



Kiwifruit (*Actinidia* spp.): A review of chemical diversity and biological activities

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ARTICLE INFO

Keywords:

Actinidia chinensis
Chinese gooseberry
Bioactive phytochemical
Underutilized species
Polyphenol
Actinidia deliciosa

ABSTRACT

Kiwifruit (*Actinidia* spp.) is a commercially important fruit crop. Various species and cultivars, non-fruit plant parts, and agricultural and processing wastes are underutilized. A broad-scope review of kiwifruit guides further innovative applications. Different kiwifruit varieties and edible and nonedible parts varied in the composition of dietary nutrients including polyphenols, vitamins, dietary fiber, and functional ingredients, such as starch and protease and bioactive phytochemicals. Kiwifruits exhibit antioxidative, antiproliferative, antiinflammatory, antimicrobial, antihypertensive, antihypercholesterolemic, neuroprotective, antiobese properties and promote gut health. Clinically significant effects of kiwifruit on prevention and/or treatment of major chronic diseases are not yet evident. Varieties and plant parts, extraction, analytical and processing methods affect the physicochemical and biological properties of kiwifruit-derived ingredients. Allergens, mycotoxins, pesticides and heavy metals are the chemical hazards of kiwifruits. Future research should be focused on sustainable uses of underutilized resources as functional ingredients, bioactive compound purification, composition-activity relationships, and physiological mechanisms and clinical significance of kiwifruits.

1. Introduction

Kiwifruit, known as the Chinese gooseberry, is the berry of woody vine species of *Actinidia* genus in the family Anacardiaceae (Henare, 2016). There are approximately seventy recognized kiwifruit species. Representatives of edible fruit-producing species include *A. deliciosa* (fuzzy kiwifruit), *A. chinensis* (golden kiwifruit), *A. arguta* [hardy (mini) kiwifruit], *A. kolomikta* (Arctic kiwifruit), *A. melanandra* (purple or red kiwifruit) and *A. polygama* (silver vine). Kiwifruits have their origins in North-Central and Eastern China (Folletta, Jamieson, Hamilton, & Wall, 2019). Over the last decades, worldwide production quantity has been kept increasing for a range of commercial cultivars and hybrids (Table 1, Supplementary Fig. 1). The most commercially significant species are *A. deliciosa* and *A. chinensis* (Folletta et al., 2019). Knowledge of nutritional properties and potential applications supports the high demand of kiwifruit from the consumers. Different species and cultivars vary in fruit shape, size, weight, skin appearance (color, thickness, hairy or smooth), eating quality (flavor, aroma, texture) and shelf life (Morton, 1987; Ferguson, 2016; Henare, 2016; Li et al., 2018; Sivakumaran,

Huffman, Sivakumaran, & Drummond, 2018) (Table 1 and Fig. 1). Kiwifruit diversity improves year-round availability, fruit qualitative traits, storage stability, and food security. The morphometric, colorimetric, textural and organoleptic characteristics, due to genotypic variations, influence the preferences of consumers (Asiche et al., 2017; Goffi, Zampella, Forniti, Petriccione, & Botondi, 2019; Han et al., 2019; Minas, Tanou, Karagiannis, Belghazi, & Molassiotis, 2016; Xia et al., 2020). Kiwifruit postharvest practices influence the nutritional and sensory quality. Morphological appearances and physicochemical features (soluble solids content, firmness, ascorbic acid content and titratable acidity) are fruit quality indices to determine maturation, harvest time and shelf life (Asiche et al., 2017; Goffi et al., 2019; Han, Park, Chul-Woo, Kim, & Lee, 2019; Kai et al., 2020a, 2020b; Nie et al., 2020; Xia et al., 2020).

Kiwifruit genetic diversity ensures great variations in composition of nutrients and bioactive phytochemicals (Table 2). Kiwifruit is a source of vitamins, minerals, dietary fibers (DFs) and organic acids (Henare, 2016; Richardson, Ansell, & Drummond, 2018; Perez-Burillo, Oliveras, Quesada, Rufian-Henares, & Pastoriza, 2018). Kiwifruit provides

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<https://doi.org/10.1016/j.foodchem.2020.128469>

Received 7 July 2020; Received in revised form 5 October 2020; Accepted 20 October 2020

Available online 26 October 2020

0308-8146/© 2020 Published by Elsevier Ltd.

Table 1
Comparison among commercially available kiwifruit representatives.

