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Potential of sea buckthorn-based ingredients for the food and feed industry – a review

Arnau Vilas-Franquesa[1], Jordi Saldo[1,2*] and Bibiana Juan[1]

Abstract

Food industries seek to incorporate nutritious ingredients as they could bring added value to the final food products. One of the most interesting options is that sea buckthorn contains high concentrations of vitamin C, carotenoids, tocopherols, and other bioactive compounds, in addition to the unique lipid profile in the berry pulp, seed, and peel. This review summarizes the state-of-the-art of potential applications of sea buckthorn within the food and feed industry based on previously described applications. Products such as cheese, yoghurt or beverages already benefit from its application. Moreover, using sea buckthorn in feed products also derives into higher quality final products (e.g. meat quality, egg quality). Poultry, pig, and fish farming have been studied for that purpose. Despite all the accumulated articles depicted in the present review, the use of this fruit in food product formulation is nowadays scarce. New options for food product development with sea buckthorn are herein discussed.

Keywords: Food science, Feed additive, Product development, Health, Bioactive compounds, Added value, Sea buckthorn

Introduction

Sea buckthorn (*Hippophae rhamnoides* Linnaeus) is a flowering plant (Angiosperm) of the order Rosales and Elaeagnaceae family. Sea buckthorn (SB) is morphologically described from a bush to a small tree, with different growing thorns all around the plant, and it naturally grows in locations near to the sea, specific traits which build up its name. It is stated that its latin name *Hippophae rhamnoides* comes from ancient Greece, from the words 'hippo' – horse – and 'phaos' – shine –, for the horses fed with leaves from this plant developed a shining coat and weighed more (Kalia et al. 2011; Li and Hu 2015).

* Correspondence: jordi.saldo@uab.cat
[1]Centre d'Innovació, Recerca i Transferència en Tecnologia dels Aliments (CIRTTA), XaRTA, TECNIO, MALTA-Consolider, Departament de Ciència Animal i dels Aliments, Facultat de Veterinària, Universitat Autònoma de Barcelona (Cerdanyola del Vallès), Barcelona, Spain
[2]Instituto Politécnico Nacional (IPN), Centro de Desarrollo de Productos Bióticos (CEPROBI), Yautepec, Morelos, Mexico

The plant naturally grows in cold and dry regions around the globe. Himalaya is the region with the highest density of this plant (Kalia et al. 2011). It also grows on cold desert areas of China, Russia, North America, India, and Europe among others (Li and Hu 2015; Rousi 1971). Its highly adaptable characteristics allow the plant to grow in very different environmental situations, being able to grow at temperatures ranging from -40 to +40 °C (Kalia et al. 2011) and high altitudes (Ma et al. 2016). It could endure dry, alkaline or high salinity soils, and inundations (Kalia et al. 2011). The plant normally flowers around March and gives fruits around September. The fruit is a small (geometric average diameter measurements of nine varieties grown in Estonia ranged from 8.64 to 12.57 mm (Lougas et al. 2006)), orange-to-yellow berry weighing 375 mg as average (Beveridge et al. 1999).

Research on SB has grown considerably in the last two decades and several subspecies have been confirmed by means of new phylogenetic techniques. The division of

H. rhamnoides L. into 8 subspecies – confirmed by Bartish et al. (2002) – seems to be the most currently used and accepted classification (Sun et al. 2002; Ma et al. 2016).

As SB gains more importance, more contributions are being made on the topic, especially on the composition of the berry (Zielińska and Nowak 2017; Kaur et al. 2017) and its health effects (Olas 2018). Similarly, the number of research articles investigating the application of SB ingredients on current food products is increasing as well. However, there is no such a review on the application of SB ingredients in food or feed products. Therefore, the aim of the present review is to give an overview of all the investigated applications of SB on current food products and to discuss the potential of future research and applications in the field. Articles related to the use of SB for the development of food supplements do not suit the aim of the present review and have therefore been excluded after initial screening.

Sea buckthorn products

SB can be easily processed into valuable products. Once harvested, the first clear division is the leaf and the fruit. The leaf itself can be easily processed to obtain tea (Ma et al. 2019) or aqueous extracts, shown to have antioxidant, cytoprotective, and antibacterial effects (Upadhyay et al. 2010). However, its application to food production is difficult since it has not been recognized as a food product in specific areas of the world (i.e. Europe). In contrast, the berry is the most consumed part of the plant worldwide, and therefore, the present review will focus on SB berry rather than on leaf-derived products.

SB berry is the most consumed part of the plant worldwide. It could be conveniently processed into various products as well. The fruit consists of a hard peel, the pulp, and a seed. By using a worm-driver, the aqueous part of the fruit (i.e. the juice) can be separated from the seed, the peel, and some residues of the pulp (Cenkowski et al. 2006). Both products resulting from this extrusion can be further processed. On the one hand, the juice can be clarified by centrifugation. The clarification by centrifugation gives out three different products, namely the clarified juice (main layer), the oily part of the pulp (supernatant), and the residue left at the bottom, which is usually constituted by seeds and peel. On the other hand, the seed and peel can be separated firstly by drying, and later by using a mechanical sieve. SB products could then be classified by their fatty nature (i.e. oil from seeds, pulp, and peel) or aqueous nature (i.e. clarified juice). The yield percentage for juice extraction is about 70% (Cenkowski et al. 2006). The yield percentage for seed oil extraction is approximately 12% whereas the peel and the pulp give out an approximate yield percentage value of 6% (Dulf 2012).

Most important components of sea buckthorn

Aqueous fraction

The juice coming from SB berry processing is a complex product but can be easily further processed to obtain a clarified juice. The clarified juice is the only source of hydrophilic compounds.

The most stand-out trait of SB is high content of vitamin C. Beveridge et al. (1999) reviewed vitamin C values from 360 to as high as 1676 mg/100 g of berry, whereas Tiitinen et al. (2006b) reported values from 128 to 1300 mg/100 ml of berry juice, which is clearly higher than the concentration naturally found in naturally vitamin C rich fruits, such as lemons, oranges (Christaki 2012) or even kiwis (Dumbravă et al. 2016). The highest concentrations are only comparable with exotic fruits like acerola (Cefali et al. 2018). Thus, SB emerges as a great source of vitamin C after considering that one of the lowest values found in literature is 80.58 mg of vitamin C/100 g of fresh berries (Teleszko et al. 2015).

According to the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) of the United Nations, the recommended vitamin C intake (RNI) for an adult is about 45 mg/ day, and for a lactating woman the requirement increases to 70 mg/ day (World Health Organization and Food and Agriculture Organization of the United Nations 2004). If we consider the lowest value found in literature, by only eating 50 g of fresh SB berries, one adult person would meet the recommended dietary intake.

Nevertheless, vitamin C is rapidly degraded under certain processing conditions. Light, temperature, pH, enzymes, metallic catalyzers, and oxygen are parameters that can severely accelerate vitamin C degradation (Gutzeit et al. 2008; Santos and Silva 2008). The starting concentration of vitamin C in the raw product is a major factor affecting the final concentration of this vitamin after processing. The high concentration values reported for SB allows obtaining high vitamin C products even after processing. This is of great importance since a lot of products have difficulties in conserving adequate vitamin C levels after processing.

