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Taste masking in vegan food processing with natural substitutes

EMEL HASAN YUSUF[1*]

[1]Department of Fruit, Vegetable and Plant Nutraceutical Technology, The Wrocław University of Environmental and Life Sciences, Wrocław, Poland

* Corresponding author: emel.hasan.yusuf@upwr.edu.pl

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Climate change, sustainability issues, and increased risks of a meat diet on both ecology and human health cause changes in the eating habits of individuals. Plant-based foods supply protein sources with health-promoting compounds. The bitterness of plant-based foods is challenging for both food manufacturers and consumers. So far, artificial taste blockers, salt, sugar, and fat have been applied to mask the bitterness of plant-based products. However, people are conscious of "clean labelling" and "natural" food ingredients. Thus, natural taste blockers are the new trend for vegan food manufacturing to mask bitterness. The review focuses on providing information about natural salt, sugar, and fat replacers for foods as taste blockers of bitterness. The study highlights the recent natural taste blockers, application trends, and regulations for food processing.

1. Introduction

We need to eat to survive, but today we also want to feel satisfied with the appearance, aroma, and flavour of the food. Accordingly, society and global trends influence our food preferences; novel foods, and advertisements for new food trends create attractiveness for us (Prescott *et al*., 2002). However, food trends adhere to varied factors such as global conditions, politics, and ecology (Arenas-Jal *et al*., 2019). Nowadays, environmental issues are the most important game-changers like climate change and sustainability, creating huge concerns for future food systems. Indeed, the world population is estimated to exist at about 10 billion people by 2050 (UNDESA, 2017). Thus, the significance of the subject increases with the question of how we can feed a huge amount of human mass.

Alternative proteins, such as plant and insect-based proteins, are gaining popularity. However, people are unprepared to consume insects as protein sources because they are afraid to try and have a negative perception of insects (de Koning *et al*., 2020). Hence, plant sources can be used as an alternative protein. A meat-based diet consumes a lot of water, land, and energy (Sabaté & Soret, 2014). In contrast, a plant-based diet protects people against non-communicable diseases such as cancer, cardiovascular diseases, type 2 diabetes, and obesity (Jakše *et al*., 2019).

Therefore, the vegan food market is predicted to reach USD 26.1 billion by 2026 (expertmarketresearch.com). The most attractive vegan products are alternative meat, egg alternatives, and dairy substitutes for non-vegan people.

During the coronavirus disease 2019 (COVID-19) pandemic, sustainable and healthy diet preferences have been boosted (Lonnie & Johnstone, 2020). According to case studies, consumption of meat, poultry, and dairy products decreased in China (Jia *et al*., 2021) and Spain (Rodríguez-Pérez *et al*., 2020). The main reason is animals carried viruses, and the terminology is "zoonosis" which is thought to possess more functions in the future among different species in nature to cause diseases like COVID-19 (Attwood & Hajat, 2020). Thus, individuals cease consuming meat and animal-based food products to prevent the transmission of infectious pathogens.

In reality, many individuals are unprepared to replace meat with plant derivatives. Some reasons include eating habits and the taste of meat. However, one of the biggest challenges is bitterness and the strong aroma of plant natural products that demonstrate increased bitterness with boosted health functions (Behrens *et al*., 2018).

Without a doubt, bitterness is unacceptable to consumers, even though the food has elevated health benefits. For instance, glucosinolates from Brassicaceae (Cabbage family) are popular with their specific unpleasant aroma and health advantages (Verkerk *et al*., 2009). In a study, the undesirable aroma of cabbage compounds has been masked with sucrose, and the final product has proved the palatable cabbage juice (Beck *et al*., 2014). Thus, sugar is a stunning taste-masking agent for bitterness.

Inasmuch as, sugar, salt, and fat are the most applied taste blockers against bitterness in foods (Goldberg *et al*., 2017). Even if, the proper amounts of salt, sugar, and fat are crucial for healthy body functions (Downs *et al*., 2020), consumption rates increase with processed food products. Besides, salt, sugar, and fat cause many health issues such as cardiovascular disorders, obesity, type 2 diabetes, and cancer. Therefore, health authorities recommend reducing or replacing sugar, salt, and fat with natural alternatives (Saraiva *et al*., 2020).

This review aims to discuss natural and recognized sugar, salt, and fat replacers with health-promoting activities, application benefits, and challenges in vegan food processing. The scope included identifying substitutes of sugar, salt, and fat as natural food ingredients without changing the mouthfeel, texture, and/or flavour characteristics of fat, salt, and sugar in foods. Hence, recommendations are given for vegan processed foods.

