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Vine tea (*Ampelopsis grossedentata*): A review of chemical composition, functional properties, and potential food applications

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ABSTRACT

Herbal teas like vine tea (*Ampelopsis grossedentata*) have been traditionally consumed worldwide because of their health-promotion and pleasant taste. Vine tea and its main bioactive component, dihydromyricetin, have gained attention because of their potential applications in food, material, and pharmaceutical sciences. Vine tea and dihydromyricetin have been suggested as potential natural antioxidants to extend shelf life of foods. Studies have also suggested potential application in packaging and food safety. Additionally, dietary supplementation with vine tea extract have shown great potential to prevent metabolic diseases, which can justify its application in novel functional foods. This review discusses the chemistry, functional properties, and potential applications of vine tea and dihydromyricetin in the food industry. Although vine tea extracts and dihydromyricetin have shown promising results, further studies on optimal application, thermal stability, synergetic effect with other natural antioxidants, consumer acceptability, and sensory profile of vine tea are needed to support food product innovation.

1. Introduction

Vine tea (*Ampelopsis grossedentata* Hand.-Mazz.), also known as "Teng Cha", "Tocha", "Rattan tea", "Duan Wu Cha", "Mao Yan Mei" or "Moyeam", is a healthy herbal tea, rich in the natural antioxidant dihydromyricetin (DHM) or ampelopsin, and whose dried leaves and stems have been a significant plant resource in medicinal food research (Fig. 1) (Fang, Wang, & Tang, 2011; Gao et al., 2009; Kou & Chen, 2012; Ye, Wang, Duncan, Eigel, & O'Keefe, 2015; Zhao, Deng, Chen, & Li, 2013; Zheng et al., 2014). DHM extracted from vine tea has been shown to have significant anti-inflammatory properties *in vitro* and *in vivo*, and it has been recommended as a potential therapeutic agent for inflammatory-related diseases (Chen et al., 2015; Qi et al., 2012). Other pharmacological properties that have been associated to vine tea and its major component DHM were reviewed by Kou & Chen (2012), who cite reports of anti-bacterial, anti-hypertension, and neuroprotective effects, regulation of plasma lipids and blood glucose, hepatoprotective function, and anti-tumor activity.

Although vine tea consumption is still not very popular in Western countries, the number of researchers studying vine tea chemical components, health-promoting attributes, and functional properties has been increasing significantly in recent years worldwide. Vine tea supplementation was recently suggested as a potential alternative to prevent metabolic diseases related to high-fat diets, such as non-alcoholic fatty liver disease (NAFLD) (Fan et al., 2020; Tong et al., 2020; Xie, He, Chen, Sakao, & Hou, 2020). In mice fed for 12 weeks with a western-diet characterized by high sugar, fat, and cholesterol contents, Xie et al. (2020) reported that supplementation with 1–2% vine tea extract (VTE) led to significant decrease of body, liver, and epididymal fat weights, as well as significant reduction of hepatic lipids content and the serum levels of insulin and two common biomarkers for liver damage: alanine transaminase and aspartate transaminase. In China, vine tea is commonly sold in boxes of single serving tea bags, but consumers also have the choice to consume it through dietary supplements and more innovative functional products, such as fruit flavored jelly (Ye et al., 2015; Zhang, 2002; Zhang, Zhang, & Zhang, 2004). In the U.S., DHM supplement is marketed to prevent alcohol hangover (Fan et al., 2018). The proven health benefits associated with vine tea and DHM intake suggest their potential application in novel functional food products that can also be attractive to consumers in Western countries. VTEs and DHM have already been suggested to improve shelf-life and quality of food products such as edible oils, meat products, and breads (Baek, Neilson,

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Fig. 1. Dried leaves and stems of commercial vine tea (*Ampelopsis grossedentata*).
Source: Carneiro (2016)

Eigel, & O'Keefe, 2015; Ma et al. (2020); Ye et al., 2015; Zhang, Xu, Xue, Jiang, & Liu, 2019). Nevertheless, sensory and consumer studies are lacking, as well as application studies focused in other types of foods, such as snacks and dairy products, which can also be high in fat and sugar contents. The objective of this review is to discuss available information on vine tea's chemical constituents, functional properties, and potential applications in the food industry.

2. Chemical components in vine tea

2.1. Polyphenols

Although rich in nutrients, vine tea is well known for its medicinal aspects, which are related to the secondary metabolites such as polyphenols. In recent studies, the total phenolic content (TPC) of vine tea extracts was estimated by following the Folin–Ciocalteu method (Baek et al., 2015; Xie et al., 2019; Ye et al., 2015; Ying, Xu, Huang, & Wang, 2011) or a modified ferrous tartrate colorimetry method (Jia et al., 2021). TPC of a freeze-dried vine tea extract (VTE) obtained through ethanol extraction process (vine tea: commercial dried leaves and stems of *A. grossedentata*; solvent: 74% (v/v) aqueous ethanol; extraction conditions: 65 °C for 30 min; ethanol was evaporated (60 °C) from extract, then residue was frozen and freeze dried (−50 °C for 3 days); yield: 3.49 g extract (yellow powder)/10 g dried vine tea) was reported as 649 mg GAE/g (milligram of gallic acid equivalents (GAE) per gram) (Ye et al., 2015). Baek et al. (2015), who followed similar extraction method, reported their vine tea extract had a much lower TPC (310 mg GAE/g) and the TPC of green tea (*Camellia sinensis*) and grape seed extracts were 180 mg GAE/g and 380 mg GAE/g, respectively. Jia et al. (2021) recently reported TPC of extracts from young vine tea leaves as 444 mg GAE/g for green leaves and 446 mg GAE/g for red leaves; the researchers used 70% ethanol as solvent and an ultrasonic extraction procedure (30 min, room temperature), which was followed by filtration, evaporation of the solvent, and lyophilization. As a matter of comparison, TPC content of ethanol extracts from other tea or herbal tea ingredients were reported as following: green tea 144.52 ± 5.36 mg GAE/g tea, mate tea (*Ilex paraguariensis*) 66.86 ± 0.66 mg GAE/g tea, persimmon leaf tea (*Diospyros kaki*) 46.42 ± 0.95 mg GAE/g tea, and rosemary tea (*Rosmarinus officinalis*) 39.44 ± 0.92 mg GAE/g tea (Oh, Jo, Reum Cho, Kim, & Han, 2013). Despite of the wide TPC range reported in the literature, it is clear that vine tea polyphenol composition is extraordinarily high in comparison to other "healthy" tea ingredients.