Along with vitamin C, polyphenols confer SB fruit its high antioxidant activity (Kim et al. 2011). The polyphenolic fraction of SB could be one of the factors contributing to the bactericidal potential of SB extracts. Total polyphenolic concentration is most of the time quantified through mg of gallic acid equivalent, one of the simplest polyphenols – although other polyphenols can be used depending on the major phenolic present in the sample (Singh et al. 2016). Cioroi et al. (2017) have recently reported values from 78 to 95 mg gallic acid equivalent (GAE)/ g dry weight, depending on the origin of the berry. These values are relatively high compared to a polyphenol-rich product like coffee. Hečimović et al. (2011) studied different coffee varieties and roasting temperatures and found the highest value of medium roasted coffee beans was 43 mg GAE/ g. According to Zadernowski et al. (2005), the main phenolic acid present in the non-flavonol glycoside fraction of SB was salicylic acid, reaching values as high as 1500 mg GAE/ kg of dry matter of berries, closely followed by gallic acid (Arimboor et al. 2008). Reported values of flavonol glycosides in fresh berries range from 23 to 250 mg/ 100 g (Ma et al. 2016), making it the most important phenolic fraction of the fruit (Arimboor et al. 2008).

Oil fraction

The fruit contains two different oil fractions; one obtained from the seed and one retained within the pulp. Unsaturated fatty acids and tocopherols are the major compounds of both oily fractions. Nevertheless, they differ significantly in their concentration. The seed oil contains greater concentrations of tocopherols (Kallio et al. 2002) and alpha-linoleic acid whereas the pulp oil has greater concentrations of palmitoleic acid.

Tocopherols are unequally distributed in SB seed, peel and pulp oil. For instance, α-tocopherol is found at higher concentrations in seed than in the full fruit whereas δ-tocopherol is found at greater concentrations in peel rather than pulp or seed oil (Burčová et al. 2017). Levels of total tocopherols can reach values of more than 160 mg/100 g of seed oil (Beveridge et al. 1999). These values are close to other oils valued for their high concentrations of tocopherols, such as soybean oil (100–200 mg/100 g soybean oil (Carrera and Seguin 2016)) or sunflower oil (50–150 mg/100 g sunflower oil (González Belo et al. 2017)), and much higher than other high-quality oils, such as olive oil, containing 21.24 mg/ 100 g of oil (Gimeno et al. 2002). Conversely, peel oil has been found to contain greater concentrations of δ-tocopherol rather than α-tocopherol (Burčová et al. 2017). β-tocopherol has been identified as the least present in either seed and pulp and peels oil (Burčová et al. 2017; Kallio et al. 2002).

Similarly, saturated fatty acids in SB are unevenly distributed in seed and the rest of the fruit. The seed contains a residual amount of saturated fatty acids (Yang and Kallio 2001) whereas the peel and pulp oil contain as much as 40% (Fig. 1; Dulf 2012). Almost all the fraction of the saturated fatty acids present in pulp oil is built by palmitic and stearic acids, common fatty acids within the plant kingdom (Dulf 2012).

The fraction of unsaturated fatty acids is also very different between pulp and peel when compared to seed oil. Pulp and peel oil contain greater amounts of mono-unsaturated fatty acids whereas seed oil contains a large fraction of polyunsaturated fatty acids (68%, Fig. 1). The main fatty acids present in seed oil are linoleic (C18:2 ω-6), α-linolenic (C18:3 ω-3) and oleic acids (C18:1 ω-9), accounting for approximately 40, 30 and 16% of the total fatty acids in seed oil, respectively (Fig. 2, (Dulf 2012; Teleszko et al. 2015)), whereas palmitoleic fatty acid (C16:1 ω-7) is found in negligible amounts in seed oil (about 0.5% of total fatty acids). Although oleic fatty acid is found at relatively acceptable concentrations in SB seed oil (13–20% of total fatty acids (Dulf 2012)), other vegetable oils such as olive oil contain much higher concentrations (70% of total fatty acids (USDA Food Composition Database 2018)). Contrarily, pulp and peel oil contain greater amounts of palmitoleic and oleic acids (Fig. 2).

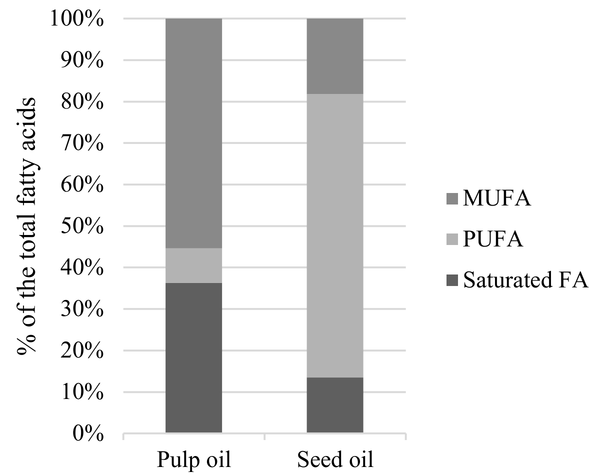

Fig. 1 Graphical representation of total fatty acids presents in sea buckthorn oils, adapted from Dulf (2012). MUFA; mono-unsaturated fatty acids, Saturated FA; saturated fatty acids, and PUFA; poly-unsaturated fatty acids

The role of ω-6 and ω-3 unsaturated fatty acids in human health have been extensively investigated over the years. Different reviews have been published on that field, showing the great implication of unsaturated fatty acids on human health and their importance in any diet (for instance; Innes and Calder 2018; Russo 2009; Zárate et al. 2017).

Palmitoleic acid is the only ω-7 fatty acid, and its presence within the plant kingdom is very rare. SB, together with macadamia nuts contain great amounts of palmitoleic fatty acid when compared to other vegetable oils (11 to 27% of the total fatty acids in peel and pulp oil (Dulf 2012), and 24 to 36% of total fatty acids (Aquino-Bolaños et al. 2017), respectively). Palmitoleic acid intake has been associated with improvements in insulin sensitivity, cholesterol metabolism (Marsiñach and Cuenca 2019), or acceleration of wound healing due to its potential anti-inflammatory effect on skin (Weimann et al. (2018)).

Besides tocopherols and fatty acids, SB contains considerable amounts of different carotenoids. Carotenoids

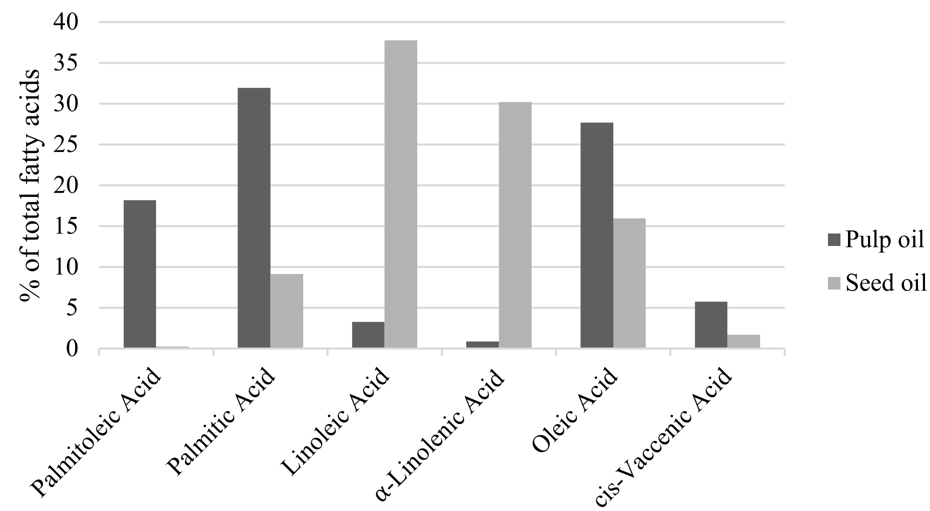

Fig. 2 Graphical representation of specific saturated and unsaturated fatty acids presents in sea buckthorn oils, adapted from Dulf (2012)

are present in pulp oil, conferring the fruit its characteristic orange-bright color. Carotenoids in SB can reach approximate concentration values of 12 mg/ 100 g of fresh weight (Teleszko et al. 2015). Although these concentration values are much lower than those found in oils known for being good sources of carotenoids, such as crude palm oil (54 mg/100 g (Manorama and Rukmini 1992)), these concentrations are higher than those found in other berries, such as black currant, blueberry or strawberry (Marinova and Ribarova 2007).