2. Literature

2.1 The impact of sugar, salt, and fat in processed foods

In the early 1900s, the food industry discovered sugar, salt and fat can increase the taste of food products (Rao *et al*., 2018). Indeed, sugar is an essential component for food processing with stability, texture, mouthfeel, flavour, colour, and preservation features (Erickson & Carr, 2020). Furthermore, sugar provides energy to our body as a carbohydrate, however, the origin of the sugar is the main point such as the sugars of fruit and vegetables are natural and rich in fibres (Misra *et al*., 2016). However, excessive sugar consumption is an important reason for obesity (Stanner & Spiro, 2020). Salt occurs with sodium and chloride, which is an essential compound for body fluid regulation, and transmission of nerve and muscle impulses (Gilbert & Heiser, 2005). Interestingly, excessive and minimal salt consumptions than recommended values cause problems in the body like myocardial infarction (Nikiforov *et al*., 2021), but low sugar consumption demonstrates no adverse effects on the body.

An adequate amount of fat is essential for health because fats and proteins construct our cell membranes elastic and permeable. Nevertheless, excessive fat consumption creates difficulties in transferring cell waste and obtaining essential nutrients in the cell; a low-fat diet causes constipation, carbohydrate desire, infertility, and insomnia (peaksofhealth.com).

According to the World Health Organization (WHO, 2020a), a healthy diet should include vegetables, fruits, legumes, nuts, whole grains, less than 30% of total energy intake from fats, less than 10% of free sugars, and less than 5 gram of salt for adults. Hence, the recommended amounts of sugar, salt, and fats are essential, however, overconsumption of salt, fat, and sugar causes a weakening of immunity (Moss, 2014). Moreover, relationships between high sugar, salt, and fat consumption and poor diet may create obesity, diabetes, cardiovascular disorders, and cancer (Andarwulan *et al*., 2021).

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Processed foods, which are rich in sugar, salt, and fat, increase dopamine levels in the brain and make people addicted to junk foods (Onaolapo & Onaolapo, 2018). Various food products include hidden salt and sugar as bread and bakery products are the hidden salt sources (Bhat *et al.*, 2020); packaged soups, sauces, salad dressings, canned vegetables, and ready meals are the hidden sources of sugar (Zupanič *et al.*, 2019). Moreover, sugar and salt are excellent preservatives for processed foods because sugar and salt relocate water out of the cell and microorganisms disappear (Barba-Orellana *et al.*, 2020). Thus, to prevent the overconsumption of sugar, salt, and fat in processed foods, Mexico, and Denmark apply over-taxation for junk foods (Blakely *et al.*, 2020).

2.2 Why should sugar, salt, and fat be replaced with natural substitutes?

Sugar is the most utilized taste blocker for the bitterness of plant-based foods. Inasmuch as sugar revokes the first sensory signal to reach the brain. Otherwise, sugar demonstrates bitterness masking function as the consequence of mixture suppression, which combines with bitterness sources and influences the cognitive area of the brain (Keast, 2008). For example, soy protein and pea protein are the most popular plant-based proteins due to their gluten-free and fat-free profiles (Bashi *et al.*, 2019). However, those vegan food components have an unpleasant aroma for consumers. Hence, food manufacturers have utilized sugar to avoid the undesirable flavour of plant-based proteins, and sugar conceals the odour of plant derivatives during food processing (Bangratz & Le Beller, 2020).

Human-kind desires sweet taste as genetically as an evolutionary survival mechanism (Breslin, 2013). Particularly, sweet consumption exhibits psychological necessity, and sweetness is a kind of addiction with numerous adverse effects such as tooth decay, weight gain, obesity, type 2 diabetes mellitus, dyslipidaemia, high blood cholesterol, stroke, depression, and cancer (Pérez *et al.*, 2016; Cediel *et al.*, 2018; Knüppel *et al.*, 2017). Regarding the side effects of sugar consumption, Lustig *et al.* (2012) have suggested removing sugar from the GRAS (Generally Regarded as Safe) list of the FDA (U.S. Food and Drug Administration).

Today, children possess the highest rates of sugar consumption in all age groups (Putnik *et al.*, 2020), and children are potential diabetic individuals of the future. WHO and FDA suggest reducing sugar intake rates to less than 10% per day, due to the connection of sugar with diseases (Johnston *et al.*, 2013). Nevertheless, the sweet desire causes one to search for alternative sources of sugar. For instance, artificial sweeteners had been applied for a while since scientific studies proved synthetic sweeteners generate brain tumours, weight gain, and bladder cancers (Putnik *et al.*, 2020). However, natural and non-nutritive sweeteners might be a solution to the sweet desire of human-being without any caloric content and with a palatable sweetness in an eating plan (Fitch & Keim, 2012).