The polyphenolic content of VTEs can be affected by extraction conditions, such as solvent type and concentration, and the extraction time and temperature (Xie et al., 2019). VTEs obtained through extraction with distilled water had significantly lower polyphenol content than extracts obtained through the use of organic solvents (acetone, ethanol, ethyl acetate, and methanol) (Xie et al., 2019). For all extracts, the vine tea (grinded and sifted (0.60 mm sifter) dried leaves and stems of *A. grossedentata*) to solvent ratio was 1:5. Glass tubes used for extraction had a condenser pipe connected and were placed in a thermostatic water bath (15 ℃) in a fume hood. Extracts were filtrated (0.45 μm organic filter), concentrated (rotary evaporator), purified (nonionic polystyrene-divinylbenzene resin), and freeze-dried for three days before analysis. In addition, the authors suggested the following conditions for an optimal phenolic extraction (highest yield) from vine tea: use of 70% (v/v) aqueous ethanol as solvent and extraction (ultrasonic treatment) at 70 ℃ for 40 min (power of the ultrasonic device was not reported).

Among the polyphenolic compounds, several flavonoids can be found in vine tea. The total flavonoid content of four *A. grossedentata* plant parts were recently reported as following: tender tip leaves 791.51 ± 20.79 mg/g, young green leaves 776.56 ± 23.95 mg/g, old green leaves 645.53 ± 16.21 mg/g, and unripened fruits 582.60 ± 23.43 mg/g (Jia et al., 2020). Also, green young leaves

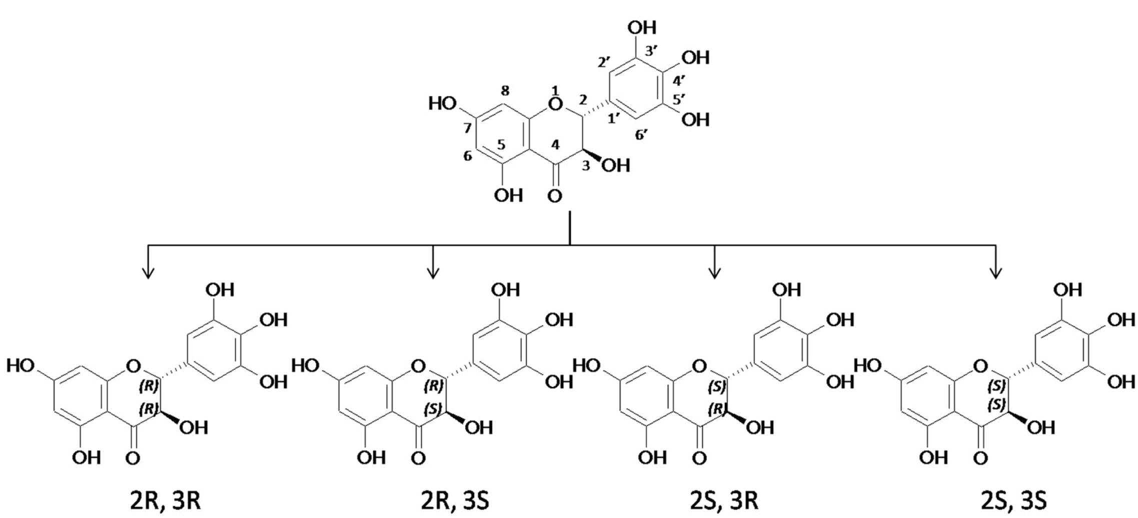

Fig. 2. Chemical structure of dihydromyricetin (ampelopsin) and four enantiomer.
Adapted from Wang et al. (2016).

contained significant more flavonoids than old green leaves and both young and old red leaves (Jia et al., 2021). The flavonoid compounds that have been identified in VTE includes apigenin, dihydromyricetin, dihydroquercetin, 3-dihydroxyquercetin, hesperitin, *iso*-dihydromyricetin, kaempferol, kaempferol-3-*O*-*α*-L-rhamnoside, luteolin, myricetin, myricetin-3-*O*-*β*-D-glucoside, myricitrin, phloretin, phloridzin, quercetin, quercetin-3-*O*-*α*-L-rhamnoside, quercetin-3-*O*-*β*-D-xyloside quercitrin, rutin, and vitexin (Gao et al., 2017; Ying et al., 2011). However, the major flavonoid component present in vine tea is dihydromyricetin (DHM), (2R,3R)-3,5,7-trihydroxy-2-(3,4,5-trihydroxyphenyl)-2,3-dihydrochromen-4-one, also known as ampelopsin (Ye et al., 2015; Zheng et al., 2014). DHM's chemical structure (molecular formula $C_{15}H_{12}O_8$; molar mass 320.25 g/mol) is presented in Fig. 2 and this important flavonoid is further discussed in the section 2.2.