Health benefits of sea buckthorn: recent advances

Consumer trend towards healthier food choices is unquestionable. As more evidence is added to the field, consumers can take a more informed and healthy decision upon many different food products. Food industries are constantly adapting to fulfill the rapidly changing consumer wishes. In turn, food ingredients are being designed to give an added value to the food product and possibly trigger its choice. As naturalness is more related to values of nutrition and health, food components or ingredients coming from a natural source are becoming an important tool for the development of food products. Sea buckthorn builds up a clear example of what would be easily incorporated as a food ingredient. Having a clear natural origin and the nutritional quality herein reported, sea buckthorn is gaining importance as a promising plant source of several ingredients (either coming from the pulp or the seed).

Research on the association between sea buckthorn consumption and health has been ongoing for several years. The interest of late research has been on the polyphenolic fraction as well as the effects of its oil (either from the pulp or from the seed) on indicators of several diseases. The beneficial effects of isolated compounds that may be found in great proportion and are essential to human life (such as vitamin C or tocopherols) are well known. Therefore, research on SB focused on newly produced extracts (for instance a polyphenolic-rich fraction from the pomace after the extraction of the juice).

The phenolic fraction can be sourced from several SB products and has recently been a matter of study due to its possible attributed health effects. According to Ma et al. (2016), one of the major aglycones from sea buckthorn is isorhamnetin. Isorhamnetin, primarily found in the aqueous fraction of the fruit, had been shown to present a high antioxidant activity, even more than that exerted by ascorbic acid, at least in various chemical assays (FRAP, DPPH), as reported by Pengfei et al. (2009). Nowadays, many food companies thrive to achieve clean-label products, and the phenolic fraction of sea buckthorn emerges as a possible natural antioxidant substitute. Besides, the phenolic fraction of SB fruit had been shown to significantly decrease the peroxidation of plasma induced by hydrogen peroxide and increase the clotting time in a test-tube study, therefore showing an interesting anticoagulant activity (Olas et al. 2018).

In addition, isorhamnetin has been studied for its possible role as immunosuppressive therapy. Shi et al. (2018) conclusively proved that isorhamnetin could effectively suppress dendritic cell's maturation and trafficking. Dendritic cells are major targets of immunosuppressive therapies, and therefore, isorhamnetin could be used in the prevention and treatment of inflammatory and autoimmune diseases, including cases of transplantation rejection. Subsequently important, isorhamnetin had also been found to be more biologically active after digestion when compared to its pure form, at least on the regard of its antioxidant and antiproliferative activity (Guo et al. 2017 b). Indeed, several authors have studied the bioavailability and transformation of polyphenols from sea buckthorn juice in the gastrointestinal tract. As Attri et al. (2018) conclusively showed, sea buckthorn juice experienced an increase in total polyphenols after gastric and small intestine digestion, doubling the original value in the latter. The original polyphenolic compounds may probably be digested and transformed by beneficial bacteria, resulting in a final increase in caffeic and chlorogenic acids, rutin, and quercetin. However, results were different from those previously found by other authors (Guo et al. 2017 b). The polyphenolic fraction of sea buckthorn juice promoted the growth of beneficial bacteria groups *Bacteroides, Prevotella*, and *Bifidobacteria* in a significant manner (Attri et al. 2018).

After its oil extraction, sea buckthorn seed residue could be used as a source of polyphenols, since the oil extraction usually does not include the extraction of polar compounds. Wang et al. (2014) demonstrated that a procyanidin extract from SB seed powder showed a powerful inhibitory effect against fatty acid synthase (FAS), therefore inducing cell apoptosis in the human cancer cell line MDA-MB-231, which shows specially overexpressed FAS activity. Recently, Wang et al. (2016) tested the efficacy of orally administered procyanidin extract from SB seed powder against visible light-induced retinal degeneration in rabbits. The intake of the studied extract effectively maintained the retinal structure and reduced the effect of inflammatory cytokines, induced by light exposure.

Polyphenols constitute a great fraction of SB, and extracts from different sources (berry juice, pomace, or seed residues) show a different polyphenolic profile. Extracts with different polyphenolic profiles have been tested depending on the main polyphenol found in it, and most of the studies show interesting results, as herein presented. SB emerges as a good source of natural antioxidants as the concentration of polyphenols in the raw matrix is already high, and benefits from the putative antioxidant effects of vitamin C. Also, SB may also be the source of purified extracts constituted primarily of polyphenols. These extracts may prove to be useful to the formulation of food supplements, which benefit from the addition of functional compounds. However, clear epidemiological evidence on the effects of polyphenols extracted from SB is still missing and further research should address to fill that gap.

In addition to polar components such as polyphenols, SB is the source of many other different non-polar compounds, primarily found in SB oil, either coming from the seed or the pulp and peel. Several studies have explored the consuption of SB oil to understand the health implications or, in some cases, of its external application. Pulp and peel oil – also known as fruit oil – is rich in palmitoleic fatty acid, as reported in the previous section, a rare fatty acid in the plant kingdom. Research has shown that palmitoleic acid may have a role in glucose homeostasis as well as in the metabolism of fatty acids. Gao et al. (2017) investigated the effect of sea buckthorn fruit oil in vitro and in vivo and found that SB oil intake could significantly improve glucose homeostasis, insulin sensitivity, and liver injury in HepG2 cells and SD male rats. The oil is partly present in SB juice and therefore SB juice may have also an effect on improving insulin sensitivity and postprandial glycaemia. However, Mortensen et al. (2018) did not found a significant effect on postprandial glucose nor insulin concentration by using a sea buckthorn smoothie before a meal in overweight and obese male subjects. The smoothie, however, consisted of 35 g of added sucrose and protein, which may not be ideal to see an improvement in glucose homeostasis.

Oral administration of pulp oil has recently been reported to effectively reduce tear secretion by 80 and 93% in stress-induced dry eye rats and mice, respectively, compared to tear secretion before oil intake (Nakamura et al. 2017). These results would possibly explain the hydration and protective capacity of SB fruit oil. Also, Hou et al. (2017) proved that treatment with SB oil could suppress the development of atopic dermatitis-like lesions in mice, possibly proving the regenerating capacity of SB fruit oil.

Smida et al. (2019) have interestingly proved the efficacy of SB pulp oil as a mouthwash product. They found that a preparation containing SB pulp oil could have a bactericidal and anti-biofilm activities against oral bacteria species, although antifungal activities were not proved.