Salt is the other taste-masking ingredient for processed foods. Keast (2008) has recommended adding salt reduces the bitterness of foods, because salt inhibits the tongue receptors, and decreases the signal transfers to reach through the brain cells. Moreover, psychophysical studies demonstrate salt works as a specific compound in bitterness to supply a favourable taste (Breslin & Beauchamp, 1997). Nevertheless, excessive salt consumption causes kidney damage, neuronal injury, cardiovascular disorders, stomach cancer, and hypertension (Downs *et al.*, 2020; O'Sullivan, 2020; He & MacGregor, 2009).

When we checked salt consumption rates in history, the evolutionary salt intake was 0.25 g per day (Eaton & Konner, 1985), but processed food has increased the rate of salt consumption up to 9-12 g per day with the help of processed meat, bread, and cheese products (Brown *et al.*, 2009). Therefore, salt reduction is fundamental, and recommended salt intake is lower than 5 gr per day, and the WHO aims to decrease salt intake rates by about 30% by 2025 (WHO, 2020b).

Officially recommended salt intake levels create pressure on food manufacturers to produce healthy food products with clean labelling (Erickson & Carr, 2020). The challenge is reducing sodium rates in foods but not accompanied by the salty flavour of foods, so the best solution is to replace salt with natural and healthy alternatives.

Fat is another ingredient of foods, and food manufacturers apply lipids to make the process stable and obtain the right texture (Matheson *et al.*, 2018). Dietary fat increases with passive overconsumption, which is called "high-fat hyperphagia" (Ludwig, 2016), and excessive fat consumption causes changes in neurochemical dopamine levels with disorders in mood, weight gain and obesity (Downs *et al.*, 2020; Chauhan & Kumar, 2016). Thus far, during food processing varied chemical contents have been utilized to replace fat. However, consumers are aware of artificial chemicals, and the damage of synthetic compounds to the body (Silver & Bassett, 2008). Thus, consumers are looking for natural ingredients in food products (Saraiva *et al.*, 2020).

To sum up, vegan food products include high amounts of salt, sugar, and fat to prevent off-flavours of plant derivatives (Tso & Forde, 2021). However, high sugar, fat, and salt consumptions cause side effects on the human body. Therefore, health authorities recommend declining sugar, fat, and salt consumption rates (WHO, 2020b), and with the latest trends, consumers are looking for "clean labels" and natural ingredients in food products without side effects (Erickson & Carr, 2020). The main challenge is salt and sugar is significant parameters for food manufacturing due to the texture, and stability of food products. Thus, suggested natural replacers of sugar, salt and fat can be applied in vegan food products to overcome the faced challenges in vegan food processing.

2.3 Natural replacers of sugar, fat, and salt as taste blockers in vegan food products

2.3.1 Neohesperidin dihydrochalcone (NHDC)

NHDC is a derivative of neohesperidin, which is a flavanone from bitter orange (*Citrus x aurantium* L.), and *Oxytropis myriophylla* (Pall.) DC. NHDC has been identified as a natural plant product, and a non-nutritive sweetener. The sweetness rate is 1800 times more than sucrose (Braune *et al.*, 2005). For food processing, through the pasteurization period, NHDC stays stable, and the solubility of NHDC increases in water (Nabors, 2001). Besides, NHDC demonstrates satisfactory results for taste blocking in small amounts with a menthol flavour. Therefore, in some food applications, the menthol flavour might be unacceptable, but innovative vegan food products such as alternative meat from different sources with NHDC may create palatable results for consumers and may increase the popularity of future food applications.

Moreover, NHDC is approved by health authorities as a sweetener and flavour enhancer (Borrego & Montijano, 2001). NHDC obtained GRAS from FDA and European Union has approved NHDC (E-959) as a food additive with suggested consumption rates of 5 mg kg-1 of body weight per day (EFSA, 2011). The other countries which approved the NHDC as a flavour enhancer are Australia, Japan, and New Zealand (ISA, 2015) (Table 1). Thus, approvals from food authorities of the compound are promising to see novel foods in the future.

Thus far, the bitterness-blocking feature of NHDC has been studied for different food and beverages. For instance, caffeine is the most studied compound for bitterness which is a naturally occurring alkaloid in plant-based foods. NHDC increases the hedonic acceptability of caffeine to reduce bitterness (Ly & Drewnowski, 2001). In another literature study, NHDC has been utilized for bitter corn peptides, however, the challenge was the low water-soluble activity of NHDC due to phenolic compounds (Dong *et al.*, 2017a). Therefore, some methods have been suggested to increase the water solubility of NHDC, such as graft reaction, inclusion complex, and reverse micelle. In detail, porous structures and small molecules with similar size, polarity, and shape to cavities can create inclusion complexes (Astray *et al.*, 2010). On the other hand, grafting is an improvement of the main structure with different molecules for collaboration (Siafaka *et al.*, 2016), and finally, reverse micelle is polar and nonpolar phases reverse roles and surfactants are upturned in a micelle (Dong *et al.*, 2017a). Thus, different food processing methods may help to increase the possible uses of NHDC as a taste blocker for novel vegan food products.