Species ^{1,3}	Cultivars ^{1,3,4} (brand name)	Harvest time ¹	Country of origin ^{1,3}	Fruit appearances ^{1,3}	Fruit flavor ^{1,2} , Brix ¹ , and Vc ¹ (mg/100 g FW)
<i>A. deliciosa</i>	Cuixiang (Ximi No. 9)	Early September	China	Fruit shape: ovoid, protruding at styler end Fruit weight (g): 92 Skin: yellowish brown with hairs (brown, stiff, sparse) Flesh: green	Juicy, good flavor Vc: 100–185
	Emihoutao No. 1 (Jinkui, Jinshui II-16–11)	Late October early November	China	Fruit shape: cylindrical, wider towards styler end Fruit weight (g): 100 Skin: brown with hairs (dense and easily shed, stiff) Flesh: green	Juicy, sweet Brix: 18–21° Vc: ~240
	Guichang (Qianzi 82–3)	October	China	Fruit shape: long cylindrical Fruit weight (g): 85 Skin: brown with hairs (grey–brown, long, stiff) Flesh: light green	Juicy Brix: 12–16° Vc: ~110
	Jinxiang	Mid-September	China	Fruit shape: ellipsoid uniform, styler end deeply depressed Fruit weight (g): 90 Skin: yellow–brown with hairs (yellow, stiff) Flesh: green	Juicy, good texture, sweet Brix: ~14° Vc: ~70
	Miliang No. 1	Mid October	China	Fruit shape: uniform, long cylindrical, styler end slightly protruding Fruit weight (g): 90 Skin: dark brown with hairs (long, stiff) Flesh: yellow–green	Juicy, sweet Brix: 15–19° Vc: 140–200
	Qinmei	Late September Early October	China	Fruit shape: large, ovoid, distinctive beak at distal end Fruit weight (g): 100 Skin: greenish–brown with hairs (stiff, yellow–brown) Flesh: light green	Juicy, fine texture Brix: 14–17° Vc: 190–240
	Xuxiang	Late October	China	Fruit shape: oblong cylindrical Fruit weight (g): 75 Skin: shin, easily peeled, yellowish–green with hairs (yellow–brown, stiff) Flesh: green	Brix: ~14° Vc: 100–120
	Yate (Zhouzhi No. 1)	Late October	China	Fruit shape: large, cylindrical Fruit weight (g): 120 Skin: brown with hairs (stiff) Flesh: green	Vc: ~190
	Yumihoutao No.2 (Huamei No.2)	Early-mid September	China	Fruit shape: large Fruit weight (g): 110 Skin: yellowish brown with hairs (long, dense, persistent) Flesh: light green	Juicy Brix: 9.4–14.6° Vc: ~165
	Hayward	Early October	New Zealand	Fruit shape: small oval Fruit weight (g): 70–80 Skin: dull-brown and hairy Flesh: translucent and vibrant green flesh containing rows of black seeds	Tangy, sweet sour, invigorating ² fine flavor Storage life ≤ 6 months.
	Zespri® Sweet Green ⁴	May to November	New Zealand	Fruit shape: oval Fruit weight (g): N/A Skin: green–brown to brown with soft hairs Flesh: bright emerald green with black edible seeds	Tangy-sweet Vc: 150
	Tschelididis (Megakiwi™)	Slightly ahead of 'Hayward'	Greece	Fruit shape: large cylindrical, slightly depressed styler end Fruit weight (g): 170–180 Skin: brown and hairy Flesh: green	N/A
	Convi (Green Light®, Convi97001, Green Star)	30–40 days before 'Hayward'	Italy	Fruit shape: cylindrical Fruit weight (g): N/A Skin: brown and hairy Flesh: green	Less acidic than 'Hayward'
	Earligreen® (Boverlig 02)	40–50 days earlier than 'Hayward'	Italy	Fruit shape: cylindrical Fruit weight (g): N/A Skin: brown with stiff hairs Flesh: green	Short shelf-life
	Summerkiwi 3373 (Summerkiwi®)	7 weeks before 'Hayward'	Italy	Fruit shape: cylindrical, slight beak at styler end Fruit weight (g): 108 Skin: brown and hairy Flesh: green	Less acidic than 'Hayward'
<i>A. chinensis</i>	Cuiyu (Liangmei No. 1)		China	Fruit shape: ovoid Fruit weight (g): 90 Skin: greenish brown, short downy hairs (easily shed) Flesh: green	Good flavor Brix: 14.5–17.3° Vc: 95–145
	Wuzhi No. 3 (Wuzhi 81–36)	Late August early September	China	Fruit shape: ellipsoid Fruit weight (g): 85	Juicy, aromatic Brix: 12–15° Vc: 275–300