Seed oil, on the other hand, has been recently used to investigate the association between its intake and cardiovascular risk factors (Vashishtha et al. 2017). The authors performed an animal and a human study. They found that SB seed oil, administered at dosages of 0.75 ml significantly reduced total cholesterol levels, oxidized low-density lipoproteins, and triglycerides in plasma in hypercholesterolemic human subjects. Besides, Hao et al. (2019) have lately proved that supplementation with SB seed oil could positively modulate the relative abundance of beneficial gut bacteria groups, and together with an improvement in intestinal cholesterol excretion. It would be effective in reducing the blood cholesterol in hypercholesterolemic hamsters. These studies add up to a very interesting outcome that sea buckthorn could be used as a potential therapy against cardiovascular events possibly by inhibiting cholesterol deposition in the arteries (Olas 2016). The seed oil has also been tested on humans suffering from dry eye symptomatology. Larmo et al. (2019) have recently found that a four-times-a-day dosage of a sprayable solution containing 0.4% of SB seed oil could significantly decrease the symptomatology related to dry eye when compared to a control solution without SB seed oil. The potential in skin hydration and regeneration from SB either attributed by seed or pulp oil has been proven more than once, probably due to the high content of unsaturated fatty acids, tocopherols, and carotenoids (depending on the oil source).

Reviews of SB and health have lately increased in number. Most of the published reviews aimed at summarizing the high number of publications related to a specific sea buckthorn health benefit. For instance, Olas et al. (2018) published a review focusing on the health benefits derived from oil consumption, highlighting its cardioprotective and hepatoprotective properties, anticarcinogenic potential, antioxidant capacity, and dermatological benefits. More interestingly, Guo et al. (2017a) published a meta-analysis of 11 independent randomized controlled trials. The review aimed at elucidating the relationship between the consumption of sea buckthorn and changes in blood lipid profiles.

Recent health advances show the most interesting paths to keep making research on the effects of SB components. The role that the polyphenolic fractions of SB have on human health, either from fruit pomace or from seed residue, varies depending on the phenolic profile of the extract. Several extracts have been reported to exert positive benefits on human health. However, most of them are performed using a highly pure extract, which does not match the real concentration in SB raw materials. Most of the health outcomes herein depicted from this fraction could interestingly be used by pharmaceutical or nutraceutical industries, in which the product developed relies exclusively on its potential health attributes. The fact that the residues could be processed further may also benefit the sustainability and cost of the production process. Nonetheless, SB oil, either from the fruit or from the seed, has been recently used to demonstrate possible health implications derived from its consumption. The oil consumed as such is already proven worthwhile for its use, making the extraction process quicker and simpler compared to other extracts from SB. Even though SB oil may not be included in food products to see a positive health benefit after its consumption. SB oil still possesses great antioxidant activities due to the high presence of bioactive compounds such as tocopherols and carotenoids, as already discussed. Likewise, instead of adding polyphenol extracts to food products, the juice itself could be used to tackle the costly production process of the extract.

Sea buckthorn in new food product development

New product development is a technique most of the food industries nowadays use in order to be competitive in the market. This strategy allows them to develop food products according to consumer's wishes. Consumers are every time more aware of their lifestyle. A healthy lifestyle involves several aspects, one of which is following healthy food habits. Thus, food companies are leading their new product development strategies towards more healthy and nutritious products. SB has emerged as one of the most promising ingredients for food companies, because of the already detailed physic-chemical profile and its derived health benefits. Nevertheless, in sensory quality terms, SB has a well-defined sour and astringent taste (Tiitinen et al. 2005), which makes the formulation of food products with SB quite a challenge. In an attempt to describe the origin of this sourness and bitterness, some authors have added evidence highlighting the importance of malic acid in the sourness profile of SB juice (53.8–74.1% of the total acid content) (Ma et al. 2017). In addition, they also found that ethyl β-D-glucopyranoside, an alkylated glucose of SB, may play a complex and prominent role in the bitterness of SB juice. Sweetness and fruity flavor are also poorly present features in SB juice (Tiitinen et al. 2005). The astringency, also an important attribute of SB juice, could be derived from specific phenolics: proanthocyanins or condensed tannins, as detailed by Lesschaeve and Noble (2005). Nevertheless, to the best of our knowledge, there has been no investigation on the proanthocyanins or condensed tannins in formulated SB-based products.

Fermentation of sea buckthorn juice

Some of the main components contributing to the sourness of SB juice are its organic acids. Malic acid and quinic acid constitute up to 90% of organic acids in the juice, and malic acid is the most prevalent (Zeb 2004). To tackle this issue, Tiitinen et al. (2006a) studied the effect of malolactic fermentation on SB juice. By inoculating *Oenococcus oeni* at a cell density of 10^9 CFU/mL they achieved a moderate increase in pH (from 2.8 to 3.1) after only 1 day of fermentation, and the final juice contained only 3 g/L of malic acid (instead of its original 16 g/L). After 24 h of fermentation, there were significant reductions in sourness and astringency and an increase in sweetness. One of the drawbacks the authors pointed out was the development of unwanted off-flavors, which increased upon increasing fermentation time. One year later, the same authors published more results related to this project (Tiitinen et al. 2007). Interestingly, they subjected four different varieties of SB to the malolactic fermentation detailed in their previous work (at a cell density of 109 CFU/mL over 18 h at 28 °C). This short fermentation time impeded certain compounds to be formed and decreased the off-flavors derived from fermentation. The fermentation rate was found to differ between varieties. Two of the varieties showed a higher conversion rate of malic acid into lactic acid, a determinant factor when evaluating the fermentation of SB juice. In the study mentioned above, they found that the fruity flavor was enhanced due to the production of esters during the fermentation process. Besides, as found in their previous work, they observed a reduction in sourness and astringency after fermenting the juice in all studied varieties.

Using sea buckthorn in fermented food products

Besides attempting to tame the harsh flavor of the juice by fermentation, other authors have investigated the use of SB juice preparations in different fermented food products. Recent findings suggest that SB juice promotes the development of different beneficial gut bacteria, probably due to its prebiotic characteristics (Attri et al. 2018). Indeed, Selvamuthukumaran and Khanum (2015) already showed that SB may have a positive effect on the proliferation of different lactic acid bacteria. Their work consisted of including SB syrup in the stage prior to yoghurt fermentation. They studied how different concentrations of SB syrup and milk powder affect the sensory, physical, and functional quality of yoghurt (the latter being prebiotic bacterial counts at the final product). The optimum addition of SB syrup in yoghurt was 15%. This concentration achieved higher counts of *S. thermophiles* and *L. bulgaricus*, as well as an improvement in taste. More importantly, the developed SB yoghurt contained higher amounts of vitamin C, E, carotenoids, phenols, and anthocyanins when compared to commercial variations containing other fruits. One of the most important drawbacks was the addition of sugar in the development of SB syrup, which included 50 g of sugar per 100 g of syrup. This could explain the higher taste acceptance found in yoghurt containing SB syrup. Similarly, Gunenc et al. (2016) studied the effect of SB whole fruit, and purified mucilage addition in yoghurt on the final bacterial count after 28-day storage at 4 °C. Just as Selvamuthukumaran and Khanum (2015) previously found, homogenization with SB whole fruit or mucilage prior to incubation was found to increase the final bacterial viability in terms of bacterial counts. Addition of SB berries or mucilage also derived in a decrease in pH and an increase in titratable acidity after 28 days of storage at 4 °C. This marked drop probably happened due to the addition of pure SB fruit and mucilage, which sours the product if not treated before, especially due to its high content in organic acids.

Using SB in the development of yoghurts seem to have great potential, for different authors have provided evidence on the prebiotic ability of SB on lactic acid bacteria (Selvamuthukumaran and Khanum 2015; Gunenc et al. 2016). The berry juice was found by other authors to promote the growth of lactic acid bacteria and bifidobacteria as well as enhance the ratio Bacteroides/Prevotella, groups of bacteria classified as beneficial for the organism (Attri et al. 2018). Thus, SB-based yoghurt could be a good product to invest in, although more research is needed to find out means to improve the organoleptic characteristics of the final product.

