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Cocoa and Chocolate as Ingredients in the Development of Foods for Special Dietary Regimens

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Abstract: Cocoa and chocolate are not just indulgent foods—they contain bioactive compounds (polyphenols, alkaloids, fatty acids, vitamins, minerals) that can be harnessed in foods for special dietary uses (FSDUs). These compounds have antioxidant, anti-inflammatory, neuroprotective, and cardiovascular benefits, making cocoa an excellent candidate for functional and therapeutic foods.This review examines how cocoa and chocolate—rich in polyphenols and alkaloids—can be incorporated into foods for special dietary uses (SFDs) to support prevention and management of chronic conditions. It summarizes mechanisms of action, evaluates formulation opportunities and constraints, and outlines practical recommendations for developing evidence-based SFDs that harness cocoa's bioactive profile to improve cardiovascular, oncological, and cognitive health.

Keywords: Polyphenols, special food diets, antioxidant, neurochemical

INTRODUCTION

The role of diet in disease prevention was recognized as early as Hippocrates (Greece, 460–377 BC) [1]. Through careful clinical observation, Hippocrates promoted preventive medicine and emphasized the therapeutic value of diet, encapsulated in the aphorism "Let food be thy medicine, and medicine be thy food". This ancient insight, together with Antoine-Laurent Lavoisier's 18th-century principle that "Life is a chemical function," [2] provides a historical and philosophical foundation for modern nutritional science, suggesting that deliberate control of diet can help prevent deterioration of bodily functions and support health maintenance.

The long-standing connections among food science and technology, nutrition, and medicine—rooted in traditions such as Chinese medicine—have recently been re-framed using terms such as functional foods, nutraceutical, and medical foods. The close relationship between diet, nutrition, and health is well established and underpins food security and, by extension, national resilience. A well-nourished population is healthier, requires fewer medical interventions, and reduces public healthcare spending, thereby contributing to broader social and state stability.

The connection between diet and health means the food-production chain must explicitly account for consumer well-being. Therefore, in addition to producing foods for the general population, manufacturers should develop targeted products for people with noncommunicable diseases and other specific nutritional needs, offering formulations that

support disease management, reduce risk factors, and ensure safety and accessibility throughout production, distribution, and labeling [3].

Nature, particularly the plant kingdom, offers numerous food sources rich in macro- and micronutrients and trace elements that align with preventive medicine and the Hippocratic aphorism. Adequate, nutrient-dense feeding beginning early in life can reduce the risk and severity of many chronic diseases, indicating that systematic dietary management across the lifespan is a powerful strategy for disease prevention and long-term health maintenance [3,4].

Cocoa fruits and its derivatives, beyond providing macronutrients and micronutrients, are rich in phytochemicals with potential health benefits. These plant secondary metabolites— including purine alkaloids (methylxanthines), fatty acids, biogenic amines and polyamines, and polyphenols (predominantly flavonoids)—serve protective roles in the cocoa plant yet also possess bioactive properties relevant to human nutrition. Each class of compound has distinct biochemical effects that may contribute to antioxidant, vasodilatory, neurostimulatory, or other protective actions in consumers, supporting the potential role of cocoa-derived ingredients in disease prevention and health promotion.

Cocoa fruits have a markedly higher total polyphenol content than many other foods, which contributes to its strong antioxidant capacity. Beyond direct antioxidant activity, cocoa and its derivatives—because of their diverse chemical constituents and structures—can exert additional protective effects through mechanisms such as modulation of cell signaling, improvement of endothelial function, anti-inflammatory actions, and neurochemical stimulation, all of which may contribute to health benefits distinct from simple free-radical scavenging.

Cocoa—whether as fresh fruit, fermented and roasted bean, or processed into paste, cocoa butter, powder, and various chocolate products—contains a complex food matrix associated with multiple health benefits. This review aims to summarize and critically analyze the scientific literature on the nutrient and phytochemical composition of cocoa and its derivatives, with special emphasis on bioactive components, their physiological effects, and the evidence for health outcomes, and to evaluate the suitability of cocoa ingredients for inclusion in foods designed for specific dietary needs,

COCOA AND BY PRODUCTS COMPOSITION

Cocoa and cocoa-based products provide essential nutrients—proteins, lipids, carbohydrates, vitamins, and minerals—alongside non-nutrient phytochemicals that contribute additional health benefits. These bioactive compounds exhibit antioxidant and anti-inflammatory activities and, together with the macronutrients and micronutrients, can support metabolic and cardiovascular function, modulate immune responses, and contribute to overall dietary quality [5, 6, 7, 8, 9,10].