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Table 1 (continued)

Species ^{1,3}	Cultivars ^{1,3,4} (brand name)	Harvest time ¹	Country of origin ^{1,3}	Fruit appearances ^{1,3}	Fruit flavor ^{1,2} , Brix ¹ , and Vc ¹ (mg/100 g FW)
	Chuhong (Panda™ Forest Red Kiwi)		China	Skin: dark green with hairs (soft, sparse, readily shed) Flesh: bright green Fruit shape: long, ellipsoidal, stylar (beak) end Fruit weight (g): 80 Skin: dark green and hairless Flesh: green with circle of red flesh around central white core (red coloration more intense in fruit grown at higher altitudes)	Sweet Brix: 16.5° Moderate storage life
	Qihong		China	Fruit shape: cylindrical Fruit weight (g): 100 Skin: green with sparse or absent hairs Flesh: light green to yellow	
	Hongyang (Red Sun, RS1)		China	Fruit shape: small obovoid, stylar end deeply depressed Fruit weight (g): 60–70 Skin: dark green or greenish brown with fine hairs (downy, readily shed) Flesh: green–yellow to yellow fresh, circle of red around white core	Fine texture, sweet Brix: 16–20° Vc: ~100
	Jintao (C6, WIB-C6, Jingold™)		China	Fruit shape: long cylindrical, round cross-section Fruit weight (g): 90 Skin: yellow with brown hairs (short, thick, downy, readily shed) Flesh: green–yellow to orange–yellow	Juicy, sweet Brix: 15–16° Vc: 180–250
	Ganmi No. 1 (Zaoxian No. 1, FT-79–5)		China	Fruit shape: cylindrical (medium–large) Fruit weight (g): 85 Skin: green–brown to pale brown with hairs (soft, dense, easily shed) Flesh: greenish–yellow to yellow	Juicy, good flavor Brix: 12–17° Vc: 75–100
	Ganmi No. 2 (Kuimi, FY 79–1)		China	Fruit shape: distinctively apple-shaped Fruit weight (g): 100 Skin: green–brown to dark brown with hairs (fine, easily shed) Flesh: yellow–green to yellow	Juicy Brix: 13–16° Vc: 120–150
	Ganmi No. 3 (Jinfeng, FT 79–3)		China	Fruit shape: ellipsoid, large, uniform Fruit weight (g): 80–90 Skin: yellow–brown or dark brown with hairs (short, fine) Flesh: yellow	Juicy Brix: 12–15° Vc: ~95
	Lushanxiang (79–2, Elizabeth, First Emperor, Yellow Joy).	Late September	China	Fruit shape: cylindrical, uniform Fruit weight (g): 90 Skin: brownish yellow with hairs (soft, short, easily shed) Flesh: yellow	Juicy, sweet, aromatic Brix: ~16° Vc: ~165
	Guihai No. 4	Early-mid-September	China	Fruit shape: long, cylindrical Fruit weight (g): 80 Skin: yellow brown with hairs (fine, downy) Flesh: green to yellow	Juicy Brix: 15–19° Vc: ~55
	Hort16A (Zespri® Gold, Zespri® SunGold Earligold)	April/May	New Zealand	Fruit shape: ovoid, tapering towards stylar end, prominent beak Fruit weight (g): 95–100 Skin: skin green–brown to brown with hairs (soft, silky, easily shed) Flesh: flesh yellow–green to bright yellow depending on harvest time	Strong aromatic, tropical, sweet Brix: ~16° Vc: ~110
	Sanuki Gold	Early-mid October	Japan	Fruit shape: very large, squat, wider at stylar end Fruit weight (g): 160–180 Skin: brown with hairs (soft, sparse, persistent) Flesh: bright yellow	Brix: 6–18°
	Wanhong	N/A	China	Fruit shape: cylindrical Fruit weight (g): 110–140 Skin: green–brown with rare hairs Flesh: yellow–green to bright yellow	N/A
	Soreli (Ac 171.76).	~1 month before 'Hayward'	Italy	Fruit shape: large, oblong Fruit weight (g): > 100 Skin: brilliant brown with hairs (sparse, fine, persistent) Flesh: intense yellow	Good flavor
	Sanuki Gold	Early-mid October	Japan	Fruit shape: very large, squat, wider at stylar end Fruit weight (g): 160–180 Skin: brown with hairs (soft, sparse, persistent) Flesh: bright yellow	Brix: 16–18°
Hybrid <i>A. chinensis</i> × <i>A. deliciosa</i>	Huayou (Panda™ Golden Kiwi)	Mid-September	China	Fruit shape: ellipsoid, very pronounced beak at stylar end Fruit weight (g): 90	Sweet Brix: ~17.4 Vc: ~160