Other authors studied the inclusion of SB as an ingredient in cheese. Terpou et al. (2017) used SB berries to study the symbiotic effect with a probiotic strain of *Lactobacillus casei* (ATCC 393) included in a feta-type cheese. They used dry SB berries as an immobilization carrier for the probiotic strain. Briefly, they mixed 10 g of dry sea berries with different weights of bacteria biomass and 500 ml of Man, Rogosa, and Sharpe (MRS) broth. After fermentation, the bottom biomass solution was used as an immobilized carrier. This mixture was added after the cheese coagulum derived from rennet action was cut into 1 cm size blocks. The addition of SB positively contributed to the aroma profile of the cheese, raising the concentration of esters, terpenes, and carbonyl compounds. Interestingly, the sour taste of SB berries was masked by the strong flavor of feta cheese, and the addition of immobilized probiotics gave a soft and smooth taste according to sensory evaluation. It is interesting to note that with strong-flavoring products, successful masking of the sour and bitter taste of SB could be achieved. Recently, Terpou et al. (2019) also used SB berries as a probiotic cell immobilization carrier for the development of functional frozen yogurt. They compared their results with frozen conventional yoghurt and frozen yoghurt prepared with just the probiotic strain. Immobilization of the strains improved their survival rate during storage, and protected the probiotic against gastric conditions in vitro, as shown in their previous study (Terpou et al. 2017). In addition, after performing a hedonic test, the yoghurt with SB as an immobilization carrier was the most overall accepted. The citrus taste was scored higher for SB yoghurt, an attribute derived from its addition. However, color and dairy flavor scored hedonically lower for SB. This is understandable, since SB may mask the dairy flavor and add some orange-like color, non-characteristic of a frozen yoghurt.

Prior products focused on the potential prebiotic ability of SB derived ingredients. Nevertheless, there are other fermented food products to which SB had been included to ultimately achieve a change – in most cases improvements – in its structure, flavor, antioxidant capacity, or shelf-life, among other characteristics. Specifically, SB was included in the production process of beer and bread, achieving a higher antioxidant capacity than its former product (Adadi et al. 2017; Sturza et al. 2016; Guo et al. 2019). Other main findings of these studies are depicted in Table 1.

Beverages

Albeit having a poor taste mainly due to its sourness and bitterness, SB juice production is for many a serious chance for new product development due to its great concentration of vitamin C and other already mentioned bioactive compounds. Tang et al. (2001) developed a hedonic experiment with the juice of different varieties of SB. SB juice was diluted to 1:5 with tap water and sucrose was added as a sweetener. The sweetener was always added at the same concentrations (6.5%). Natural occurring sugars in SB made the difference between samples. Astringency, sourness, bitterness, sweetness, and color were the measured factors. The sweetness was identified as the major feature affecting the likeliness of the juice. Besides, a reduction in acidity accentuated the sweet taste in the juice and made it more pleasant.

Recently, more studies have emerged on the development of SB berry-based juices. Geertsen et al. (2016) investigated the hedonic characteristics of several newly developed SB berry beverages on the Danish consumer population. SB juice was mixed at different concentrations with locally grown rosehip, fennel, pear, aronia, beetroot, and redcurrant as novel products. The authors concluded that SB novel beverages were evenly liked by Danish consumers. Nevertheless, it was difficult for Danish consumers to include it in their day-to-day food habits. This study was interesting since it is an example of a current consumer response to hedonic features of novel SB juice preparations. Other authors have used SB to produce a highly acceptable berry squash – evaluating the most important features affecting its flavor (Selvamuthukumaran and Farhath 2017) – or by mixing sea berry squash (concentrated syrup of the fruit with the addition of sucrose, pH regulators and stabilizers) with other fruit nectars (e.g. apricot (Naik et al. 2017). Findings from these articles are presented in Table 1.

Other food products

SB is also interesting to ameliorate the negative effect that certain food products may trigger on consumers, or in other words, to give the product added value. Such is the case of sweet products. For instance, Stolzenbach et al. (2013) tested several aspects of different newly produced kinds of honey against traditional honey locally marketed in Denmark. They provided only the information on the classic and novel-produced honey. Novel kinds of honey included ingredients such as apple, SB, peppermint, mustard, or horseradish. Crushed SB was stated to be an ingredient of the SB honey. The main problem of SB honey for consumers was the probably disgusting and surprising taste, which was novel enough to trigger fear among the respondents. However, the authors highlighted the possibility that the results could be influenced by the way SB was said to be added in the honey. Further, the model used for the results explained only 79% of the variance, a percentage that could potentially be changed after a tasting experience of the real product.

Muffins are products in which SB has been added as an ingredient as well (Ursache et al. 2018). Briefly, SB carotenoids were extracted according to the method performed

Table 1 Additional articles investigating SB-juice-based beverages and other fermented food products

Authors and year	Product	Parameters evaluated	Conclusion
Naik et al. (2017)	Apricot nectar blended with SB berry squash in six different proportions	Total soluble solids (%), acidity (%), reducing sugars (%), total sugars, Brix acid ratio, and organoleptic score	A proportion of SB:apricot nectar of 40:60 was the best for consumer acceptance given the parameters measured.
Selvamuthukumaran and Farhath (2017)	Optimization of SB squash	Total soluble solids, acidity, total sugars, reducing sugars, carotenoids, anthocyanins, polyphenols, antioxidant activity, and vitamin C and E	Developed product was superior in all measurements performed when compared to pineapple or grape squash
Adadi et al. (2017)	Kölch beer with SB berries	Physicochemical parameters, microbiological stability, volatile compounds, and antioxidant capacity	SB Kölch beer showed a higher antioxidant capacity than the original Kölch beer. Hedonics were also better for SB beer as expressed by professional panelists. There were no observable changes in other parameters
Sturza et al. (2016)	Gingerbread and sponge cakes with 2 to 4% of SB flour by total flour weight	Structural and mechanical, physicochemical, and microbiological properties, and antioxidant capacity	SB flour addition to gingerbread and sponge cakes considerably improved their antioxidant capacity, conferred greater microbiological stability, improved appearance, color, and consistency but it also contributed to a greater moisture loss.

before by Ursache et al. (2017) and dissolved in blackcurrant oil. The carotenoid extract in oil was then mixed with whey protein in water solution to get oil in water emulsion. 1% w/v of gum acacia was then carefully added to the emulsion, pH was adjusted at constant stirring and temperature and finally the temperature was reduced, and samples were freeze-dried. This microencapsulated extract was then added to the mixing step of the muffin production process in a ratio of 6% of flour. The addition of microencapsulated powder made the muffin firmer and chewier, strongly correlated with the porosity of the food matrix. Contrarily, the addition of SB extract decreased cohesiveness and elasticity. Sensory analysis was statistically no significant when compared to normal muffins. Antioxidant activity was higher in the value-added muffin due to the high content of carotenoids and other bioactive compounds. Furthermore, the microbiological stability of the SB muffin was higher than the normal muffin, probably due to the marked antimicrobial effect of SB extracts.