Cocoa beans are nutritionally significant due to their rich carbohydrate and fat content. Cocoa butter, the principal lipid fraction, along with its vitamin E content, may contribute to the therapeutic potential of cocoa. Cocoa liquor (paste) is a complex matrix of bioactive compounds; cocoa butter supplies substantial fatty acids and tocopherols, while defatted cocoa solids provide vitamins, minerals, dietary fiber, and polyphenols. Chocolate

products and cocoa powder retain these nutrients and phytochemicals in varying proportions depending on processing and formulation.

A fat profile found in cocoa beans is mainly represented by stearic acid (C18:0, 29-38%), oleic acid (C18:1, 29-38%) and palmitic acid (C16:0, 20-26%), linoleic (C18:2, 2-4%), arachidic (C20:0, 1%), alfa-linolenic (C18:3, 0.1%), palmitoleic (C16:1, 0.25%) and behenic acids (C22:0, 0.2%). It can also be found in cocoa butter, in small quantities of myristic (C14:0, 0.2-0.3%), and, recently, lauric acid (C12:0, 0.01%). Furthermore, in cocoa butter a presence of soluble fat as vitamin E isomers which are natural antioxidants in cocoa butter has been proven, mainly γ-tocopherol (93.90mg/kg) with trace amounts of α-tocopherol (4.20mg/kg), β-tocopherol (3.70mg/kg) and tocotrienols (< 10mg/kg) [11, 12, 13]. Although both are saturated fatty acids, palmitic acid (C16:0) and stearic acid (C18:0) have different effects on cardiovascular risk. Stearic acid is generally neutral with respect to blood cholesterol and may lower LDL cholesterol in some settings, whereas palmitic acid has a more complex association with cardiovascular health and, in certain contexts, has been linked to proinflammatory responses and endothelial dysfunction. These divergent physiological effects help explain why cocoa butter's fatty acid composition does not translate directly into uniform cardiometabolic risk [14, 15, 16].

The monosaccharides and protein fractions in cocoa influence both its bioactive potential and sensory properties through Maillard reactions that occur during drying and roasting. Post-harvest processes—particularly fermentation—promote proteolysis of seed storage proteins, releasing amino acids and peptides that serve as essential precursors for cocoa's characteristic aroma compounds. These biochemical transformations during fermentation, drying, and roasting are therefore central to flavor development and also modulate the formation and availability of bioactive Maillard reaction products [17].

As reported by Kühn et al., in 2018 [18] cocoa beans from different growing regions contain vitamin D2. Particularly high vitamin D2 content was found in cocoa powder and butter. Kalvatchev et al. [7] point out the composition of the cocoa bean presenting it as an alternative in human health, these authors validate as many other investigations [19, 20] that the fat component in the cocoa bean is the most important, also describing the amino acid profile of its proteins, and reporting the contents of calcium, phosphorus and iron, vitamin C and the B complex.

Kühn et al. (2018) [18] reported that cocoa beans from various growing regions can contain vitamin D2, with particularly high concentrations observed in cocoa powder and cocoa butter. Other authors [7, 19, 20] have emphasized the nutritional potential of the cocoa bean, highlighting its lipid fraction as a major component while also documenting its amino acid profile and significant levels of minerals (calcium, phosphorus, iron), vitamin C, and B-complex vitamins. These compositional features support consideration of cocoa and its derivatives as nutrient-dense ingredients with possible benefits for human health.

Cocoa byproducts—fruit husk, mucilage, and shell—are generated in large quantities during harvesting, post-harvest processing, and chocolate production and represent underutilized agro-industrial resources. These materials contain nutrients and bioactive compounds that make them suitable for human and animal use and for incorporation into special dietary regimens as functional ingredients. Dehydrated husk and shell can be milled into flours for fortifying breads, cookies, and other baked goods, while mucilage can be fermented or processed into beverages, vinegar, or natural sweeteners. Valorizing these

byproducts reduces waste, adds economic value to cocoa supply chains, and creates ingredient options for nutrient-dense, sustainable SFD formulations [9].