In addition to the group of flavonoids, four isoflavones were isolated from methanol extract of vine tea (whole plants of *A. grossedentata*): 6,7-dihydroxy-3′-methoxy-4′,5′-methylenedioxy-isoflavone; 6,7-dihydroxy-3′-methoxy-4′,5′-methylenedioxyisoflavone 6-*O*-β-D-glucopyranoside; 6,7-dihydroxy-3′-methoxy-4′,5′-methylenedioxyisoflavone 6-*O*-α-L-rhamnopyranoside; and 6,7-dihydroxy-3′-methoxy-4′,5′-methylenedioxyisoflavone 6-*O*-β-D-xylopyranosyl-(1–6)-β-D-glucopyranoside (Wang, Zheng, Xu, & Zheng, 2002). The authors reported that vine tea material (1.5 kg, crushed, 20–30 mesh) was extracted with boiling methanol (three times), filtered, and concentrated.

Two flavonoid glycosides were obtained from aqueous extract of vine tea leaves (200 g of leaves were extracted two times with 1.5 L of hot water (60 ℃) then concentrated to 500 mL. Concentrated solution was extracted with chloroform then lyophilized) and the use of high-speed counter-current chromatograph (HSCCC) performed with a two-phase solvent system (*n*-hexane–ethyl acetate–methanol–water, 1:6:1.5:7.5, v/v): 5,7-dihydroxy-3′,4′-trihydroxyflavone-3-*O*-6″-rhamnose, and 5,7-dihydroxy-3′,4′-dihydroxyflavone-3-*O*-6″-rhamnose (Du, Chen, Jerz, & Winterhalter, 2004). Recently, the total content of anthocyanins was measured in extracts of different vine tea tissues (tender tip leaves, young green leaves, old green leaves, and unripened fruits of *A. grossedentata*). Tender tip leaves presented the lowest amount of anthocyanins (22.53 ± 3.04 mg/g) while unripened fruits presented the highest content (102.69 ± 6.40 mg/g (Jia et al., 2020).

Furthermore, vine tea can be naturally fermented in a similar manner to *Camellia sinensis*, and during the fermentation process, the rolling and crushing of the leaves and stems allows the oxidative enzymes polyphenol oxidase and peroxidase to react with the phenolic compounds, which may change the flavonoid composition (Zheng et al., 2014). For instance, besides DHM and myricetin, three other flavonoids were identified in naturally fermented vine tea: 3-dihydroxyquercetin, *iso*-dihydromyricetin, and myricetin-3-rahmnose (Zheng et al., 2014).

2.2. Dihydromyricetin (DHM)

DHM is the main bioactive component in vine tea and multiple review publications (Kou & Chen, 2012; Li et al., 2017; Liu, Mao, Ding, & Zeng, 2019; Tong et al., 2020) have already discussed the potential health benefits of this flavonoid, such as antioxidant, anti-cancer (e.g., inhibition of apoptosis, regulation of proliferation, metastatic inhibition), anti-inflammatory, anti-hypertension, hepatoprotective, and neuroprotective activities, as well as its promising use to prevent or treat metabolic diseases, such as NAFLD, diabetes mellitus, atherosclerosis, and osteoporosis. In a recent study *in vitro*, Fan et al. (2018) reported that DHM can alter the composition of the gut microbiota, but the flavonoid could be metabolized by it. Additionally, DHM was reported to improve physical performance under simulated high altitude, so its use may possibly avoid exercise intolerance and altitude-related illnesses caused by hypobaric hypoxia (Zou et al., 2014).

In order to determine DHM content in vine tea samples, several researchers reported the use of high-performance liquid chromatography (HPLC) as their method of choice (Baek et al., 2015; Gao et al., 2009; Muhammad et al., 2017; Ye et al., 2015). Nevertheless, thin-layer chromatography (TLC), high-performance counter current chromatography (HPCCC), and high-speed counter current chromatography (HSCCC) are examples of other chromatographic techniques that can also be used for this purpose (Liu et al., 2019). DHM content in vine tea was reportedly 22.6% (w/w) (Ye et al., 2015) and 26.2% (w/w) (Baek et al., 2015), both on a dry weight basis. Ye et al. and Baek et al. (2015) also reported the DHM content in their dry vine tea extracts as 64.7% (w/w) and 69.3 (w/w), respectively. In a previous study, Gao et al. (2009) reported DHM content as 32.96 ± 1.18% in vine tea leaves and higher than 75% in two different products (A and B) extracted from its leaves. Researchers obtained product A through ethanol extraction process (10 g tea leaves/ 250 mL of solvent; water bath was set at 80 ℃ for 5 h; extract was filtered and filtrate was concentrated (45 ℃) under vacuum, then freeze-died (process conditions not reported) and reported its DHM content as 77.15 ± 1.98%. Product B was obtained through hot water extraction process and its DHM content was 95.12 ± 2.86%.

Even though vine tea leaves contain relatively high amounts of DHM, it can be challenging to obtain high purity DHM from them (Gao et al., 2009). Due to its good solubility in organic solvents such as ethanol, DHM is commonly extracted in laboratory by Soxhlet extraction, then recrystallized (Hu, Luo, Wang, Fu, & Shu, 2020). For extraction with hot deionized water, Hu et al. (2020) reported that a new chelation extraction process that includes the addition of Zn^{2+} to form a DHM-Zn complex improved DHM yield, reduced quinone impurities, and demanded less time when compared to a traditional batch extraction method. In previous report, high purity DHM (over 99% pure; HPLC at 254 nm) was obtained from dried leaves of vine tea using a high-speed counter current chromatograph equipped with three scale-up columns for purification (two-phase solvent system: *n*-hexane-ethyl acetate-methanol-water, 1:3:2:4 v/v) (Du, Cai, Xia, & Ito, 2002). However, HSCCC is not a simple process for industrial use, so Gao et al. (2009) suggested recrystallizing DHM from water five times as a simpler process to produce DHM at approximately 95% purity. Microwave multi-stage countercurrent extraction was also suggested as another alternative method in terms of cost and efficiency for extracting DHM from vine tea leaves (Du et al., 2004). This method was reported to be 20–30% more efficient than microwave static batch extraction under similar conditions (Li et al., 2007).