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Table 1 (continued)

Species ^{1,3}	Cultivars ^{1,3,4} (brand name)	Harvest time ¹	Country of origin ^{1,3}	Fruit appearances ^{1,3}	Fruit flavor ^{1,2} , Brix ¹ , and Vc ¹ (mg/100 g FW)
Hybrid <i>A. eriantha</i> × <i>A. chinensis</i>	Jinyan	Late October to early November	China	Skin: brown or yellow with hairs (sparse, downy) Flesh: light green to yellow Fruit shape: cylindrical, slightly sunken at styler end Fruit weight (g): 100–110 Skin: thick, yellow–brown (containing small red spots) with hairs (fine, sparse) Flesh: brilliant yellow	Juicy, aromatic, sweet Brix: ~16° Vc: ~110
<i>A. eriantha</i>	White (97–4)	Late October	China	Fruit shape: long cylindrical Fruit weight (g): 90 Skin: green–brown, readily peelable, hairs (dense) Flesh: white	Not juicy Vc: 600 (very high)

FW, fresh weight; Vc, vitamin C, N/A: Not available. References: ¹ Ferguson, 2016; ² Stonehouse et al., 2012; ³ Henare, 2016; ⁴ Sivakumaran et al., 2018.

bioactive phytochemicals, such as polyphenols and non-starch polysaccharides (Ahn et al., 2020; Commisso et al., 2019; Jiao, Quek, Gu, Guo, & Liu, 2020; Wojdylo, Nowicka, Oszmianski, & Golis, 2017). Phytochemicals contribute to antioxidative, antiproliferative, anti-inflammatory, antimicrobial, antihypertensive, neuroprotective, and gut health (Table 3). The chemical and biological properties of kiwifruit are critical to consumer acceptance and commercial success.

Kiwifruit becomes a versatile ingredient for formulating food products. Various kiwifruit-derived ingredients have been developed in nutraceutical, pharmaceutical, cosmetic, detergent and textile industries (Supplementary materials). Recent research has focused on omics-based breeding programs, agricultural practice, harvesting and field handling, and optimization of preservation/storage of post-harvested fruits (Table 4) (Burdon, Pidakala, Martin, & Billing, 2017; Folletta et al., 2019; Han et al., 2019; Horák, Šnurkovič, Ondrášek, Balfk, & Srilaong, 2019; Meng, Zhang, & Adhikari, 2014; Nieuwenhuizen, Allan, & Atkinson, 2016; Oh, Muneer, Kwack, Shin, & Kim, 2017; Vivek & Subbarao, 2018). These approaches have improved the yield, tolerance to diseases, and eating-quality of kiwifruit. Underutilized kiwifruit resources, such as thinned young kiwifruits (TYK), culled fruits, and certain plant parts (peels/seeds/leaves/roots) deserve exploration for food and other applications. Reducing underutilization and food wastes are strategies that maximize kiwifruit resources. Allergenicity and mycotoxins, pesticides, and heavy metal contamination in kiwifruit products are major concerns of food safety (Luo, Li, Yuan, & Yue, 2016; Wang, Vanga, McCusker, & Raghavan, 2019).

Previous reviews have addressed comparative studies of the chemical composition and/or bioactivities of green and gold kiwifruit (Stonehouse et al., 2012; Richardson et al., 2018), or between kiwifruits and persimmon (Perez-Burillo et al., 2018) or particular species, such as *A. chinensis* (He et al., 2019) and *A. arguta* (Baranowska-Wójcik & Sz wajgier, 2019; Latocha, 2017; Pinto, Delerue-Matos, & Rodrigues, 2020). Others reviewed particular topics regarding kiwifruits, including flavors (Garcia, Quek, Stevenson, & Winz, 2012), allergens (Wang, Vanga, McCusker et al., 2019), production and process technologies (Guroo et al., 2017), and anticancer potential (Lippi & Mattiuzzi, 2020). Importance of the latest (recent 5 years) findings and technological advances in different topics, such as starch, phytochemicals, underutilized resources, and bioactive compounds and their bioactivities of diverse *Actinidia* species has not been covered adequately in these previous reviews. The paper provides a broad-scoped overview of kiwifruit from comprehensive literature. The literature was searched between 2015 and 2020 from the databases, including PubMed, Scopus, ScienceDirect, Web of Science and Google Scholar. Broad match keywords including “*Actinidia*”, “kiwifruit”, “chemical”, “phytochemical”, or “bioactivity” were used.

