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2025 Volume 10, Issue 3
Journal of Medicines Development Sciences
ISSN: 2382-6371(Online) ISSN: 2382-6363(Print)

Research Progress on Chemical Constituents and Bioactivities of the Ice Plant (*Mesembryanthemum crystallinum* L.)

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Abstact: *Mesembryanthemum crystallinum* L. has unique physiological characteristics and is rich in nutrients, which is regarded as a potential functional food resource. Studies have found that the ice plant is rich in a variety of minerals, including five essential macroelement: sodium, potassium, calcium, magnesium, phosphorus and seven essential trace elements: iron, zinc, selenium, copper, molybdenum, chromium, cobalt; it rich in a variety of vitamins, mainly vitamin C and β-carotene; it contains 18 kinds of total amino acids, including 9 kinds of essential amino acids including histidine. And rich in dietary fiber. Ice plant also contains active ingredients such as flavonoids, polysaccharides, polyphenols and alkaloids, which have antioxidant, hypoglycemic, antibacterial, acetylcholinesterase inhibition, immune regulation and other functions. In this paper, the nutritional value, active ingredients and biological activity of ice vegetables were reviewed to provide reference for the development of new functional dietary resources and the further research and development of the ice plant.

Keywords: Ice plant; Chemical constituents; Nutritional components; Bioactivity

Online publication: September 26, 2025

1. Introduction

Ice plant (*Mesembryanthemum crystallinum* L.), also known as crystalline iceplant or African ice plant, is an annual or biennial herb belonging to the family Aizoaceae and genus Mesembryanthemum[1]. Its leaves are opposite, rhombic or ovate, succulent, smooth, thick, and light green. It possesses a well-developed fibrous root system, with lateral branches emerging from each leaf axil. Dense transparent bladder cells containing saline fluid cover the young leaves and stems. These cells reflect sunlight, giving the plant a glistening, crystalline appearance, hence the name "crystalline iceplant"[2].

The characteristic salty and juicy taste of ice plant arises from saline fluid stored within its epidermal bladder cells[2,3]. When mineral absorption (salts, etc.) from the roots exceeds its regulatory capacity, excess components are sequestered in these specialized cells on the stems and leaves[3]. Consequently, ice plant is a rich natural source of inorganic elements like Na, K, and Ca[4]. It thrives in saline-alkali soils and arid conditions, originating from dry regions such as the Namib Desert in South Africa, and is now distributed worldwide[5]. It is cultivated in regions of China including Xinjiang, Shandong, and Tianjin. Successful pilot cultivation has been achieved in the Taiping Town area of Tianjin Binhai New Area, where plans are underway to utilize ice plant agriculture to support rural revitalization[6](**Figure 1**).

In China, ice plant is primarily consumed raw in salads. Its full food value remains underutilized. Current research mainly focuses on cultivation conditions[7-9], with fewer studies on its chemical composition, bioactivities, and product development. This review aims to summarize the nutritional composition, chemical constituents, and bioactive effects of ice plant to support its broader development and utilization.

Figure 1. Illustration of ice plant (*Mesembryanthemum crystallinum* L.)

2. Nutritional and Bioactive Components

Ice plant is a highly valuable health-promoting vegetable, primarily consumed for its tender, crystalline-coated stems and leaves. It boasts a rich nutritional profile, including inorganic elements, amino acids[4,10], and polyols (e.g., myo-inositol, pinitol, ononitol)[11]. It has high moisture content (up to 95.7%) and ash content. Ice plant contains the seven essential nutrient groups for humans, with notably high levels of inorganic elements, vitamins, protein, and water compared to common vegetables. It contains lower amounts of insoluble dietary fiber and carbohydrates, and negligible fat content[4].

2.1. Plant-derived Electrolytes

Minerals play crucial roles in vital physiological functions. As the human body cannot synthesize them, they must be obtained from the diet[12]. Ice plant contains various inorganic elements (**Table 1**), including sodium, potassium, and calcium, which show therapeutic potential for conditions like salt-sensitive hypertension, hyperlipidemia, diabetes, and cardiovascular diseases[13]. Its salty taste originates from natural plant-based sodium salts, which are beneficial to health[1].

Mineral accumulation in ice plant primarily occurs within its epidermal bladder cells[2]. These structures are key to its salt tolerance. Studies show that as seawater concentration increases, salt content in both the whole plant and epidermal bladders rises proportionally. Epidermal bladders can sequester up to 31.059% of Na^+ and 35.527% of Cl^- within the plant[14].