The cacao plant synthesizes a diverse array of phytochemicals, including alkaloids (notably purine methylxanthines), benzopyrans, fatty acid amides, catecholamines such as dopamine, terpenes, anthocyanins, sterols, and a wide spectrum of polyphenols. These compounds have distinct biochemical activities—stimulatory, antioxidant, anti-inflammatory, and signaling-modulatory—that together contribute to cocoa's complex organoleptic properties and its potential health effects [20, 21, 22, 23, 24, 25]. Perez et al. [7] have reported the relevant phytochemicals, classifying them as alkaloids and polyphenols, and describing their positive or negative effects on consumer health. The alkaloids, widely used in medicine for their properties, are usually toxic at high concentrations but, at low concentrations, have positive therapeutic effects. Among the alkaloids, Perez et al., [7] point out the methylxanthines or purines (caffeine, theophylline, theobromine); the pyridines (nicotine and myosmine), isoquinolines (salsinol); fatty acids: amide type (anandamide); monoamines: (tryptamine, phenylethamine) and polyamines (spermines).

Alkaloids—bioactive nitrogenous compounds widely used in medicine—can be toxic at high doses but often exert beneficial therapeutic effects at low concentrations. In cocoa, the principal alkaloids include methylxanthines or purines (caffeine, theophylline, theobromine), as well as other nitrogenous and amine compounds reported in the literature, such as pyridines (nicotine, myosmine), isoquinolines (salsolinol), fatty acid amides (anandamide), monoamines (tryptamine, phenylethylamine), and polyamines (spermidine and related spermines) [7] . These molecules contribute to cocoa's stimulant, neuromodulatory, and metabolic activities and must be considered when evaluating both potential benefits and safety in dietary applications.

Perez et al., [7] also reported the polyphenols which are represented by flavonoids such as flavon-3-ol, catechins (-epicatechin, +catechin, +gallocatechin, -epigallocatechin) and anthocyanins (cyanidin-3-arabinose and cyanidin-3-galactose) and pro-anthocyanidins (dimers, trimers, tetramers, oligomers and polymers). The authors [7] describe their functions as potential for use in food development , noting that methylxanthines such as; caffeine, theophylline, theobromine (Figure 1) have positive effects on the central nervous system, such as increased muscle activity and improved mood. Furthermore, the methylxanthines are antioxidants for excellence, aid in thermogenesis and energy balance, stimulates the heart, lung, and bronchial muscles, facilitates intracellular signaling, acts as a diuretic, vasodilator, and muscle relaxant. For example, caffeine is permitted up to 400 mg per day (approximately 5.7 mg/kg of body weight per day), except for pregnant women.

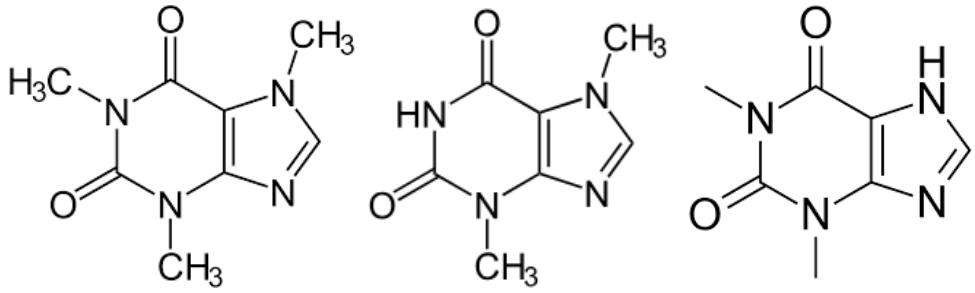


Figure 1: Chemical structure of Theobromine.

Caffeine is a bitter, odorless, white crystalline alkaloid found in the leaves, seeds, and nuts of many plants. As a xanthine-type organic compound, it acts as a psychoactive stimulant, contributes to flavor, and functions biologically as a natural pesticide in the plants that produce it.

There is an amino nitrogen at position 9 of the caffeine (1,3,7-trimethylxanthine) heterocyclic structure, which is composed of pyrimidinedione and imidazole ring systems. Although concerns have been raised about caffeine and cancer risk, current evidence does not classify caffeine as a human carcinogen, and large reviews find no convincing link between moderate caffeine intake and cancer; some studies even report lower risks for certain cancer types. Caffeine has multiple physiological effects—stimulant actions on the central nervous system, impacts on cardiovascular and reproductive systems, and influences on fetal development when consumed in high amounts—so its risks and benefits depend on dose, individual susceptibility, and life stage. For most adults, moderate caffeine consumption is considered safe and can have beneficial effects such as improved alertness, but caution is warranted for pregnant people, those with certain medical conditions, and individuals sensitive to stimulants [26].