The antimicrobial effect could be derived from specific compounds in SB berry, such as phenolics. However, the antimicrobial effect might be enhanced by the low pH of the berry juice. Nonetheless, products with a naturally low pH, such as fruit jam, are not much affected by the additional sourness brought by SB. Indeed, some countries have commercially available SB-derived jam. Fruit jelly containing ground SB cryopowder had also been developed and tested. Cryopowders were used by Gubsky et al. (2016) in the development of the fruit jelly. Cryopowders were produced by freeze-drying prior to low-temperature grinding. The study focused on the antioxidant capacity of the fruit jelly with a defined percentage of different cryopastes and cryopowders, one of which included SB-whole berry cryopowder. Among the 9 cryopowders used in their study, SB presented the second-highest total antioxidant activity employing bromine assay, preceded only by rosehip cryopowder. Fruit jelly was developed by mixing a syrup of approximately 80% of solids content consisting of pectin and sugar with a selected cryopaste. Cryopowder was added to the mixture after cooling of cryopaste addition. Thereupon, the developed SB fruit jelly also contained another cryopaste ingredient. SB berry jelly fruit was developed with either carrot or pumpkin cryopaste. Again, total antioxidant capacity was the second highest after any rosehip cryopowder jelly fruit developed.

Sea buckthorn in feed products

The development of food products often relies on ingredient sourcing and expensiveness. For example, the value of animal-derived ingredients is most affected by the growth rate of these animals, which is clearly influenced by the type of composition in their feed, among other variables. Different feeding products may have a different impact on the development of the animals and ultimately on the quality of the end-product or ingredient, leading to different end-point quality. Due to the interesting nutrient profiling of SB oils and juice, several authors have investigated its effect on the final quality of different animal products. Egg quality, broiler or pig meat quality, and sturgeon growth performance are few of the studied outcomes of including SB as a supplement in the feeding products.

Poultry farming

Broiler production efficiency is quite high per se, for the growth and development of a broiler to full potential does not take much more than 30 days. However, different and more natural strategies are needed to achieve the same or higher production efficiency, plainly because of the increasing consumer awareness on the feeding products. In that line, Vlaicu et al. (2017) studied the effect of three different diets on the carcass development, blood, and production parameters of broiler chicks. They compared three different diets in the growing and finishing stages of broiler chicks against a conventional diet, one including rapeseeds and grape meal and another including flaxseeds meal and SB meal. The diet was different in the two studied stages of broiler production (growing and finishing). Related to the overall meat quality, those broilers who were fed a diet with SB and flaxseed meals showed significantly higher concentrations of omega-3 polyunsaturated fatty acids when compared to the control or the group fed with rapeseeds and grape meal. However, by the end of the third phase of feeding (finished), the authors observed differences in the feed conversion ratio between the broilers fed with SB and the control-fed group. In other words, the final weight of SB-fed broilers was significantly lower than those fed with either a common diet or rapeseed and grape meal.

Another recent study performed by Pathak et al. (2015) interestingly used different parts of SB, including a leaf extract, pulp, and seed oil. In contrast to what Vlaicu et al. (2017) had later claimed to observe, supplementation with either leave extract, pulp, or seed oil increased the final bodyweight of the broiler. As reported earlier (Ma et al. 2015), supplementation with SB (any part) increased breast intramuscular fat, but contrarily decreased thigh intramuscular fat when compared to control. The authors found it reasonable to conclude that SB leaves, pulp, and seed oil could be introduced to a normal broiler's diet to help achieve better productivity and better overall carcass traits. Other authors also investigated SB as a potential ingredient for feeding broilers, at different concentrations. Some of the authors also used flavones extracted from SB instead of SB fruit or derived products. Feeding flavones extracted from SB berries lead to the higher intramuscular fat content in thigh and breast tissue and final body weight (Ma et al. 2015). However, one of the main drawbacks of the study is the variability of flavonoid content in SB berries. The most common flavone is isorhamnetin, but no information on the feeding quantity was provided in the experiment. Thus, the effects on broiler meat quality or broiler productivity (i.e. broiler weight) cannot be attributed to a specific flavone but the flavones of the specific variety of berries used therein. As well, extraction of flavones from sea berries does not seem the most applicable way to provide SB's advantages in animal farming because of the extraction and probably costly step.

Other studies on the productivity and other hedonic parameters of broilers fed with SB supplements (berries, fruit residues) also claim to observe different beneficial effects. However, one of them claimed to observe a lower weight of broilers fed with berry residues when compared to the control group (Ben-Mahmoud et al. 2014), different than what was observed in other already detailed studies. The main findings of the mentioned articles appear textually depicted in Table 2.

Egg quality

Egg quality is an important feature to be assessed. As already depicted in Table 2, some authors have already assessed egg quality by production ratio (number of eggs per hen) or by weight. However, there are other features to be measured when speaking of egg quality. One of the main important traits is the color of the yolk, which has a significant impact on the overall egg quality. The color of the egg strongly relies on the diet with which the broiler has been fed. Different compounds could influence yolk color. For instance, carotenoids can influence the color of the eggs, when included as a supplement of a normal diet (e.g. Alay and Karadas 2017). As described before, SB contains considerable amounts of carotenoids, mainly present in the juice and the fruit residues of the berry. Thus, using either SB fruit extract or juice residues could have an influence on yolk color. In that line, Dvořák et al. (2017) and Shaker et al. (2018) have recently published evidence on the relationship between SB pomace (or fruit cake residue) and different parameters related to egg quality from old hens.

Dvořák et al. (2017) used SB pomace (fruit residue from juice extraction) as a supplement in different concentrations (2, 5, and 10%) to evaluate viscosity and color of egg yolk. They allocated 20 old hens in 4

Table 2 Additional articles investigating the effect of SB on broiler overall quality

Reference	Product	Parameters evaluated	Conclusion
Ma et al. (2015)	Diet supplementation during 42 days with flavones from SB fruits at 0,05, 0,10 or 0,15% of the total daily intake	Growth performance, carcass quality, fat deposition, and lipid metabolism	Supplementation of flavones from SB fruits at all ranges leads to an improved daily gain and final body weight. Intramuscular fat content in thigh and breast tissue was higher in broilers fed with flavones from SB fruits, yet abdominal fat percentage was significantly reduced in these groups when compared to control.
Kang et al. (2015)	Ad libitum diet supplemented with 0,1% vitamin C; 0,1% SB; 0,5% SB and 1% SB for 4 weeks	Egg production, feed conversion ratio, intake, egg weight, carcass yield, partial ratio (breast and neck), level of leukocytes, and erythrocytes. In addition, they measured DM, crude protein, crude fat, and crude ash as proximate analysis, and meat color, water holding capacity, cooking loss, and fatty acid concentrations.	Supplementation of SB in old laying hens for 4 weeks resulted in increased intake and increased partial ratio (breast/neck) only in 0.5% SB-fed hens. Egg weight was higher in basal and vitamin C-fed hen group. Other measured parameters did not show significant differences between groups.
Ben-Mahmoud et al. (2014)	Broilers included in the study were classified into 3 groups and were fed with diets supplemented with either natural color "Avizant Yellow 20S", 5% of SB fruit residues, or with no supplement (control).	Total weight, intake and feed conversion rate, health and mortality, dressing percentage, skin color, and metabolizable energy.	Broilers fed with 5% supplemented SB fruit residues diet showed a higher pigmentation of their skin. Weight was higher during the starter and grower diets when the diet was supplemented with SB fruit residues but lower at the finisher stage when compared to the control group. Skin pigmentation, final live weight, and feed conversion were surprisingly higher in the group fed with the colorant when compared to both other groups.

distinct groups, three of them receiving each one different concentration of SB pomace in their feed and the other acting as a control. The color of egg yolk changed significantly and could be visually appreciated and was more intense in the group fed with a higher amount of SB pomace. Egg yolks from hens supplemented with SB had a more intense red-yellow color. These eggs also showed lower viscosity. The authors firmly stated that both traits found on the eggs from SB pomace-fed hens were those preferred by consumers.