2.3.2 Neodiosmin

Similar to the NHDC, neodiosmin is a compound of bitter orange. However, neodiosmin is a tasteless and odourless flavonoid (Horowitz & Gentili, 1969), and it may reduce the bitterness of varied compounds (Dong, *et al.*, 2017b). For instance, so far, the compound has been used against the bitterness of caffeine, limonin, para-methoxycinnamaldehyde from cinnamon, and quinine (Fletcher *et al.*, 2015). Hence, the compound supports many functions for future food applications as a bitterness blocker. However, the

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health authorities have not approved the neodiosmin for food applications yet, maybe in the forthcoming, it will be possible to see more implementations of the neodiosmin in vegan food products, after the safety approvals.

2.3.3 Thaumatin

Thaumatin is another natural, non-nutritive sugar substitute (Masuda *et al.*, 2011). The arils of the African species *Thaumatococcus daniellii* Bennett include the sweet-tasting thaumatin proteins (Mackenzie *et al.*, 1985). The sweetness level of thaumatin is 3000 times higher than sucrose without measurable caloric values (Faus & Sisniega, 2003). Besides, the solubility of thaumatin is 80% at pH 6 and 40% at pH 10. Thaumatin is more stable at pH between 2.5 and 5; moreover, thaumatin stays stable above 100 °C (Farag *et al.*, 2022). Thus, food applications with thaumatin may present attractive results as a natural ingredient, and thaumatin supplies clean labels for novel food products as well.

So far, thaumatin has been approved as GRAS for flavour enhancement by FDA (FEMA GRAS Number 3732), and European Union (Table 1). Also, thaumatin has been accepted as a sweetener in Australia, Switzerland, and the United Kingdom (Carocho *et al.*, 2017). Moreover, thaumatin has been approved as safe in the pregnancy period by the United States Academy of Nutrition and Dietetics (Arévalo *et al.*, 2019), and the allowed consumption rate of thaumatin is a maximum of 0.5 mg kg-1 per day (EFSA, 2015). Therefore, the safety characteristics of the compound are an important parameter both for vegan food manufacturers and consumers.

According to the literature studies, the antifungal activity of thaumatin may help to increase shelf-lives of vegan food products as well and the amylase inhibition activity of thaumatin increases its functionality against diabetes (Farag *et al.*, 2022). In another literature study, thaumatin has been investigated for the potential changes in blood glucose levels, and weight gain in rats. The study results have been compared with aspartame and sucrose. According to the results, thaumatin has exhibited no changes in the blood glucose levels and weights of the rats. Thus, thaumatin has been suggested as natural sugar replacer (Khayata *et al.*, 2016).

Until now, thaumatin has been applied to ice creams, soft drinks, and chewing gums to increase peppermint and spearmint flavours (Lindley, 2012; Joseph *et al.*, 2019). However, thaumatin reacts with colourants in beverages and loses the sweetness feature (Miele *et al.*, 2017). Thus, thaumatin can be implemented for colourant-free novel vegan food products without any change in the compound features.

2.3.4 Brazzein

Brazzein is the smallest sweet-tasting protein (Hung *et al.*, 2019), and is a derivative of *Pentadiplandra brazzeana* Baillon. The sweetness of brazzein is 500 and 2000 times higher than 10% and 5% sucrose solutions respectively (Izawa et. al., 1996). The water solubility of brazzein is 50 mg/mL, the sweetness continues for 4h from 2.5 to 8 pH values (Farag *et al.*, 2022), and brazzein is stable during the heating period up to 80 °C (Rajan & Howard, 2018). Moreover, the taste of brazzein is described as similar to sucrose (Guggenbuhl *et al.*, 2020).

Without any after-taste or bitterness characteristics of brazzein, the sweet taste starts slower than sucrose and continues. Also, brazzein may apply to prevent tastes of steviol glycosides, NHDC, and/or other natural taste-masking agents (Hellekant & Danilova, 2005).
In the literature, brazzein and a 10% sucrose solution have been tested with mice, and the results of the study show that brazzein does not cause obesity, insulin resistance, or hypertrophy (Kim *et al.*, 2020). Moreover, brazzein shows anti-inflammatory, anti-allergic and antioxidant activities (Chung *et al.*, 2017). Nevertheless, FDA or EFSA has not approved brazzein yet.

2.3.5 Curculin (Neoculin)

Curculin is extracted from *Molineria latifolia* (Dryand. ex W.T.Aiton) Herb. ex Kurz, which is native to Malaysia (Neiers *et al.*, 2016). Local people consume dried fruits of *Molineria* against the bitter taste of black tea and sour foods (Behrens *et al.*, 2011). Curculin demonstrates 550 times more sweetness features than sucrose on a weight basis (Yamashita *et al.*, 1990), acts as a flavour enhancer, and provides a sweet taste after water and bitter food products. Moreover, water solutions of the curculin exhibit a strong sweet taste at low pH (Behrens *et al*., 2011). Curculin is stable at 50 °C for 1 hour and pH between 3 to 11 with antifungal activities (Farag *et al*., 2022). However, FDA and EFSA have not approved curculin for food applications yet.