Caffeine in cocoa and cocoa products varies significantly, with raw cacao powder containing the most (around 12-26 mg/tablespoon) and white chocolate having negligible amounts. Dark chocolate has more caffeine than milk chocolate (e.g., 40-80 mg/100g for dark vs. 20 mg/100g for milk), while hot chocolate can range from minimal caffeine in mixes (5-10 mg/serving) to higher amounts in homemade versions (24-36 mg/serving).

Theophylline, also known as dimethyl xanthine reduce inflammation in conditions such as asthma well as long term obstructive lung disease at low level of concentration [27, 28, 29]. Theophylline in cocoa is present at very low amounts. It have been reported that fresh cocoa had theobromine and caffeine contents of 27 and 6.1 mg g-1, respectively, whereas fermented cocoa had 21 and 4 mg g-1, respectively [30]. Processing, cocoa content, origin, and preparation method all influence the final caffeine level and theophylline [27].

Zoumas et al. (2006) [27] reported that theobromine concentrations varying by product: chocolate liquor averaged about 1.22% theobromine, commercial cocoa powders averaged ~1.89%, sweet (plain) chocolate ~0.46%, milk chocolate ~0.15%, and prepared hot cocoa beverages contained roughly 65 mg of theobromine per serving. These differences reflect formulation and processing and help explain the varying stimulant and physiological effects of cocoa products.

Recent studies have highlighted the potential of theobromine, which may act as antitumoral, anti-inflammatory or cardiovascular protector molecule without the undesirable side effects described for caffeine. The main mechanisms of action of theobromine are inhibition of phosphodiesterases and blockade of adenosine receptors but, interestingly, it exhibits other important adenosine receptor-independent effects as the reduction of cellular oxidative stress or regulation of gene expression. In this sense, theobromine could be considered a safe and natural alternative in the treatment of some human diseases and may serve as lead compound for the development of novel drugs [29].

Usually the pyridines (nicotine and myosmin) found in low concentrations in cocoa show negative effects, acting as a pro-oxidant; however, nicotine has been linked to improvements in patients with ulcerative colitis [31].

Among the isoquinolines that complement the flavor and aroma of cocoa is mentioned the salsolinol (6,7-dihidroxi-1-metil-1,2,3,4-tetrahidroisoquinolina), which helps with chocolate addiction [32]. It is also useful in the treatment of Parkinson's disease, and acts as a neuromodulator or neurotransmitter. Salsolinol is an alkaloid found in cocoa around 25μg/g25 μg/g that has dopaminergic and opioid activity. It is a bioactive compound that, although described as having analgesic effects, has a limited ability to cross the blood-brain barrier [33]. This ability of salsilinol (Figure 2) helps with its effects as a dopaminergic and opioid in the body. Substances can cross through mechanisms like lipid solubility (for fats or for many psychoactive drugs like ethanol and nicotine enter the brain), carrier-mediated transport (for nutrients), or by exploiting specific entry systems.

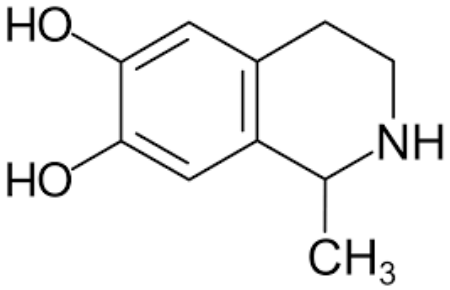


Figure 2: Salsolinol chemical struture [7]

Anandamide (arachidonoylethanolamide) (AEA) is a endogenous ligands of cannabinoid receptor with neurotransmitter properties derived from arachidonic acid C20:4ω6 that produces the same effects as plant-based cannabinoids: it activates brain functions related to perception, learning, memory, mood, movement, hormone secretion, etc. Anandamide is thought to be involved in the formation of short-term memory, since there is a high proportion of cannabinoid receptors in the hippocampus region of the brain. Its action is mediated by cannabinoid receptors CB1 (located primarily in the central nervous system) and CB2 (in the peripheral nervous system), which are G protein-coupled sequences [34].