Similarly, Shaker et al. (2018) found that supplementing 5% of the wheat from a conventional diet with SB fruit residue leads to a darker and more intense yolk color of the eggs, a trait of importance by the consumers. As well, the authors found differences in the total number of laid eggs at the end of the experiment, the hens fed with 5% supplementation of SB had higher number of eggs. However, this difference became insignificant when adjusted by the number of hens. All other measured parameters to test egg quality did not give significant differences between groups.

Pig farming

Pigs are other important animals to consider investigating for meat quality. Meat producers use most of the carcass to produce meat and products thereof, swine rearing is a very profitable practice. The quality of the products derived from swine rearing is of utmost importance for the benefit of the companies who are producing it and for the consumers. Similar to what has been the base of supplementing with SB the broilers' diet, swine's diet could be similarly manipulated to investigate the overall resulting quality of the meat.

Nuernberg et al. (2015) recently investigated the effect of SB pomace supplementation at concentrations of 4, 8, and 12% in the finishing performance of a specific breed of meat-producing pigs. They investigated different meat quality parameters and intramuscular fatty acid and vitamin C contents in the muscle of pigs. None of the studied values showed significant differences between feeding diets. However, the authors observed a slight difference in the concentration of ω-3 fatty acids. The highest concentration was found in pigs fed with 12% supplementation of SB pomace. The authors conclude that the overall meat quality, including meat color, pH, or nutrient composition, was not different between experimental groups. They suggested a need of reformulating the pigs' diet to see a true and pronounced effect.

Lately, Dannenberger et al. (2018) used the results from the previous study (Nuernberg et al. 2015) to investigate the effect of supplementation of SB fruit pomace on circulating fatty acids, peripheral immune parameters and mRNA expression of different inflammatory-related hormones (namely corticotropin-releasing hormone, mineralocorticoid receptor, and glucocorticoid receptor) and receptors in hypothalamus and spleen of growing pigs. The experimental design was the same as previously reported (Nuernberg et al. 2015). Pigs fed with 12% SB for 8 weeks were selected for their study. The supplementation with SB turned in an increased concentration of linoleic acid in plasma and subsequently in an increase in ω-6/ω-3 ratio when compared to the control group (fed with 0% SB, same time span). No significant differences were observed on any other parameter related to circulating fatty acids, peripheral immune parameters, or mRNA expression of inflammatory-related hormones and receptors in the hypothalamus and spleen. The authors pointed out that effects derived from supplementation with a rich source of ω-3 fatty acids (such as SB) might be more appreciable on stressful situations.

Fish farming

Rearing fish to produce fish-meat at a competitive price is already a reality. Different from conventional fishing, fish farming does not involve the destruction of the marine ecosystem, a practice encouraged by many ecosystem protection organizations. In addition, productivity and quality of the final product are outcomes that can be changed through the fish feed, something unachievable by conventional fishing. There are several types of fish that can be reared in a confined space. Some of the already reared fish species with a noticeable profit which could be found in the market are salmon or sturgeon, among others. The use of SB has been spread to fish farming, mainly to investigate the effect of SB consumption in productivity and mortality of the reared fish. The weight of the fish is very important for greater efficiency in production and better quality in the end-product. Also, some studies have shown interesting results on lipid peroxidation (Antache et al. 2013), an important matter in fish quality, considering the high percentage of unsaturated fatty acids found in fish meat.

Not only SB, but other plant extracts are of interest when investigating the performance of fish farming. In that line, Antache et al. (2013) investigated the influence of rosemary, SB, or ginger supplementation on oxidative stress of reared Nile tilapia. They classified all the fish for the experiments in either control (receiving none of the experimental supplementations), 1% rosemary, 1% SB or 1% ginger powder group. Groups were fed for 6 weeks. Oxidative stress was assessed by the concentration of malondialdehyde and total antioxidant capacity from muscle, liver, gut, and plasma and reduced glutathione from the blood. SB supplementation to the feeding of Nile tilapia derived in a decrease in malondialdehyde concentration in blood plasma. Malondialdehyde concentration is often referred to as a great index to assess lipid peroxidation. The total antioxidant capacity did not show significant differences between groups. The following year, Antache et al. (2014) published a second article evaluating other important biochemical indexes, such as hemoglobin concentration, hematocrit percentage, or cortisol concentration in blood. The experiment was the same as previously described (Antache et al. 2013). The authors observed that supplementation with 1% SB leads to an overall improvement of the physiological status in Nile tilapia most likely due to its influence on several biochemical blood parameters.

More recently, SB has been used as a supplement in the diet for different species of fishes. Dorojan et al. (2015) used a supplementation percentage of 1% on sturgeon juveniles with different genetic backgrounds. Understood as a positive control, they added vitamin E at concentration values of 500 mg/kg feed. Sturgeons were fed by 60 days, 3 times per day, with a daily ration of 2.6% of the fish body weight. Different from what previous authors had measured, the authors evaluated the growth performance of sturgeons. They found that the beneficial effect of SB supplementation was similar between groups with a genetically different background. After supplementing the fish feed with 1% SB/ kg feed and part of vitamin E (500 mg / kg feed), all groups showed a significant increase in the final weight and total length of the fish.

Discussion

Sea buckthorn as a food ingredient

There is a continuous growing awareness of healthy eating in our society. The consumption of plant-derived products is taking over the consumption of other products from animal origin, plainly due to emerging evidence proving their health-related benefits. SB is a very interesting plant fruiting little berries to which several health-related improvements have been attributed. Not only this, but SB has many applications within the food and feed industry. This review has summarized recent advances in the field. Indeed, SB derived food supplements are already commercialized, probably because of its old habit to be used as a natural medicine against several health problems. More interestingly, due to the well-established health benefits resulting from consuming SB, the addition of SB-derived ingredients to normal food products could serve to turn them into value-added food products. These value-food products, if marketed, would ameliorate the harmful effect of certain consumption patterns on human health. Besides, adding such a valuable ingredient into already marketed food products could open a wide window for product development and could be used by any company as a new spot in the market where to settle.

However, considerations should be taken when addressing the real needs of the consumer market. One of the most interesting opportunities that could be considered is the juice market. In 2015, fruit juice consumption was 9.6 billion liters in the European Union (EU), which translates to 18.9 l per capita. The global consumption of fruit juice and nectar consumption was 38.5 billion liters, with the EU having the greatest consumers, followed by North America (AIJN European Fruit Juice Association 2016). The likely tendency following the growing demands for natural fruit and vegetable juices is to find a spot where to include SB juice as part of a multi-fruit juice. This will exaggeratedly raise the content of vitamin C of the juice and will confer it a very nice strong-orange color (depending on the added amount). A multi-fruit juice is a great product benefiting from SB juice, but there are many other applications within the juice industry. For instance, when developing a long shelf-life fruit juice, it has to undergo elevated temperatures to achieve a microbiologically safe product. This treatment will inevitably damage several compounds naturally retained in the fruit, such as vitamin C. The addition of SB juice would lead to reduced damage on the vitamin C content due to its additional incorporated vitamin C concentration and its derived very high antioxidant activity (Ursache et al. 2017; Guo et al. 2017b ; Papuc et al. 2008). It is important to note that the inclusion of SB juice will also bring a strong astringent taste, which could be difficult to mask. As explained before, strong flavors could help hide this specific astringent taste (Tiitinen et al. 2006b).

The antioxidant activity of SB, together with its antimicrobiological activity (Michel et al. 2012) could be used for product formulation. Many different products have shelf-life problems that SB could help tackle, for instance, a ready-to-eat food product. Sturza et al. (2016) highlighted the significant improvement in the microbiological stability of their studied food product – in that case, bread – when adding an SB-derived ingredient into the food matrix. Besides helping extend its shelf-life due to its natural composition, the SB ingredients would also bring an added value to the products where it is incorporated.