2.3.6 Mabinlin

Mabinlin is another sweet-tasting protein, found in the seeds of *Capparis masaikai* Levl. from Yunnan Chinese region (Neiers *et al*., 2016). Mabinlin is heat stable and the sweetness maintains following 48 hours of incubation at 80 °C. Moreover, the sweetness of mabinlin is 400 times higher than sucrose on a molar basis (Kant, 2005). However, FDA and EFSA have not approved the compound for food applications yet. Therefore, similar to other taste-masking agents, the natural characteristics and stunning sweetness rates of the material may make it an attractive food ingredient for future vegan foods.

2.3.7 Miraculin

Miraculin, which is found in *Richardella (Synsepalum) dulcifica* (Schumach. & Thonn.) Baehni, demonstrates an unsweet feature. However, miraculin can transform a sour taste into a sweet feeling. The specific features of miraculin provide abilities to apply taste-enhancing of acids (Kurihara & Beidler, 1969). The rhesus monkey, chimpanzees, and individuals have tested the miraculin for taste modification. The activity of miraculin is thought that the molecule binds directly to sweet taste receptors and activation of the receptors occurs with the acidic pH including food intake. Therefore, the sweetness characteristics of miraculin are equal to 0.4 M sucrose after taking 0.1 M of citrate with 1 μM of miraculin, and miraculin 400 000 times sweeter than sucrose (Tafazoli *et al*., 2019). Indeed, the compound might be an attractive ingredient for alternative meat production from fermented materials to prevent high acids in foods.

The sweetness of miraculin continues for more than 1hour (Misaka, 2013). When miraculin was consumed with lemon and strawberry, the sweet feeling of these fruits increased. Moreover, the savour of miraculin is close to sugar. Miraculin is a protein and is unstable under heating conditions but freeze drying or freezing is suggested to overcome the issue. More interestingly, the miraculin protects its stability for more than 6 months at 4 pH and 5 °C. The sweetness feature of miraculin demonstrates activities for insulin sensitivity and decreasing metallic tastes of foods for patients who take chemotherapy (Demesyeux *et al*., 2020).

Recently, miraculin has obtained GRAS from FDA (FDA, 2021) (Table 1), and EFSA has approved the dried fruit of *Richardella* as a novel food (Turck *et al*., 2021). Dried fruit has been suggested as a food supplement for adults except for pregnant and breastfeeding women. However, miraculin has not been approved by EFSA yet.

2.3.8 Monellin

Monellin is a sweet-tasting protein of *Dioscoreophyllum cumminsii* Diels. The sweetness characteristic of monellin is 4000 times higher than sucrose on a weight basis (Xue *et al*., 2009). Besides, monellin has been applied as a sweetener, and flavour enhancer. The highest activities of monellin can be seen at pH between 2 and 9, however high pH and heating over 70 °C can denature the protein (Kaul *et al*., 2018).
Monellin possesses a zero glycemic index which can be applied to the diets of diabetic people (Liu *et al*., 2015). Moreover, any adverse effects of monellin have not been reported for food applications so far (Cai *et al*., 2016). Nevertheless, except in Japan, EFSA or FDA has not approved monellin for food applications yet (Guggenbuhl *et al*., 2020) (Table 1).

2.3.9 Steviol glycosides (SGs)

The leaves of the *Stevia rebaudiana* Bertoni are called 'stevia'. (Ramos-Tovar & Muriel, 2019). The sweetness-responsible compounds of stevia are stevioside, rebaudiosides (Reb) A, B, C, D, E, F, and M. Reb A and stevioside are the common compounds of the plant and the sweetness levels are 300 times higher than sucrose. According to sensory evaluation tests of two compounds, flavour of Reb A is close to sugar with fewer astringency characteristics. Lastly, Reb M and Reb D have been explored for their potential sensorial characteristics, and Reb M has exhibited quick sweetness, less off-taste, and less astringency. Nevertheless, Reb D has demonstrated higher sweetness and lower off-taste than Reb A (Mora and Dando, 2021).

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Low caloric contents of SGs promote activities against obesity and type 2 diabetes with antifungal, antioxidant, antimicrobial, anti-tumour, anti-inflammatory, anti-hyperglycemic, and diuretic activities (Panagiotou *et al*., 2018; Zou *et al*., 2020; Lemus-Mondaca *et al*., 2012). Moreover, the digestion of SGs occurs poorly in the stomach and upper intestine. Then in the large intestine with the help of intestinal flora, the glycosides are hydrolyzed to aglycone steviol, in the enterohepatic circulation steviol is transformed into the steviol glucuronide and finally, extracted with the urine (Urban *et al*., 2013).