2.3. Fatty acids

Fatty acids constitute another group of important chemical components present in vine tea (Fan, Chen, Chen, & Suo, 2014); they add nutritional value and contribute to aroma formation. Thirty-one free fatty acids (FFA) were investigated in vine tea and the major fatty acids detected were 16:0 (palmitic, hexadecanoic acid), 18:0 (stearic, octadecanoic acid), 18:2ω6 (linoleic acid), 18:3ω3, ω6 (α-linolenic acid), and 20:4ω6 (arachidonic acid). Arachidonic acid was reported at an average of 4.3–4.4%, and was possibly misidentified. Arachidonic has not been identified in higher plants as the biosynthetic pathways do not exist. Linoleic acid was reported as the primary unsaturated fatty acid (PUFA), and octadecanoic acid was identified as the primary saturated fatty acid (SFA) in vine tea (Fan et al., 2014). Fatty acid content can be affected by vine tea harvest time (April, July or September) (Fan et al., 2014), which suggests vine tea aroma may be similarly affected by harvest.

2.4. Flavor chemistry

Flavor profile contributes to consumer acceptability of herbal teas and characteristic flavors, such as "robust", "refreshing", and "tea-like", are known to be greatly desired in high quality herbal teas (Lasekan & Lasekan, 2012). Besides harvest conditions, processing parameters can also influence tea flavors and aromas (Cheetham, 2002). Vine tea can be processed similarly to green tea; tender stems and leaves are plucked and immediately pan-fired to inhibit the activity of oxidative enzymes

Table 1
Potential applications of vine tea (*Ampelopsis grossedentata*) and dihydromyricetin in the food industry.

Potential Application	Main Features	References
Food safety – Antibacterial activity	• Dihydromyricetin (DHM) had inhibitory effect on *Vibrio parahaemolyticus*. DHM increased cell injury, cell membrane permeability, and cell surface hydrophobicity.	Liu et al. (2016)
	• DHM interacted with *Staphylococcus aureus* DNA through the groove binding mode. It presented bactericidal activity by damaging cell membrane and binding to intracellular DNA.	Wu et al. (2017)
	• DHM extracted from vine tea leaves showed antibacterial activity against *Bacillus subtilis, Escherichia coli, Pseudomonas aeruginosa, Salmonella paratyphi,* and *Staphylococcus aureus.*	Xiao et al. (2019)
Food preservation - Antioxidant	• Vine tea extract (VTE) delayed oxidation of menhaden fish oil when stored at 40 °C for eight days.	Baek et al. (2015)
	• VTE reduced lipid oxidation in soybean oil and cooked ground beef. DHM inhibited oxidative degradation of soybean oil more effectively than BHA.	Ye et al. (2015)
	• DHM reduced the formation of heterocyclic aromatic amines (HAAs) in fried ground beef patties.	Zhou et al. (2017)
	• Fortification with DHM reduced lipid and protein oxidation in chia oil cookies and the formation of toxicants (advanced glycation end products (AGEs), malonaldehyde, protein carbonyls, and carboxymethyl lysine)	Teng et al. (2018)
	• VTE increased shelf life of mixed pork patties by reducing lipid and protein oxidation during refrigerated storage.	Zhang et al. (2019)
	• VTEs were more effective antioxidants than BHT in canola and sunflower oils.	Jia et al. (2020)
	• VTE and DHM significantly inhibited the formation of acrylamide (probable human carcinogen) in bread without affecting consumer acceptability.	Ma et al. (2020)
	• VTE obtained from green leaves had stronger antioxidant effect in rapeseed and sunflower oil than VTE from red leaves. VTEs had antioxidant capacity equal or superior than BHT.	Jia et al. (2021)
Packaging – Antioxidant/ Polymer stabilization	• DHM extracted from vine tea was a more efficient thermal antioxidant than Irganox 1010. It improved thermo-oxidative stability of several polymers: polypropylene (PP), low-density polyethylene (LLDPE), high density polyethylene (HDPE), thylene vinyl acetate copolymer (EVA), polystyrene (PS), natural rubber, and nitrile butadiene rubber.	Zheng et al. (2010)
	• The ortho-trihydroxyl group (B ring) in DHM and hydroxyl group of 7-position (A ring) displayed reversibility to acidic or alkaline medium and also affected the antioxidative ability of EVA.	Xin et al. (2013b)
	• DHM improved PP thermo-oxidative stability. Two DHM antioxidant mechanisms were proposed: 1) center hydrogen atom is donated; 2) two side hydrogen atoms are donated.	Xin et al. (2015)
	• The number of hydroxyl groups affects DHM antioxidative efficiency. DHM extracted from vine tea stabilized linear LLDPE without discoloration of the polymer.	Xin et al. (2013a)
	• DHM was an efficient polyethylene (PE) melt stabilizer at low concentration, but affected PE color.	Kirschweng et al. (2016)

(Wan, Jiang, Sun, Xu, & Xiao, 2017). Leaves can also be submitted to natural fermentation (Zheng et al., 2014), which opens the door to a wide variety of flavor profiles in a similar manner to green, oolong, and black teas. Nevertheless, there is still little information available on vine tea processing and further studies are suggested to understand the impact of processing parameters in vine tea quality.