SB contains great amounts of different polyphenols and other compounds which have a demonstrated antimicrobiological effect. The composition and nature of the berry make the use of SB-based ingredients unsuitable for fermented food products. However, as some authors already claimed, SB does not only affect the growth of other beneficial bacteria but also improves it. This promoting benefit of adding SB has been observed in yoghurt (Selvamuthukumaran and Khanum 2015). In addition, it also serves as an instrument to upgrade the phytochemical characteristics and aroma profile of feta cheese if applied as an immobilization carrier for specific strains of *L. casei* (Terpou et al. 2017). It is not clear yet why SB exerts these promoting effects on probiotic bacteria strains. Undoubtedly, it is one of the fields with great potential for SB, since any resulting product would also bear the antioxidant capacity of SB.

The application of SB ingredients is strongly dependent on industry interests and therefore, research in this field would most likely be reliant on industries' new product development programs. These programs also focus on the profitability of the entire process, which becomes strongly dependent on the residue produced. From SB juice production, as in many other berry processing, a major residue is formed, the berry pressed cake. The pressed cake has a great antioxidant capacity and relatively high amounts of phenolic compounds when compared to other common Finnish berries, which makes it a good value-added by-product for its further use within the food industry. It could be either sold as a food ingredient or as a feed ingredient. Either way, it could be seen the potential of SB to be included as a food ingredient, not only for its versatile applicability in many different food products but for the profit its by-products result in.

Sea buckthorn as a feed ingredient

There is an increasing demand worldwide for high protein products. This high demand evokes the high competitiveness of this market, where the overall product quality gains more importance than ever. On top, a high protein product demand inevitably turns into more research focusing on improvements in animal farming productivity.

Besides having several interesting health-benefits derived from its direct consumption, SB has been recently investigated due to its promising potential of improving the performance of animal production when supplemented in the feed (Table 2). As disclosed in the present review, several parameters have been subject to investigation for the performance and health of different animals to achieve better productivity. The most studied animals in terms of animal husbandry which have been subject to supplementation with SB are poultry. This is reasonable, for broilers usually grow to its full potential within a month, making it possible to study the final effect of SB supplementation in a short period.

Most of the published studies investigating broiler productivity remark the positive effect of SB supplementation. Most of the herein presented scientific research showed positive results, yet many others did not find a significant contribution to different evaluated parameters (i.e. final weight) when using SB as a feed ingredient. The observed controversy could be influenced by the type of broiler used to perform the study as well as the type of SB ingredient supplied to them. One the one hand, different species of broilers have different metabolic rates and feed conversion ratios. On the other hand, every SB product has its own profile and its own physiological implications in broilers.

Parts of the positive effects observed on broiler also seem to be true for swine production. SB supplementation could lead to an increased concentration of intramuscular fat, mainly unsaturated fatty acids in pigs (Dannenberger et al. 2018). However, other parameters such as improvement in productivity have only been appreciated in broilers. Swine production needs a longer time span to achieve a full-grown individual, ready to be butchered. In addition, the metabolic rate of swine and boilers differ drastically. The nature of the animal is a critical factor to consider the feeding time, quantity, and concentration of SB to be used.

Another important quality factor for animal products is the color. Different techniques can be used to achieve better color in meat. However, SB has not been used as such, since its color improvement ability is proven to be very limited (i.e. skin pigmentation increased (Ben-Mahmoud et al. 2014)). SB has been used to change colors of animal products strongly dependents of their carotenoid composition. Previously detailed, SB fruit contains significant amounts of carotenoids (Pop et al. 2014). Carotenoids are uniquely produced by plants, bacteria, and fungi and are considered precursors of vitamin A. Carotenoids are responsible for the orange color that can be observed in different fruits and vegetables or even in deciduous trees on specific seasons. Carotenoids can be absorbed by animals and can be stored in the fat tissue due to its lipophilic nature. Orange colors of some animal products are derived from increased carotenoid consumption and from the greater ability to store it. This is the case of eggs. SB supplementation in egg-producing hens influences egg yolk color, deriving in more intense orange color (Dvořák et al. 2017). Egg yolk color is one of the main factors affecting egg overall quality (Roberts 2004). The more intense the color is, the better the quality is perceived by consumers. Most of the studies herein discussed egg quality highlighted the efficiency of using SB as a feed ingredient for egg-producing hens when evaluating egg yolk color. Carotenoids from SB are principally found in the oily part of the pulp – although some can be found in the peel. Therefore, the use of SB pulp oil on the development of feeding ingredients for egg-producing hens is a newly explored field to increase egg quality.

Additionally, other orange-colored animal products could also benefit from the use of SB pulp oil. Salmon flesh quality benefits from carotenoid concentration. Flesh color is the most important attribute by consumers when buying the captive salmonid (Scientific Committee on Animal Nutrition 2002). Salvage salmon gets its orange color from ingesting krill and other shell-fish retaining carotenoids. On the contrary, farmed salmon does not have this advantage. It is thus important to incorporate carotenoids in captive salmon's feed to obtain an approximate quality. To the best of our knowledge, no study has been conducted to evaluate the possible incorporation of SB pulp oil (or a carotenoid extract) to salmon's feed to achieve a stronger orange color.

Salmon flesh and egg yolk color are two highly commercialized food products that could benefit from SB addition as an ingredient. Usually, the feed used in the egg and salmon industries is efficient because they bear acceptable concentrations of carotenoids. These carotenoids can be used gently at a low cost. However, the addition of these compounds is continuously evaluated due to the awareness of their sourcing and stability. For instance, canthaxanthin has been widely used for this purpose and has been strictly evaluated because of that, resulting in different limitations (European Food Safety Authority 2014). The use of SB would be a natural and effective alternative to help improve the color of the aforementioned animal colors.

SB supplementation in fish farming has been recently used for other purposes as well. Recent studies have demonstrated that SB could be included as a feed supplement to improve the overall health in Nile tilapia (Antache et al. 2013) and to possibly improve growth performance in sturgeons (Dorojan et al. 2015). However, it should be noticed that studies investigating this improvement in productivity are scarce. Results coming from this usage in fish farming should be further studied to evaluate their significance. Nevertheless, when it comes to fish farming, the most interesting field of study is salmon rearing, because of the already discussed reasoning.

Conclusion

The shift towards healthy food and life habits among consumers is now a reality. Consumers constantly look for healthy products in the market, and most recently to what is commonly designed to as "superfoods". Superfoods are those food products that have a very high concentration of one or more bioactive compounds to which certain health benefits have been attributed. This is the case of SB. Even though it is narrowly produced – and consumed – in specific geographical areas, where it has been used for a long time. SB has an enormous exploitability within the food industry. There have been different applications of SB in food product development (e.g. SB-based yoghurt) whereas others are new ways of innovation. Specific bioactive compounds (e.g. carotenoids and egg yolk color) are advantages of SB application in food industry. Either way, its impressive phytochemical profile makes it suitable for applications such as those discussed herein and many others still unexplored. Thus, the use of SB in the food industry is highly encouraged and should be widely exploited.

Abbreviations

SB: Sea buckthorn; WHO: World Health Organisation; FAO: Food and Agriculture Organisation of the United Nations; ω-7: Omega-7 fatty acid; ω-6: Omega-6 fatty acid; ω-3: Omega-3 fatty acid; AIJN: European Fruit Juice Association; MRS: Man-Rogosa-Sharpe culturing medium; CFU: Colony Forming Units; GAE: Gallic Acid Equivalents

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