Research indicates high levels of Na, K, Ca, and Mg in ice plant. Wang et al. [10]used inductively coupled plasma mass spectrometry (ICP-MS) to analyze 24 inorganic elements in introduced varieties, finding a total content of 12.709 mg/g. Levels of toxic heavy metals (As, Pb, Hg, Cd) were all ≤0.06 mg/kg, well below national safety limits. Jiao[4]detected 10 inorganic elements, including 5 macroelements (K, Na, Ca, Mg, P) and 5 microelements (Fe, Zn, Se, Mn, Cu), with Na, K, and Ca being particularly abundant. This confirms ice plant as an excellent mineral source, especially for Ca, Fe, Zn, and Mg. Its natural high Na and K content makes it suitable for formulating sports drinks to replenish electrolytes without added salts.

Table 1. Content of inorganic elements in ice plant (mg/100 g)

Element	Jiao et al.[4]	Wang et al.[10]	Adult Requirement (mg/d)[12]
Na	2965±49.0	587.00	1500
K	1825±21.21	499.80	2000
Ca	288.00±4.24	120.30	800
Mg	137±1.41	59.70	330
P	22.12±0.04	-	720
B	-	0.16	-
Al	-	0.591	-
Ti	-	0.116	-
V	-	0.0029	-
Cr	-	0.0078	30
Mn	1.40±0.00	1.090	4.5
Fe	17.6±1.13	1.090	M 12 F 20
Co	-	0.0024	-
Ni	-	0.0063	-
Cu	0.40±0.00	0.087	0.8
Zn	33.90±2.97	0.804	M 12.5 F 7.5
As	-	0.001	-
Se	0.29±0.00	0.0008	60
Mo	-	0.007	0.1
Cd	-	0.006	-
Ba	-	0.018	-
Hg	-	0.0002	-
Ti	-	0.0044	-
Pb	-	0.004	-

2.2. National Vitamins

Vitamins are essential micronutrients crucial for normal physiological function, growth, metabolism, and development. They are classified as fat-soluble (e.g., Vitamins A, D, E, K) or water-soluble (e.g., B vitamins, Vitamin C), differing in solubility, absorption, excretion, and deficiency symptom onset[15]. Ice plant primarily contains water-soluble vitamins like Vitamin C[16], folate, pantothenic acid[4], and Vitamin B4 (adenine)[17]. Excessive intake of water-soluble vitamins is generally non-toxic as excess is excreted in urine; however, deficiency symptoms manifest rapidly. Fat-soluble vitamins in ice plant include Vitamin A and β-carotene. Deficiency in Vitamin A can lead to clinical symptoms like night blindness, xerophthalmia, and conjunctival dryness, and can impair skin/mucous membrane integrity and growth.

Studies comparing ice plant to common vegetables show higher vitamin levels. Liu et al.[16]determined Vitamin C content using the molybdenum blue colorimetric method, finding 15.42 ± 0.15 mg/100g, significantly higher than common lettuce. Jiao[4] compared vitamins in ice plant, romaine lettuce, spinach, and lettuce, finding ice plant had markedly higher

Vitamin C and β-carotene content, but the vitamin content of ice vegetables was also affected by its variety, producing area and planting environment. SHU et al.[17] isolated and identified Vitamin B4 (adenine) in ice plant ethanol extracts.

Ice plant is rich in polyols (e.g., myo-inositol, pinitol). Its polyol accumulation levels are comparable to cowpea, known for high polyol accumulation[7]. Myo-inositol, a vitamin-like compound, promotes fat metabolism, lowers cholesterol, and prevents fatty liver and atherosclerosis[1]. Under salt stress (400 mM NaCl), myo-inositol peaked at 0.7 mg g^{-1} FW (Fresh Weight) in seedlings after 3 days but decreased over time. Control plants generally had higher inositol concentrations. In mature plants, highest concentrations (1.7, 2.8, 7.9 mg g^{-1} FW) were found in control leaflets at 25, 35, and 45 days post-treatment initiation[11].

Ice plant also contains natural folate, pantothenic acid (Vitamin B5), retinol[2], and other vitamins less common in vegetables, making it a potential source for nutritional supplements.