Even though volatile components are of great importance to the quality of herbal teas, only one exploratory study has provided information about flavor chemistry of vine tea infusions (Carneiro, Wang, Duncan, & O'Keefe, 2020). Twenty-one volatile components were identified in vine tea infusions brewed from commercial samples and the list of volatile compounds included aldehydes, ketones, and alcohol. As discussed by the authors, some aldehydes such as hexanal, (E,E)-2,4-heptadienal, and nonanal were previously reported in camellia teas (e.g., black, green, and oolong teas). Further studies are needed to understand the importance of each volatile compound to the overall flavor profile of vine tea, as well as to understand possible variabilities originated, for example, from differences in genotype, production area (location), and processing conditions. In addition, vine tea infusions (prepared with boiling distilled water, pH = 7) were described as dark, reddish-yellow color and had pH ~ 4.3 (Carneiro et al., 2020). Likewise, acidic pH values were also reported for black tea infusions (pH ~ 4.9; infusions prepared with boiling distilled water) (Liang & Xu, 2001). Aroma, color, freshness, and strength are important tea quality attributes; tea odor and aroma result from volatile compounds, whereas color and taste are mostly a consequence of phenolic compounds (Yang, Baldermann, & Watanabe, 2013). Further studies can help understand which major components contribute to vine tea color and acidic characteristics, which may restrict VTE use in food applications.

Terpenoids were also reported among flavor compounds present in vine tea. Terpenoids contribute to flavor characteristics of several herbs and spices, such as peppermint and cinnamon (Lasekan & Lasekan, 2012). In vine tea, six limonoids were isolated from the ethyl acetate fraction obtained by partition of the methanol extract of vine tea: methyl deacetylnomilinate, nomilin, rutaevin, rutaevin acetate, rutaevin-7-*O*-caffeate, and rutaevin-7-*O*-gallatenomilin (Wang, Liu, Lu & Zheng, 1999). An important aspect of limonoids is they are chemical compounds of moderate polarity and typically bitter in taste (Roy & Saraf, 2006). Limonoids (highly oxygenated, modified terpenoids, insoluble in water) were first isolated from oranges and limonin is an example of limonoid associated with bitterness in citrus fruits. According to Roy & Saraf (2006), researchers have given attention to these compounds due to their potential biological activities, which includes insecticidal, antibacterial, antifungal, antiviral, and pharmacological effects.

3. Potential applications of vine tea and dihydromyricetin (DHM) in the food industry

The application of natural antioxidants from under-exploited plant species or food by-products is economically relevant to the food industry (Lourenço, Moldão-Martins, & Alves, 2019). In the last decade, the

Table 2
Applications of vine tea extracts and dihydromyricetin in food products.

Treatment*	Dosage(s) tested	Food Matrix	Reference
DHM	200 ppm	Soybean oil, cooked ground beef	Ye et al. (2015)
VTE	200 ppm		
DHM + BHA	200 ppm each	Soybean oil	
VTE	200 ppm, 500 ppm, and 1000 ppm	Menhaden fish oil	Baek et al. (2015)
VTE + Rosemary Extract (RME)	200 or 500 ppm VTE + 1000 or 2000 ppm RME		
VTE + Ascorbyl Palmitate (AP) and Citric Acid (CA)	500 or 1000 ppm VTE + 200 ppm AP + 100 ppm CA		
DHM	0.05%, 0.1%, and 0.2%	Fried ground beef patties	Zhou et al. (2017)
DHM	0.25% w/w	Chia oil cookie	Teng et al. (2018)
VTE	0.1% and 0.3%	Cooked mixed pork patties	Zhang et al. (2019)
VTEs	0.02%	Canola and sunflower oils	Jia et al. (2020)
DHM	9.97 or 19.94 mg/kg flour	Bread	Ma et al. (2020)
VTE	1.25 or 2.5 g/kg flour		
VTEs	200 ppm	Rapeseed and sunflower oils	Jia et al. (2021)

*DHM = dihydromyricetin; VTE = Vine tea extract.

antioxidant properties of vine tea and its main flavonoid dihydromyricetin (DHM) have been objective of several studies associated with food science, including food preservation, food safety, and packaging approaches (Table 1).

3.1. Increasing shelf life and adding value to novel food products

Increasing food shelf life by reducing oxidative deterioration is of great value to the food industry, and the replacement of synthetic antioxidants such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and tertiary butylhydroquinone (TBHQ) by natural antioxidants attends consumer's increasing desire for clean labels (Baek et al., 2015; Lourenço et al., 2019). Green tea and rosemary extracts are examples of natural extracts already in use as antioxidants in food products, but cost, stability, and availability can justify the continuous search for novel natural sources (Lourenço et al., 2019). Edible oils and meat products have been popular food matrix choices to investigate the application of natural antioxidants from different plant sources (e.g., extracts from rosemary, hyssop, chitosan, mint, hard winter wheat, and *Ginkgo biloba* leaves), but the potential application of natural antioxidants in baked goods (e.g. bread and biscuit) and dairy products (e.g., cottage-cheese and yogurt) have also been reported (Lourenço et al., 2019). Likewise, the potential use of vine tea extract (VTE) and DHM was investigated in several food products (Table 2).

Recent studies investigated vine tea and DHM application to preserve the quality of meat products and edible oils (Baek et al., 2015; Jia et al., 2021, 2020; Ye et al., 2015; Zhang et al., 2019; Zhou et al., 2017). The antioxidant activities of pure DHM and VTE (64% w/w DHM) were compared with the synthetic antioxidant BHA in cooked ground beef, as well as in soybean oil (Ye et al., 2015). After 14 days, VTE, DHM, and BHA (200 ppm) had similar antioxidant effects in cooked ground beef stored at 60 ℃. DHM was more efficient than BHA in inhibiting soybean oil oxidation, but VTE was not successfully able to inhibit the formation of secondary oxidation products. The researchers also tested the combination DHM + BHA (200 ppm each) in soybean oil and it showed better antioxidant effect (higher headspace oxygen content and lower peroxide and anisidine values) than only BHA (200 ppm). In addition, Zhou et al. (2017) reported that DHM (0.05%, 0.1%, and 0.2%) reduced the formation of heterocyclic aromatic amines (2-amino-1-methyl-6-phenylimidazo[4,5-*b*]pyridine (PhIP) and 2-amino-3,8-dimethylimidazo[4,5-*f*]-quinoxaline (MeIQx)) in ground beef patties (60 g, 9 cm inner diameter) that were fried for 6 min at 210 ℃ (3 min each side). The study of Zhang et al. (2019) confirmed the positive antioxidant effect of VTE in another meat product: cooked mixed pork patties. Samples were packed in oxygen-permeable bags and stored for 8 days under refrigeration (4 ± 1 °C). Although VTE (0.1% and 0.3%) affected the color of the pork patties (significant lower L*, a*, b* values; Hunter color scale), the authors suggested it can be applied to extend shelf life of meat products as it inhibited both lipid and protein oxidation in the patties without affecting consumer overall acceptability. The authors also reported that samples treated with VTE had lower hardness and higher texture acceptability scores (5-point scale; 1 = "bad" and 5 = "great").