Stevia was approved as GRAS by the FDA, and the European Union accepted SGs as safe, in Argentina, Brazil, Japan, Paraguay, China, India, and South Korea approved SGs as safe as well (Table 1) (Perera & McChesney, 2021). Therefore, the recommended daily intake rate of SGs is the equivalent of 4 mg/kg body weight per day (Commission, 2011).

In the literature, Reb A, D, and M have been used as a sweetener in ice cream production and according to study results, sensorial acceptances of Reb D and M have been higher than Reb A. The characteristics of ice creams prepared with Reb D and M are described as creamy, pleasant, and sweet, but Reb A has been found with a metallic taste. More importantly, the aftertastes of Reb D and M have been described as similar to sucrose (Muenprasitivej *et al*., 2022).

So far, stevia has been applied to food products such as chocolate, chewing gum, beverages, jams, dairy products, pickles, and pastries as food additives (Ameer *et al*., 2017; Shannon *et al*., 2016). However, the aftertaste of stevia is an issue for food manufacturers because consumers are looking for palatable foods. Therefore, different techniques have been applied to eliminate the off-taste of stevia, for example, SGs have been encapsulated by freeze, spray and vacuum drying, and outcomes of the study have demonstrated that drying methods may help to remove the off-taste of stevia (Chranioti *et al*., 2016). Moreover, defined plant-based taste-masking agents in the present study can be applied to suppress the characteristic flavour of stevia for future vegan food products.

2.3.10 Glycyrrhizin

Glycyrrhizin is found in the root of Glycyrrhiza glabra L., with the well-known name licorice (liquorice) (Izawa *et al*., 2010). The sweetness levels of glycyrrhizin are 93-170 times higher than sucrose on a concentration basis (Kim & Kinghorn, 2002). Moreover, the ammonium salt of glycyrrhizic acid and monoammonium glycyrrhizinate is often applied and has been approved as a flavour enhancer by the FDA (Carocho *et al*., 2015) (Table 1). EFSA has also approved glycyrrhizin and the suggested consumption rate is 100 mg per day (Behrens *et al*., 2011). The suggested consumption rates of glycyrrhizin should not be overdosed due to its estrogenic characteristics which may cause side effects in young women, however, can be beneficial to women in the postmenopausal period to improve their bone health (Ishimi *et al*., 2019).

In the literature, glycyrrhizin has been applied to diet-related weight and insulin resistance in rats and according to study results, glycyrrhizin stabilizes the lipid profile (El-Magd *et al*., 2018). Moreover, glycyrrhizin demonstrates activities as an anti-tumour, antiviral and antioxidant agent (Zang *et al*., 2022). In the gastrointestinal tract, glycyrrhizin is converted to glycyrrhetic acid and 18β-glycyrrhetic acid 3-O-monoglucuronide by bacteria and the metabolites of glycyrrhizin are cytotoxic agents of tumour cells (Ruiz-Ojeda *et al*., 2019).

In history, glycyrrhizin was applied to soy sauces, meat products and snacks to mask the saline taste, and glycyrrhizin successfully suppressed the saltiness (Wilson, 2011). So far, glycyrrhizin has been applied to candies to give a specific licorice flavour.

The aftertaste of glycyrrhizin restricts food applications but the compound might be utilized to design innovative vegan foods with a strong taste of licorice, which can be an alternative who is looking for different flavours in vegan foods. In the forthcoming, more spicy and attractive flavours in vegan foods might be applied to be innovative and to design satisfying taste experiences for consumers as well. However, overconsumption of glycyrrhizin may create adverse effects such as pseudoaldosteronism – high blood pressure, and hypokalemia (Sharma *et al*., 2018). Thus, recommended consumption values of glycyrrhizin should be followed to not face the side effects of the compound.

2.3.11 Mogrosides

Mogrosides are compounds of monk fruit or Luo Han Guo, the Latin name of the plant is *Momordica grosvenorii* Swingle which is native to northern Thailand and southern China. Luo Han Guo demonstrates 200 times more sweetness than sucrose on a weight basis, with metallic aftertaste and long-remaining sweetness (Mora & Dando, 2021). The sweet taste of monk fruit is the result of identified major contents of mogroside V and cucurbitane triterpenoid glycosides with minor contents of isomogroside V, mogroside IV and simamenoside I (Soejarto *et al*., 2019).

In a literature study, mogrosides demonstrate anti-hyperglycemic effects in rats. Moreover, mogrosides do not change blood glucose, insulin levels, and total energy intake (Mora and Dando, 2021). Besides, mogrosides can be used against diabetes and obesity; as anticancer, and anti-inflammatory agents (Liu *et al*., 2018).

