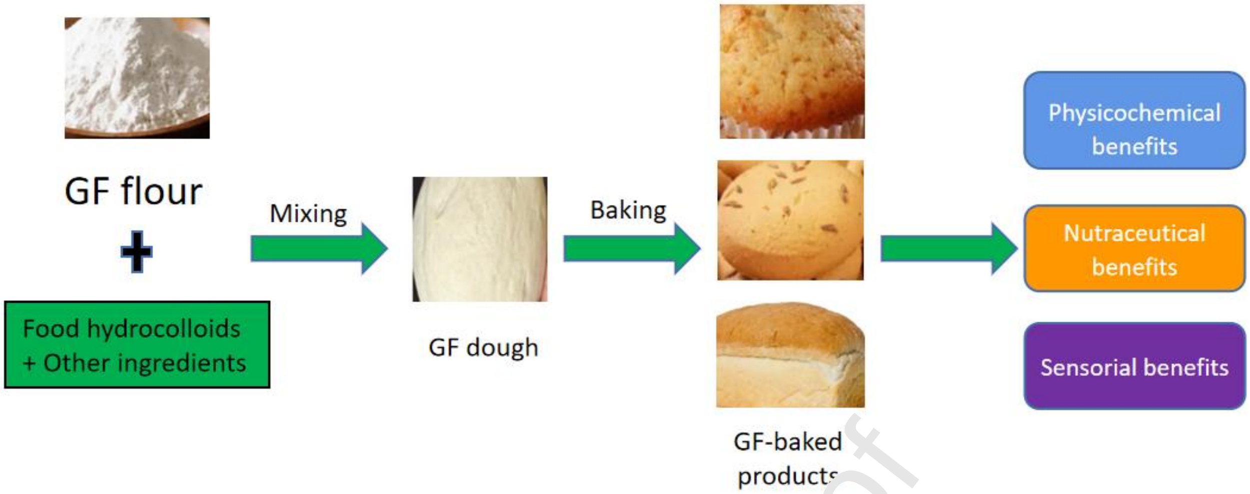
[134] M. Kaur, S.S. Kawalji, A. AmitPal, et al., Gluten free biscuits prepared from buckwheat flour by incorporation of various gums: Physicochemical and sensory properties, LWT - Food Sci. Technol. 62 (2015) 628-632. https://doi.org/10.1016/j.lwt.2014.02.039.

[135] V.A. Franco, L.G.C. Garcia, F.A. da Silva, Addition of hydrocolidics in gluten-free bread and replacement of rice flour for sweet potato flour, Food Sci. Technol. Campinas, 40 (2020) 88-96. https://doi.org/10.1590/fst.05919.

[136] A. Piga, P. Conte, S. Fois, et al., Technological, nutritional and sensory properties of an innovative gluten-free double-layered flat bread enriched with amaranth flour, Foods 10 (2021) 920. https://doi.org/10.3390/foods10050920.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.


GF flour
+
Food hydrocolloids
+ Other ingredients
Mixing
GF dough
Baking
GF-baked
products
Physicochemical
benefits
Nutraceutical
benefits
Sensorial benefits