Table 2. Composition and content of vitamins in ice plant

Category	Type	Content ((g/100g)	Reference	Adult Requirement/d[12]
Water-Soluble	Vitamin C	3000	[2]	100mg
		20800±0.11	[4]	
		15420±0.15	[16]	
	Folate	31	[2]	400mg
	Pantothenic acid	0.63	[2]	5mg
	Vitamin B4	-	[17]	-
Fat-Soluble	β-Carotene	926 406±4.15	[2] [4]	7mg
	Vitamin A (RAE)	6.20±0.05	[4]	M 800mg F 700mg
Vitamin-like	Myo-inositol	-	[4]	-

Note: RAE = Retinol Activity Equivalents; "-" indicates not detected or not specified.

2.3. Plant Protein

Proteins are fundamental macromolecules for life. Jiao[4] reported a protein content of 1.53 ± 0.01 g/100g in ice plant, higher than lettuce and romaine, while crude fat content was negligible. This indicates ice plant is a high-protein, low-fat vegetable.

Amino acids are the building blocks of proteins. Studies have analyzed ice plant amino acid composition and content [4,10]. Oh et al.[18] isolated and identified eight compounds, including three amino acids: phenylalanine, tyrosine, and tryptophan. Wang et al.[10] used an amino acid analyzer on differently pre-treated samples. Homogenized samples contained 8 amino acids (total 0.090 mg/g), including 4 essential amino acids (73% of total). Manually ground samples contained 6 amino acids (total 0.099 mg/g), including 4 essential amino acids (78% of total). Jiao et al.[4]detected 16 amino acids (**Table 3**), with essential amino acids constituting 38% of total amino acids. Non-essential amino acids accounted for 60.80%, suggesting a relatively balanced profile. Variations in reported amino acid content likely stem from differences in origin, variety, cultivation conditions, sample preparation, extraction methods, and experimental error.

Humans must obtain essential amino acids (EAAs) from diet. There are eight EAAs for adults; histidine is also essential for infants, making nine in total[12]. Ice plant contains all nine EAAs (lysine, tryptophan, phenylalanine, methionine, threonine, isoleucine, leucine, valine, histidine), making it a good source for amino acid supplementation.

Table 3. Composition and content of amino acids in ice plant

Amino Acid	Wang et al.[10] (Homogenized)(mg/100g)	Wang et al.[10] (Manual) (mg/100g)	Jiao [4] (mg/100g)	Adult Requirement (mg/kg/d)[12]
Protein	-	-	1.53±0.01	M:65g ; F:55g
Threonine (Thr*)	1.185	1.388	50±0.35	7
Valine (Val*)	0.395	-	58±0.92	10
Methionine (Met*)	0.691	-	13±0.71	13 (Met+Cys)
Leucine (Leu*)	-	-	90±2.19	14
Lysine (Lys*)	4.345	4.957	74±0.99	12
Isoleucine (Ile*)	-	0.297	52±0.64	10
Tryptophan (Trp*)	-	-	-	3.5
Phenylalanine (Phe*)	-	1.091	60±0.64	8 (Phe+Tyr)
Histidine (His*)	-	-	66±1.84	12
Glutamic acid (Glu#)	0.987	-	130±0.71	256
Cystine (Cys#)	-	1.6 85	-	13(Met+Cys)
Serine(Ser#)	0.592	-	50±0.00	131
Glycine (Gly#)	0.099	-	59±0.00	52
Alanine(Ala#)	0.790	0.496	78±0.14	143
Tyrosine(Try#)	-	-	32±0.85	8 (Phe+Tyr)
Aspartic acid ((Asp#)	-	-	99±0.07	129
Arginine(Arg#)	-	-	80±1.98	117
Proline (Pro#)	-	-	59±3.68	66
Total Amino Acids(T)	9.084	9.914	10 50±15.70	-
Essential AA Total (E)	6.62	7.733	397	-
E/T(%)	73%	78%	38%	-

Note: *, essential amino acids; #, non-essential amino acids; -, not detected. Adult requirements for sulfur AAs (Met+Cys) and aromatic AAs (Phe+Tyr) are combined.

2.4. Dietary Fiber

Dietary fiber comprises indigestible carbohydrates with significant health benefits. Recommended intake varies; Chinese adults (19-50 years) are advised to consume 25-39 g/d, with soluble fiber comprising 25%-30% and insoluble fiber 70%-75% [15]. Ice plant is rich in dietary fiber. Jiao[4] detected approximately 0.52 g of insoluble dietary fiber per 100g, comparable to levels in romaine lettuce and common lettuce.