Anandamide is also a cannabinoid mimetic neuroprotective agent that acts as an antiemetic in patients undergoing chemotherapy, improves the immune system, is analgesic, muscle relaxant, appetite stimulant and treatment of glaucoma [7, 34, 35]. The importance of anandamide in human development has been demonstrated, as it participates in the control of movement, memory, emotions, sleep regulation, body temperature, pain modulation, coagulation response, and immune response. It is also known that anandamide produces the same effects as plant-based cannabinoids: it activates brain functions related to perception, learning, memory, mood, movement, hormone secretion, etc. Anandamide (Figure 3) is thought to be involved in the formation of short-term memory, since there is a high proportion of cannabinoid receptors in the hippocampus region of the brain.

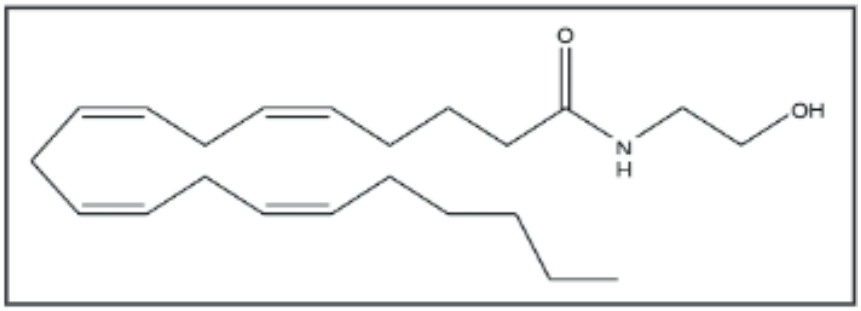


Figure 3: Anandamide chemical structure [33]

Biogenic monoamines, such as tryptamine, including serotonin and phenylethylamine, have been reported as neuromodulators or hallucinogenic neurotransmitters associated with feelings of well-being. They act on the nervous system, preventing depression and producing a feeling of pleasure. At high concentrations, they can cause headaches (migraines) and high blood pressure. They have been used in sports supplements for their effects on energy. [7].

Polyamines, such as; espermidine y la espermine have been mentioned in relation to gastrointestinal development in newborns, their importance at the immunological level, and as potential prebiotics and anti-inflammatories, and are associated with longevity. [7].

Cocoa polyphenols play a significant role in defining the sensory characteristics of cocoa and its derivatives, and in providing therapeutic properties that promote health. Polyphenols can be classified into two categories: flavonoids and non-flavonoids. Flavonoids include anthocyanins and tannins, which contribute to the color and texture of chocolate. Non-flavonoids include stilbenoids, such as resveratrol, and phenolic acids, such as benzoic, caffeic, and cinnamic acids [7].

Trans-resveratrol have been identified in dark chocolate and cocoa liquor extracts. Yet, the exceptional antioxidant activity of chocolate must be related more to its high procyanidin content than to the presence of stilbenes [36]. However, the combination and synergy of resveratrol with all others antioxidant nutrients are beneficial for both body and mind of the consumers.

There is important pointed out that some parts of the cocoa process are it has been reported that the fermentation time causing reductions of 55–76% in individual phenolic compounds and 43.5–60.57% in antioxidant capacity after seven days. While roasting tends to degrade most phenolic compounds, catechin can form or stabilize at higher temperatures and longer roasting times [37].

FOOD INDUSTRY ROLE IN HEALTH MAINTENANCE AND DISEASE

In the food industry's planning for the production of new foods, one related public health challenge is the rising burden of diseases linked to food intake, which could contribute to food security and national security. At this context naturally functional raw material (some macro and micro nutrients and phytochemical), have garnered increasing scientific and public health interest due to their potential to confer physiological benefits beyond basic nutritional value.

According to Codex 146-2009, foods for special dietary uses (FSDU) are foods primarily processed or formulated to meet particular dietary requirements, which exist due to a particular physical or physiological condition, disorder, or disease. The composition of these foods must differ significantly from the composition of conventional foods of a comparable nature, if such foods exist. The definition of foods for special dietary uses (FSDUs) has been restricted to providing a particular dietary requirement that exists due to a physical or physiological condition, such as convalescence, pregnancy, lactation, infancy, and specific diseases or disorders. They may also supply a vitamin or mineral or other dietary property as a supplement to increase total dietary intake, or to meet a special dietary need when such foods are the sole source of the daily diet [38].

At the moment, the special dietary food industry is evolving, driven by the growing demand for products for this purpose. This industry must be framed within the development and innovation of foods with specific ingredients, complying with food safety and labeling regulations to inform consumers about their benefits. The current situation of this industry includes challenges such as identification of the potential raw material for development of these foods, regulatory compliance and the need to adapt to global markets, but it also offers opportunities for growth through innovation and the adoption of sustainable practices [39, 40].