So far, mogroside V has been patented as a bitterness blocker, and the activities of the compound have been tested for grapefruit and coffee, and stunning results have been obtained (Fletcher *et al*., 2015). The Luo Han Guo has been approved by FDA (FDA, 2015) (Table 1), however, is unapproved by European Commission (Wilson, 2011).

2.3.12 *Eriodictyon* derivatives

Eriodictyon californicum (Hook. & Arn.) Torr. is well known as "Yerba Santa" which is native to North America, and has been utilized against headache, asthma, aging, rheumatism, and lung infections (Moerman, 2009). Besides, *Eriodictyon* has demonstrated function in bitterness blocking of quinine (Fletcher *et al*., 2015). Bitterness-blocking compounds of *Eriodictyon* are homoeridictyol, eridioctyol, sterubin, and sodium salt of *E. californicum* (Ley *et al*., 2006; Ley *et al*., 2005). Except for those compounds of *Eriodictyon*, 6-methoxyhesperetin, 4'-isobutyrylhomoeriodictyol, 6-methoxyhomoeriodictyol, 7-methoxylated flavanones, sakuranetin, 6-methoxysakuranetin and jaceosidin are thought to act against bitterness as well (Fletcher *et al*., 2011). Moreover, the flavanones of *Eriodictyon* exhibit health-promoting activities such as eriodictyol demonstrates antioxidant, anti-inflammatory, and antidiabetic activities (Zhang *et al*., 2012). In a literature study, overweight and obese women have been fed with *Eriodictyon* derivatives including capsules for 12 weeks and at the end of the research, the compounds demonstrate reducing features of body weight without any adverse effects (Modinger *et al*., 2021). Thus, similar to other suggested taste-masking agents in the present study, *Eriodictyon* derivatives demonstrate functions not only as taste suppressors but also as health promoters.

2.3.13 Inulin

Inulin occurs inherently in many fruit and vegetables but is yielded commercially from a dahlia, Jerusalem artichoke, and chicory (Flamm *et al*., 2001). Inulin is a part of non-digestible carbohydrates, called fructans, and the structure of inulin consists of β-(2–1)-glycosidic-bond with 2 to 60 fructose molecules and one terminal glucose (Perović *et al*., 2021).

Inulin is used as sugar, fat replacer, and soluble dietary fibre in food products (Barclay *et al*., 2010). The fat substitutive feature of inulin with long-chain fractions makes the material a stunning ingredient for alternative yoghurt, ice cream, and mayonnaise production with rich textural and sensorial aspects (Shoaib *et al*., 2016; Ahmed & Rashid, 2019). In a literature study, inulin has been applied in vegan kefir products, and study results support the benefits of inulin for alternative dairy food production (Alves *et al*., 2021). In another study, sugar-free dark chocolates have been prepared with inulin/polydextrose and stevia/thaumatin mixtures as sugar replacers. The study results have demonstrated similarities with the control group which includes 48% of sugar. However, the health benefits of non-caloric sugar replacers are higher and these natural compounds are supposed to be novel food ingredients for future foods (Aidoo *et al*., 2015).

Moreover, inulin demonstrates anti-cancer and anti-inflammatory activities. Inulin is only digested by gut bacteria and improves healthy microflora which protects from colon cancer. Inulin is non-toxic to the human body and demonstrates activities to increase cardiovascular health with increased calcium and magnesíum intake rates (Barclay *et al*., 2010).

The gelatinization, melting point, and gel integrity

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characteristics are the most attractive features of inulin for the food industry (Ahmed & Rashid, 2019). Thus, inulin may apply in meat alternatives as a fat replacer with the results of reduced-fat, enhanced texture, and increased mouthfeel features (Shoaib *et al*., 2016; Devereux *et al*., 2003). Finally, inulin has been approved by EFSA as a sugar and fat replacer (EFSA, 2007), and by FDA as GRAS (FDA, 2018) (Table 1).

2.3.14 Crude salt replacements as natural flavour enhancers

Salt reduction with substituted natural ingredients is a challenge for the food industry. Due to the features of salt, such as desired texture, long shelf life, flavour, and functionality; however, herbs, spices, and yeast extracts have been applied thus far, as flavour enhancers instead of sodium salt (Ainsworth & Plunkett, 2007; Taladrid *et al*., 2020). Furthermore, varied plant derivatives are proposed as salt replacers such as garlic, rosemary, oregano, saffron, paprika, chilli, mint, and blended herbs (Taladrid *et al*., 2020; campdenbri.co.uk). Apart from these, low–sodium-included vegetable juices have been prepared with organic acids (Allison & Fouladkhah, 2018). Also, applications of edible seaweeds are popular in Asian cuisine for salt reduction. Importantly, seaweeds promote high protein, omega-3 fatty acids, carotenoids, polyphenols, minerals, and vitamin contents (Gullón *et al*., 2021). On the other hand, umami can suppress the bitterness of plant derivatives, and increase the salty taste in foods (Wang *et al*., 2020). As, taste enhancers activate taste buds in the mouth which are linked to the umami taste receptors (Brandsma, 2006). Therefore, umami taste receptors perceive flavour enhancers as demonstrating high salt content, and the feature deceives the brain signalling. Today, the known umami taste enhancers are glutamate, aspartate, inosinate, guanylate, cytidylate, adenylate, uridylate, and succinate (Wang *et al*., 2021).