3. Functional Bioactive Components

Ice plant contains diverse bioactive compounds, with research focused on flavonoids, polysaccharides, and polyphenols[18-21]. Its total flavonoids exhibit antioxidant[19,21], hypoglycemic[22], antitumor, and free radical scavenging activities. Polysaccharide and polyphenol extracts demonstrate antioxidant, antibacterial, and immuno -modulatory effects[23-25].

3.1. Total Flavonoids

Flavonoids are representative antioxidant compounds found in plants, possessing various bioactivities like inhibiting lipid peroxidation and reactive oxygen species generation[25]. Recent studies have identified characteristic flavonoid structures in ice plant extracts.

Sun et al.[22] confirmed the C6-C3-C6 flavonoid backbone via UV-Vis spectroscopy. FT-IR spectra revealed vibration absorption peaks for functional groups like -OH, C-H, C=O, C=C, and phenolic hydroxyl, consistent with flavonoid structures. UPLC-MS/MS identified over 30 flavonoids in purified extracts, including tangeretin, nobiletin , farrerol, protocatechualdehyde, diosmin, chalconaringenin, sinensetin, naringenin, and rutin (**Table 4**). Tangeretin had the highest relative percentage (50.854% ± 0.089%). Duan et al.[9] found that total flavonoid content decreased with increasing seawater concentration; plants grown in 20% seawater had 5.500 g/100g. Kang et al.[25] reported flavonoid content (mg QE/g, Quercetin Equivalents) varied by organ: highest in cotyledons (1218.07 ± 1.00), followed by young stems (703.97 ± 0.25) and stems (671.29 ± 0.63). Variations are attributable to extraction methods, origin, etc. Analyzing flavonoid composition provides a theoretical basis for functional development.

Ultrasound-assisted extraction (UAE) is commonly used. Sun et al.[19] extracted total flavonoids using UAE, followed by sequential extraction with petroleum ether, ethyl acetate, and n-butanol. The n-butanol and ethyl acetate fractions contained the highest flavonoid levels (191.0 mg/g and 184.5 mg/g, respectively). Sun et al.[22] optimized UAE conditions: 60% ethanol, solid-liquid ratio 1:25 (mg/mL), temperature 45°C, time 120 min, power 250 W, achieving a yield of 2.776%. Wang et al.[21] also used UAE and orthogonal optimization, determining optimal conditions as 60% ethanol, ratio 1:15, temperature 50°C, time 120 min, yielding 4.91%. Ethanol concentration, solid-liquid ratio, temperature, time, and power significantly impact extraction efficiency, with ratio and temperature causing major yield variations.

Purification involves fractionation and macroporous resin adsorption. Sun et al.[22] found D101 resin effective. Optimal purification conditions were: crude extract concentration 0.30 g/L, pH 4, sample flow rate 60 mL/h, sample volume 56 mL, eluent 80% ethanol (pH 6), flow rate 60 mL/h, volume 128 mL. This increased flavonoid purity to 57.67%, a 2.98-fold improvement over the crude extract.

Table 4. Composition and relative content of purified flavonoids in ice plant [20]

NO.	Compound	Chemical Formula	Relative Percentage(%)
1	Tangeretin	$C_{20}H_{20}O_7$	50.854±0.089
2	Nobiletin	$C_{21}H_{22}O_8$	20.949±0.115
3	Farreerol	$C_{17}H_{16}O_5$	8.781±0.072
4	Protocatechualdehyde	$C_7H_6O_3$	3.962±0.107
5	Diosmi	$C_{28}H_{32}O_{15}$	2.875±0.079
6	Chalconaringenin	$C_{27}H_{34}O_{14}$	2.523±0.054
7	sinensetin	$C_{20}H_{20}O_7$	2.241±0.056
8	Naringenin	$C_{15}H_{12}O_5$	2.151±0.066
9	Rutin	$C_{27}H_{30}O_{16}$	1.723±0.052

3.2. Saccharides and Glycosides

Polysaccharides are natural polymers enhancing immunity. Ice plant contains diverse polysaccharides and glycosides (**Table 5**). Yang et al.[24] extracted polysaccharides using UAE under optimal conditions (ratio 1:20, 60°C, 60 min), yielding 11.21% (dry weight).