Oxidation of menhaden fish oil stored at 40 ℃ for eight days was also effectively delayed by VTE (200 ppm, 500 ppm and 1000 ppm) (Baek et al., 2015). DHM-rich extract from vine tea (69.3% w/w DHM) improved stability of tocopherol stabilized menhaden fish oil, especially when used combined with rosemary extract, which suggests a potential synergistic effect. The most effective combination of the two extracts was attributed to 500 ppm of VTE and 2000 ppm of rosemary extract (primary and secondary oxidation products were measured). Menhaden fish oil treated with this mixture had the lowest peroxide value (10.7 ± 1.3 meq/kg), lower anisidine value (11.2 ± 1.3), and higher headspace oxygen content (14.5 ± 0.03%) after storage (8 days at 40 ℃). Combinations of multiple natural antioxidants may reduce formulation cost of novel food products and may impact product flavor and other organoleptic properties. Thus, future studies and optimization models are recommended to better understand synergetic antioxidant activity between vine tea extracts and other natural antioxidants.

In canola and sunflower oils, vine tea leaf extracts were more effective antioxidants than BHT, which antioxidant activity was similar to vine tea fruit extract (lower flavonoid content than leaf extracts; fruits of *A. grossedentata* are not commonly utilized for tea purpose) (Jia et al., 2020). Further study confirmed the antioxidant effects of different VTEs in rapeseed and sunflower oils (Jia et al., 2021). As red leaves of vine tea are often considered waste, Jia et al. (2021) investigated the antioxidant properties of VTEs obtained from young and old leaves of both green and red colors. Overall, extracts from younger leaves were better in preventing oil oxidation than the ones from older leaves. Also, extracts from green leaves (higher flavonoids content) showed stronger antioxidant properties than extracts from red leaves (higher anthocyanin content) in both oils. However, extracts from red leaves performed similarly to BHT, which shows potential economic value.

Few studies investigated the application of vine tea and DHM in baked goods (Ma et al., 2020; Teng et al., 2018). The thermal stability, antioxidant capacity, and impact on toxicant formation of DHM and other three flavonoids (hesperetin, naringenin, and naringin) were investigated in cookies formulated with chia oil (Teng et al., 2018). Thus, among the four flavonoids, DHM was recommended as the most promising functional additive. In breads, additions of VTE (1.25 or 2.5 g/kg flour) or DHM (9.97 or 19.94 mg/kg flour) did not have a significant effect moisture content (Ma et al., 2020). However, both VTE and DHM additions affected texture profile and led to significant reductions of chewiness, gumminess, and hardness. Thus, further studies were recommended to better understand how VTE and DHM may affect gluten formation and development. The use of VTE did not significantly affect consumer acceptability of bread, even though it significantly affected appearance (color), aroma, and taste of the product. Additionally, Ma et al. (2020) reported VTE and DHM significantly reduced the formation of acrylamide (potential carcinogen) in bread and VTE application was suggested for future development of healthy bread products. The potential use of VTE and DHM in other high-fat foods, such as snacks and dairy products, still need further research as no reports that investigated these food matrices were found.

In fruit preservation, DHM has shown an antibrowning effect in fresh-cut Fuji apple slices (Liang, Wu, Qiu, Zhong, & Gao, 2014).

Researchers used DHM isolated from the pine needles of *Cedrus deodara* and their results showed that DHM (0.05%, 500 ppm) was effective in inhibiting undesired browning of fresh-cut Fuji apple slices (5 mm thick), which were dipped for 5 min in 15 mL of tested solutions, then drained and stored in vitreous petri dishes (25 °C for 24 h). In addition, DHM antibrowning effects were synergistic with ascorbic acid and better than ascorbic acid alone at 0.05% (Liang et al., 2014). The impact of DHM in the sensory characteristics of the product (e.g., flavor, taste and texture - firmness) were not investigated, and future sensory and toxicological evaluations of DHM were recommended. Undesired color changes are also a common problem in thermally processed fruits, which can be packed with syrup and are included in the Meals Ready-to-Eat (MRE) program of the U.S. Army (Maldonado et al., 2015). Preserving the quality of these processed fruit products is desired to assure, for example, that soldiers will be provided with foods that deliver necessary nutrients and are also sensory appealing. Potential application of vine tea extracts and DHM to enhance quality and improve shelf-life of processed fruits are yet to be studied.

3.2. Improving food safety

Several camellia and herbal tea extracts, such as green tea, rosemary and mate teas, have demonstrated antimicrobial activity and their possible application as natural antimicrobial preservatives has been suggested (Oh et al., 2013). Ethanol extracts of green tea (solvent: ethanol 90% (v/v)), for example, inhibited the growth of five pathogens: *Streptococcus mutans*, *Streptococcus sobrinus*, *Listeria monocytogenes*, *Shigella flexneri*, and *Salmonella enterica* (minimum lethal concentration (MLC) of 10 mg/mL for all). Ethanol extracts of rosemary tea and mate tea also inhibited the growth of *S. mutans*, *S. sobrinus*, and *L. monocytogenes* (MLC = 10 mg/mL). Although the inhibitory activity of vine tea extracts against these and other pathogens still requires further investigation, DHM has shown anti-bacterial properties that can be of great value for food safety purposes. In fact, Kou & Chen (2012) stated in their review article that *Staphylococcus aureus* and *Bacillus subtilis* can be strongly inhibited by DHM extracts, but more information regarding MLC and extract preparation were not presented.