The features of umami help to FDA to approve monosodium glutamate as GRAS (FDA, 2012). Moreover, EFSA accepts glutamates and glutamic acid implementations in foods with the recommended level of a maximum of 10 g/kg of the food product (EFSA, 2017).

Table 1. Approvals of natural taste-masking agents by health authorities

Compound	Approval by Health Authorities			
	EFSA	FDA	Other	References
NHDC	✔	✔	✔	EFSA (2011), FDA (2019), ISA (2015)
Thaumatin	✔	✔	✔	EFSA (2016), FDA (2015), Carocho et al. (2017)
Miraculin		✔		FDA (2021)
Monellin			✔	Gugenbühl (2020)
Steviol glycosides	✔	✔	✔	EFSA (2016), FDA (2015), Perera & McChesney (2021)
Glycyrrhizin	✔	✔		Carocho et al. (2015), Behrens et al. (2011)
Mogrosides		✔		FDA (2015)
Inulin	✔	✔		EFSA (2007), FDA (2018)

2.4 The challenges of natural, non-toxic taste maskers for vegan people and the food manufacturers

Depending to the Grounded-Cognition Theory of Desire (Papies *et al.*, 2020), people employ varied senses at the same time during eating. For instance, imagination or the sound of food stimulates brain cells for appetite. Moreover, the appearance, smell, and texture of the food are the priorities of consumers to purchase a food product. Nevertheless, natural replacers of salt, sugar, and fat may cause some issues with the food texture, because salt, sugar, and fat provide stable texture, enhanced flavour, and anti-microbial activity of food products (Hoppu *et al.*, 2017; Dötsch *et al.*, 2009).

Aftertastes of compounds can seem a challenge for the food industry. The specific flavours of natural taste blockers might be applied in innovative meat and dairy alternatives, and flavours may create interesting outcomes for the final food products.

On the other hand, natural food ingredients influence purchasing activities of consumers (Román *et al.*, 2017). Natural and non-toxic taste blockers function in small amounts without toxicities and with promoting health benefits. Therefore, a small number of natural taste blockers' implementations should have been investigated for food production.

3. Conclusions and future trends

A vegan diet supports healthy body functions and sustainable food systems together. Moreover, during the COVID-19 pandemic, animal-carried viruses created huge concerns (Attwood & Hajat, 2020). Therefore, many people prefer to decrease meat consumption and/or be vegetarian/vegan (Loh *et al.*, 2021).

Natural ingredients in vegan processed food products are more attractive than artificial content. Nevertheless, vegan foods with natural ingredients should exhibit acceptable texture, desirable flavour, and scent, before healthy characteristics. Bitterness and off-tastes of plant-based foods, which are unpalatable for many consumers, are suppressed by sugar, salt, and fat. However, health authorities are looking for strategies to reduce the overconsumption of sugar, salt, and fat in processed foods. Thus, natural taste-masking agents such as glycyrrhizin, miraculin, monellin, inulin, neohesperidin dihydrochalcone, steviol glycosides, and thaumatin can be utilized in small amounts with the approval of health authorities.

However, the food preferences of individuals are shaped by culture and geography (Dao *et al.*, 2021). For instance, Mexican people desire hot-spicy foods, but for many other cultures, traditional Mexican foods are extremely hot and spicy. In other words, hedonic preferences affect the food choices of people (Ludy & Mattes, 2012).

Food transformation of people to novel foods is not easy because of gained food palatabilities which are not only shaped by the appearance, smell, taste, and texture of food products, but also by genetic inheritance, dietary habits, gut microbiota, food affordability and previous experiences with food products are crucial parameters (Mennella *et al.*, 2015; Dao *et al.*, 2021; Chamoun *et al.*, 2018).

Vegan foods are not an issue due to religious beliefs. Veganism is suitable for all religions, but, the main challenge is the neophobia of people or convincing individuals to consume vegan foods because of health and environmental concerns. Thus, to find the best recipes for vegan foods which are going to be prepared with sugar and/or salt substitutes to mask the bitter tastes of plant-based ingredients, extensive sensorial tests are essential to attract many people from varied cultures with different food preferences.

Conflict of interest

The author confirms that this article's content has no conflict of interest.

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