Several studies have isolated and identified saccharides and glycosides. Li [26] isolated 5 glycosides and one saccharide derivative from ethanol extracts (**Table 5**). Further work identified 11 monomeric compounds from ethyl acetate and n-butanol fractions, including 5 glycosides, with coniferin being newly identified [27](**Table 5**). Shu et al.[17] isolated 9 compounds, including three glycosides (**Table 5**). These studies provide references for extraction and identification, supporting functional food development.

Table 5. Saccharide and glycoside components in ice plant

NO.	Compound	Reference
1	3, 4, 5-trihydroxy-6-(hydroxymethyl)tetrahydro-2H-pyran-2-yl(E)-3-(4-hydroxy-3-methoxyphenyl)acrylate	[26,27]
2	Syringin	[17,26,27]
3	2, 4, 4-trimethyl-3-(((3, 4, 5-trihydroxy-6-(hydroxymethyl)tetrahydro-2H-pyran-2-yl)oxy)methyl)cyclohex-2-en-1-one	[26]
4	6-(((1R, 2S)-2-hydroxy-4-((S, E)-3-hydroxybut-1-en-1-yl)-3, 5, 5-trimethylcyclohex-3-en-1-yl)oxy)-5-(hydroxymethyl)tetrahydro-2H-pyran-2, 3, 4-triol	[26,27]
5	2-ethoxy-5-(hydroxymethyl)tetrahydrofuran-3, 4-diol(	[26]
6	(E)-2-(hydroxymethyl)-6-(4-(3-hydroxyprop-1-en-1-yl)-2-methoxyphenoxy)tetrahydro-2H-pyran-3, 4, 5-triol	[27]
7	ixerol B	[17]
8	Jasmioside E	[17]
9	(E)-4-hydroxy-3, 5, 5-trimethyl-4-(3-((3, 4, 5-trihydroxy-6-(hydroxymethyl)tetrahydro-2H-pyran-2-yl)oxy)but-1-en-1-yl)cyclohex-2-en-1-one	[26,27]

3.3. Polyphenols

Wang et al.[28] optimized polyphenol extraction using UAE: 60% ethanol, ratio 1:10 (g:mL), 80°C, 120 min, achieving a yield of 1.42%. Kang et al.[25] dentified 17 polyphenolic compounds via UHPLC-TOF/HRMS, primarily flavonoids and O-glycoside derivatives. Content varied by organ: highest in cotyledons (115.43 ± 0.47 mg GAE/g, Gallic Acid Equivalents), followed by young stems (78.90 ± 0.27 mg GAE/g) and stems (78.83 ± 0.40 mg GAE/g).

3.4. Other Chemical Components

Beyond flavonoids, polysaccharides, and polyphenols, studies have isolated alkaloids, terpenoids, and sterols. Li[26] identified 19 compounds from ethanol extracts, including 6 saccharides/glycosides (**Table 5**), 4 alkaloids, 2 terpenoids, 2 phenylpropanoids, 1 sterol, 1 ester, along with uridine and Vitamin B4. Further work identified 11 compounds from ethyl acetate and n-butanol fractions: 2 phenylpropanoids (cis-p-hydroxycinnamic acid, ferulic acid), 2 alkaloids (nicotinic acid, ethane-1,2-diyl dinicotinate), 5 glycosides, 1 benzofuranone (loliolide), and 1 sterol (β-sitosterol)[27]. Shu et al.[17] isolated 9 compounds using various chromatographic techniques, with ixerol B being newly identified (**Table 6**).

Table 6. Other chemical components in ice plant

Category	Compound	Reference
Alkaloids	Nicotinic acid	[26,27]
	3-benzyl-6-isopropylpiperazine-2, 5-dione	[26,27]
	(1S, 3S)-1-methyl-2, 3, 4, 9-tetrahydro-1H-pyrido[3, 4-b]indole-3-carboxylic acid	[17,26]
	(1R, 3S)-1-methyl-1, 2, 3, 4-tetrahydro-β-carboline-3-carboxylic acid	[17,26]
	Cyclo(phenylalanine-valine)	[17,26]
	4-hydroxy-3-methoxybenzamide	[18]

Table 6 (Continued)

Category	Compound	Reference
Terpenoids	Loliolide	[26,27]
	(1R, 2S)-4-((R, E)-3-hydroxybut-1-en-1-yl)-3, 5, 5-trimethylcyclohex-3-ene-1, 2-diol	[26]
Sterols	Stigmasterol	[26]
	β-Sitosterol	[27]
Phenylpropanoids	cis-p-Hydroxycinnamic acid	[26,27]
	Ferulic acid	[17,18,26,27]
Esters	Dibutyl phthalate	[17,27]
	Ethane-1, 2-diyl dinicotinate	[26,27]
Others	Vitamin B4 (Adenine)	[17,26,27]
	Uridine	[17,18,26,27]
	adenosine	[18]

4. Bioactivities of Ice Plant

Research indicates ice plant possesses antioxidant[25], hypoglycemic[22], antibacterial, antitumor[18], immunoenhancing[29], and cardiovascular protective activities, likely mediated by its polysaccharides, flavonoids, polyphenols, and other bioactive components.