Three recent studies investigated DHM application for the control of foodborne diseases (Table 1). Bacterial cells of *Vibrio parahaemolyticus* (a foodborne pathogen typically found in seawater) were treated with DHM solutions (DHM purity ≥ 98% diluted in 50% ethanol); an inhibitory effect on the growth of *V. parahaemolyticus* (24 h at 37°C) was observed with a minimum inhibitory concentration (MIC) of 0.625 mg/mL (~625 ppm) (Liu, Pang, Ding, & Sun, 2016). DHM reportedly increases cell membrane permeability, resulting in cell injury as well as changing cell surface hydrophobicity, suggesting DHM could have value as a natural antibacterial agent for control of pathogen growth in aquatic/seafoods. A MIC of 0.125 mg/mL was reported for DHM against *Staphylococcus aureus* (Wu, Bai, Zhong, Huang, & Gao, 2017). DHM (HPLC purity ≥ 98%) was obtained from pine needles of *Cedrus deodora* and diluted with nutrient broth. According to the authors, DHM damaged the cytoplasmic membrane of *S. aureus*, causing the leakage of nucleotide with a loss of membrane integrity and a significant membrane hyperpolarization. DHM interaction with the lipids and proteins of *S. aureus* membranes was evidenced by the decrease of membrane fluidity and quenching of the fluorescence intensity of the phenylalanine residue in membrane protein (Wu et al., 2017). Xiao et al. (2019) confirmed the antibacterial activity of DHM against *S. aureus* (MIC = 0.625 mg/mL) and reported its inhibitory effect on other four foodborne bacteria: *Bacillus subtilis* (MIC = 1.25 mg/mL), *Escherichia coli* (MIC = 0.3125 mg/ mL), *Pseudomonas aeruginosa* (MIC = 0.3125 mg/mL), and *Salmonella paratyphi* (MIC = 0.625 mg/mL). For *S. aureus* and *E.coli*, researchers also reported that DHM antibacterial activities increased with pH < 7, but decreased with higher temperature, longer heating time, and higher concentrations of Ca^{2+}.

The antibacterial properties of DHM were also investigated in medical materials; the potential use of nanocapsule formulations containing DHM has been suggested as an innovative approach to urinary catheter biofilm treatment or prevention of biofim caused by *Pseudomonas aeruginosa* (Dalcin et al., 2017). Free DHM and DHM-loaded nanocapsules showed antimicrobial activity against *P. aeruginosa* (MIC = 2.27 mg/mL, both), but the population was not eliminated completely. In 96 h of treatment, DHM-loaded nanocapsules (concentration: 1 mg/mL) showed higher reduction of the biofilm population in urinary catheters (67%, versus 41% observed for free DHM).

3.3. Food packaging

It is well known that packaging materials help reduce degradation and increase food shelf life. For instance, smart packages made with antioxidants can increase shelf life and improve the sensory and nutritive quality of foods by reducing oxidation (Duncan & Webster, 2009). Moreover, the possible application of natural antioxidants (e.g., natural polyphenols) as polymer stabilizers has gained attention lately (Kirschweng, Tátraaljai, Földes, & Pukánszky, 2017). Due to its strong antioxidant properties, DHM has been suggested as an additive to be used in polymers. DHM has five active phenolic hydroxyl groups, the smallest hydrogen bond dissociation enthalpy (BDE) equal to 282.0 kJ/mol, and melting temperature (T_m) equal to 243 ℃ (Kirschweng et al., 2017).

A study of the thermo-oxidative stability of polypropylene (PP), linear low density polyethylene (LLDPE), high density polyethylene (HDPE), polystyrene (PS), ethylenevinylacetate copolymer (EVA), natural rubber (NR), and nitrile butadiene rubber (NBR) showed DHM was more efficient as a thermal antioxidant (stabilizer) for polymers than the synthetical antioxidant Irganox 1010, which is commonly used in the industry (Zheng et al., 2010) (Table 1). Further studies also suggested DHM could be an effective, value-added additive for use in PP (Xin, Ma, Lin, Xu, & Chen, 2015), and an efficient unhindered phenol antioxidant for LLDPE stabilization (Xin, Ma, Xu, & Chen, 2013a). In addition, the antioxidant activity of DHM in EVA depends on the pH as it loses stabilization functions under alkaline conditions (Xin, Ma, Xu, & Chen, 2013b). The stabilization effect of DHM was also investigated in polyethylene (PE) (Kirschweng et al., 2016). DHM was considered an efficient melt stabilizer (chemical additive) for PE, better than quercetin when used at small concentrations. PE melt stability was obtained with DHM concentration equal to 50 ppm. However, PE color changed to a brownish color with higher concentrations of DHM (a white powder) and higher number of extrusions (same DHM concentration). Therefore, its application was suggested only when polymer color is not of primary importance (Kirschweng et al., 2016). Studies reporting application of VTE in packaging materials were not found.

3.4. Technological limitations

Although DHM has been suggested a potential ingredient for functional foods, beverages, and nutraceuticals, its poor solubility and lipophilicity properties and limited thermal stability may limit its processability and applications in the food industry (Chen, Lin, Yao, & Teng, 2020; Liu, Du, Zeng, Chungang, & Niu, 2009; Teng et al., 2018). Likewise, poor solubility and lack of information on thermal stability were reported for VTE (Zhang et al., 2019). As shown in Fig. 2, DHM is a flavonoid that has two chiral centers and, as a consequence, it is possible to obtain four potential enantiomers (Wang, Xiong, Reddy Perumalla, Fang, & Calvin Sun, 2016). Above 30 °C, it can be oxidized to myricetin or quinone compounds (Xiao et al., 2019). In fact, temperature, pH, and metal ions (e.g., Fe^{3+}, Al^{3+}, Cu^{2+}) can affect DHM chemical stability (Liu et al., 2019). DHM was reported to be stable after heating for 30 min at 100 °C (Lin, Gao, Guo, & Ning, 2004); it was also stable in weakly acidic solutions, but unstable under basic conditions (He, Pei, Li, & Ou, 2007).