The review of Fekete et al., 2025, [41] provides a comprehensive and critical overview of functional foods from an interdisciplinary perspective. It explores their mechanisms of action, clinical evidence, regulatory landscape, and implications for public health nutrition. In addition, the study highlights emerging directions such as nutrigenomics, personalized nutrition, and the integration of artificial intelligence into food science and health research. scientifically grounded public communication strategies that support the responsible inclusion of functional foods in everyday dietary practices.

The author concluded that functional foods are gaining increasing importance in today's prevention-oriented healthcare paradigm, as they have the potential to go beyond basic nutritional value and contribute to the prevention or complementary management of chronic non-communicable diseases. However, realizing this potential requires close, multidisciplinary collaboration between nutrition science, medicine, and the food industry. Evidence-based and accessible communication to the general public is also essential—particularly in relation to substantiated health claims and the clear presentation of the true benefits of functional foods. While the body of scientific evidence continues to grow, practical implementation still faces several challenges, including unequal access and low levels of health literacy. In the future, advances in artificial intelligence, microbiome research, and nutrigenomics may open new pathways for the targeted and personalized use of functional foods in public health strategies.

PROPOSAL FOR SOME FOODS FOR SPECIAL REGIMENS USING COCOA AND CHOCOLATE AS INGREDIENTS

This proposal suggests creating functional foods using cocoa and chocolate as an ingredient to address specific health needs, such as cardiovascular health, cognitive function, and gut health. The approach involves developing specialized formulations that incorporate bioactive compounds to create healthier, functional versions of chocolate products aimed

at consumers with lifestyles or stages of life or pathologist that are preventable or controllable through diet. These products are designed to offer health benefits beyond basic nutrition and cater to consumer demand for both taste and wellness.

For older adults suffering from age-related anorexia, xerostomia (dry mouth), impaired chewing ability (loss of chewing ability) and presbyphagia (difficulty swallowing), anosmia or hyposmia (loss of taste and smell), sarcopenia (loss of muscle mass), hypothyroidism (iodine deficiency), osteopenia/osteoporosis, recipes such as: chocolate and macadamia spreads, macadamia and chocolate shake, fruit and chocolate gelatin, pureed or soft foods made with sweet potato, coconut, and chocolate, carbonated beverage flavored with cocoa mucilage, chocolate with grape skin and seeds flour, passion fruit mesocarp ice cream, chocolate and yogurt, all enriched with protein, vitamins and minerals are proposed.

Depending on the different types of vegetarianism, various recipes are proposed using different ingredients that include cocoa and its derivatives. One example is a chocolate with anchovies or caviar with white chocolate for pesco-vegetarians, chocolate meringue elaborated with aquafaba for vegans, vegetarian ham with mole, chocolate pizza, with vegetarian cheese and fruits.

For athletes who, depending on their activities, require different metabolic equivalents (METs) per hour, foods with high energy potential are proposed, such as: chocolate and macadamia/peanut spreads, energy bars with chocolate, nuts, dried fruit, cocoa nibs with guarana and moringa, macadamia milkshake with chocolate and avocado, fruit and chocolate/beetroot gelatin, sweet potato, coconut, and chocolate compotes, mucilage-infused water, and chocolate with açaí, among others.

For consumers with gluten-free requirements, it is propose chocolate pizza which base is made with rice flour and soy protein enriched with vitamins and minerals; gluten-free mix for cakes and pancakes made with cassava flour; gluten-free pasta and bread made with alternative flours; plantain, banana, rice, cassava and/or cocoa and chocolate.

For diabetics, the following recipes are suggested: ginger cookies, dark chocolate and sugar-free nuts, chickpea and chocolate bit cookies, dark chocolate and sugar-free ginger or licorice, passion fruit mesocarp ice cream, chocolate and yogurt, unfermented cocoa nib capsules, breadnut/eggplant flour cake with dark chocolate.

And for phenylketonuric consumers, it has been reported that cocoa husk powder have a intense chocolate flavor and the phenylalanine (Phe) content is quite low, which would be useful for the development of different pre-mixtures to make foods with low *Phe* content [40].

CONCLUSION

The cocoa sector offers the necessary ingredients with excellent and potential nutritional and therapeutic characteristics to develop numerous foods that meet the needs of consumers with special dietary requirements.

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