4.1. Antioxidant Activity

Flavonoids, polysaccharides, and polyphenols contribute to antioxidant activity. Wang et al.[28] found ice plant polyphenols dose-dependently scavenged DPPH and hydroxyl radicals. At 0.10 mg/mL, scavenging rates reached 64.19% and 88.10%, respectively. Kang et al.[25] measured antioxidant activity via DPPH and hydroxyl radical scavenging, showing leaves had higher activity than stems, correlating with polyphenol content. Wang et al.[21] demonstrated ice plant flavonoid extracts (0.02-0.10 mg/mL) exhibited dose-dependent antioxidant activity against DPPH and hydroxyl radicals. Yang et al.[24] showed ice plant polysaccharides effectively scavenged hydroxyl radicals, DPPH, and nitrite ions, and exerted dose-dependent antioxidant effects in animal and vegetable oils.

4.2. Hypoglycemic Activity

Total flavonoids[30], polyols like pinitol[24] and myo-inositol contribute to hypoglycemic effects. Sun et al.[22] found ice plant flavonoids inhibited α-glucosidase and α-amylase activity in vitro. Crude extract, purified flavonoids, and acarbose all inhibited α-glucosidase more strongly than α-amylase. Purified flavonoids showed inhibition comparable to acarbose and significantly higher than crude extract, suggesting potential as natural enzyme inhibitors. Kim et al.[31]reported fermented ice plant extract had stronger anti-diabetic effects (inhibiting lipid accumulation, reducing fasting blood glucose, improving glucose tolerance) than non-fermented extract in db/db mice. The mechanism involved upregulating IRS-1, PI3K, and Akt expression/phosphorylation. Zhang et al.[32] optimized D-pinitol extraction from ice plant (IPE). Optimized IPE effectively lowered fasting blood glucose, improved glucose tolerance, and protected/repaired pancreatic β-cells in type 2 diabetic rats, linked to improved islet function and gut microbiota modulation.

4.3. Antibacterial Activity

Polysaccharides, polyphenols, and flavonoids exhibit antibacterial properties. Yang et al.[24] found ice plant polysaccharides inhibited Escherichia coli and Bacillus subtilis, with stronger activity against Gram-positive (B. subtilis) than Gram-negative (E. coli) bacteria. Wang et al.[28] demonstrated ice plant polyphenols significantly inhibited E. coli, with an inhibition zone diameter of 12 mm at 3 mg/mL.

4.4. Other Bioactivities

Beyond antioxidant and antibacterial effects, ice plant show cognitive-enhancing[30] and immunomodulatory activities. Extracts inhibited acetylcholinesterase (77.72 ± 3.30%), comparable to the positive control tacrine[33], suggesting potential for cognitive improvement. Choi et al.[29] showed extracts enhanced IL-6 and TNF-α production in macrophages, upregulated iNOS gene expression, and increased NO production in IFNγ-stimulated macrophages, indicating immunomodulatory activity. Ice plant also shows cardiovascular protective effects and inhibits tumor cell growth[34,35].

5. Prospects

Ice plant possesses high nutritional value, rich in inorganic elements, amino acids, vitamins, flavonoids, and other bioactive substances, along with diverse bioactivities (antioxidant, hypoglycemic, antibacterial), giving it significant development potential. Currently, few ice plant-based products exist beyond fresh consumption. Limited research explores food applications: Yuan et al.[36]developed a fermented beverage using kale, ice plant, and purple carrot; Xiao et al.[37] optimized a jelly using ice plant and hawthorn. Taiping Town in Tianjin is actively researching saline soil cultivation and collaborating (e.g., with Tianjin Liuyefeng Co.) on medicinal food development[38]. Given its high nutritional value and significant bioactivities, ice plant is poised to become a premium raw material for low-fat, high-energy meal replacements, sports drinks, and other functional products.

Disclosure statement

The author declares no conflict of interest.

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