In their review article, Liu et al. (2019) suggested the following approaches to improve DHM solubility and bioavailability: solid

Table 3
Dihydromyricetin (DHM) solubility in different surfactants, co-surfactant and oil phases that can be used in food production.

Vehicle	Chemical Substance	DHM Solubility	Reference*
Co-surfactant	Diethylene glycol diethylene ether (DGDE)	196.6 ± 5.8 mg/g	[1]
	Glycerol	160.8 ± 5.0 mg/g	
	Polyethylene glycol 400 (PEG 400)	137.6 ± 6.2 mg/g	
	Glycol	54.8 ± 2.2 mg/g	
	Polyglycerol polyricinoleate (PGPR)	131.9 ± 8.1 mg/mL	[2]
	Span 80	73.2 ± 2.1 mg/mL	
	Span 40	68.1 ± 2.5 mg/mL	
	Span 60	65.3 ± 2.0 mg/mL	
	Polyglyceryl-10 decaoleate	54.4 ± 2.1 mg/mL	
	Polyglyceryl monooleate	50.2 ± 1.1 mg/mL	
Surfactant	Caprylate glyceride	71.6 ± 4.0 mg/g	[1]
	Cremophor-RH40	70.1 ± 3.2 mg/g	
	Tween 20	60.4 ± 2.9 mg/g	
	Tween 80	59.8 ± 1.5 mg/g	
	Cremophor-EL	58.5 ± 1.8 mg/g	
	Tween 80	229.6 ± 8.3 mg/mL	[2]
	Polyglyceryl-10 monooleate	183.6 ± 10.7 mg/mL	
	Tween 20	170.0 ± 3.7 mg/mL	
	Tween 40	163.3 ± 2.1 mg/mL	
	Tween 60	158.3 ± 2.5 mg/mL	
	Polyglyceryl-6 monooleate (P6)	146.5 ± 5.1 mg/mL	
	Polyglyceryl-10 monolaurate	140.8 ± 1.6 mg/mL	
Oil phase	Castor oil	8.1 ± 0.2 mg/g	[1]
	Medium chain triglyceride (MCT)	0.3 ± 0.1 mg/g	
	Ethyloleate	Insoluble	
	Isopropyl myristate (IPM)	Insoluble	
	Triolein	Insoluble	
	Octyl and decyl glycerate (ODO)	1.6 ± 0.1 mg/mL	[2]
	Linseed oil	1.1 ± 0.1 mg/mL	
	Camellia seed oil	1.0 ± 0.1 mg/mL	
	Evening primrose oil	0.8 ± 0.0 mg/mL	
	Coco oil	0.8 ± 0.1 mg/mL	
	Corn oil	0.6 ± 0.1 mg/mL	

* [1] Chen et al. (2020); [2] Wang et al. (2019).

dispersion, nanoencapsulation, microemulsion, cyclodextrin inclusion complexes, co-crystallization, phospholipid complexes, chemical acylation, and enzymatic acylation. A DHM–lecithin complex was recommended by Liu et al. (2009) to improve DHM solubility in oil and results showed the complex significantly improved DHM solubility in *n*-octanol from 9.63 to 22.38 mg/mL. However, the stability of the complex in oil was worse when the ratio of lecithin to DHM was lower than 1. In addition, the DHM–lecithin complex was an efficient scavenger of 1,1-diphenyl-2-picrylhydrazyl (DPPH) radicals, and more active than BHT. The IC_{50} (concentration needed to cause 50% inhibition of the DPPH radical) of the DHM–lecithin complex and BHT were 22.60 μg/mL and 43.27 μg/mL, respectively. Chen et al. (2020) recently suggested a thermodynamically stable self-nanoemulsifying drug delivery system (SNEDDS) as a promising strategy to improve DHM water solubility. Formulations that improved DHM solubility and stability contained glycerol (co-surfactant), cremophor-RH40 (surfactant), and medium chain triglyceride (oil phase). In previous study, Wang et al. (2019) proposed a solid self-emulsifying delivery system (S-SEDS) of DHM based on octyl and decyl glycerate (ODO) and linseed oil, which improved DHM bioaccessibility and antioxidant activity in comparison with pure DHM (98% purity). DHM solubility in different co-surfactants (co-emulsifiers), surfactants (emulsifiers), and oil phases that can be used in food production are presented in Table 3 (Chen et al., 2020; Wang et al., 2019).

4. Conclusions

VTE and DHM have shown to be beneficial for food safety purposes (potential natural antimicrobial preservatives) and in packaging applications, but their greater potential application in the food industry may be as food ingredient of novel heathier and clean label products free from synthetic antioxidants. VTE and DHM have successfully reduced oxidation in different oil systems and meat products, as well as reduced the formation of a potential carcinogen (acrylamide) in bread and toxicants (malonaldehyde and advanced glycation end products) in cookies. Despite of their darker color, meat products (cooked mixed pork patties) and baked goods (bread and cookies) enriched with VTE or DHM showed good consumer acceptability and are examples of novel functional foods that could potentially offer positive health benefits, such as prevent metabolic diseases. Overall, the natural antioxidant properties of VTE and DHM can play an important role in the group of functional foods, but future studies are recommended to identify use limitations (e.g., dosage, solubility, and thermal stability), which may impact desired quality and lead to lower consumer acceptability. Moreover, further research on synergetic applications with other natural antioxidants are vital to guide future product development and possibility reduce cost of new formulations.

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