Focusing on different kiwifruit plant parts [edible fruits (or peels), flowers, leaves, stems and roots]) and varieties (species and cultivars), this review summarizes nutrients, phytochemical compounds, bioactives and their associated health benefits. This review also updates technical strategies for maximizing functional ingredient extraction,

quality, safety, and shelf life of kiwifruit products. Different kiwifruit varieties are compared within each study of chemistry and bioactivity. Recent diverse/innovative products used in food and non-food sectors are supplemented. This review provides a comprehensive chemical and bioactive overview of a wide variety of kiwifruit resources in recent research in order to provide scientific supports for maximizing unitization of kiwifruit resources.

2. Chemical properties of kiwifruit

Great variations of chemical composition are present in different kiwifruit varieties (Table 2). Integration of metabolomics and transcriptomics identified dynamic changes of 285 metabolites over the development of tetraploid yellow-flesh Chinese *A. chinensis* ‘Jinshi 1’ (Xiong et al., 2020). These 285 metabolites includes 19 carbohydrates, 99 organic acids and derivatives, 86 amino acid and derivatives, 69 lipids, and 12 vitamins and derivatives (Xiong et al., 2020). NMR-based metabolomic analysis of *A. arguta*, *A. deliciosa* ‘Hayward’, and *A. eriantha* ‘Bidan’ identified 41 metabolites, including organic acids, phenolics, flavonoids, fatty acids, and amino acids. Different varieties affect more to kiwifruit metabolite constituents than cultivation origin (Abdul Hamid et al., 2017).

2.1. Proximate composition

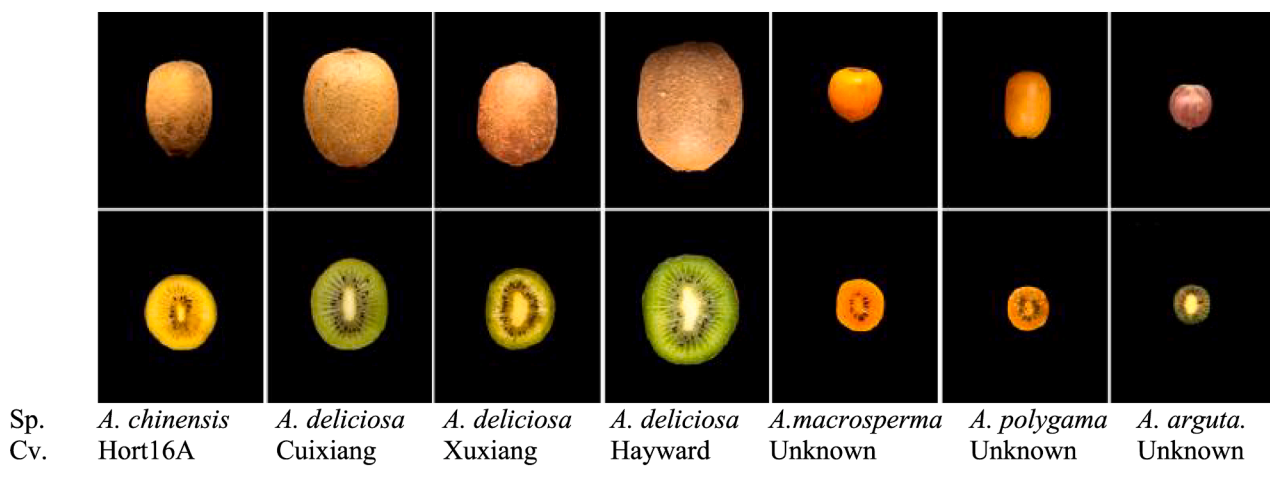
Different kiwifruits varieties have a moisture content of over 80% (USDA, 2017; Chakraborty, Chakraborty, & Saha, 2020; Dias et al., 2020; Özcan et al., 2020). Based on fresh weight (FW), moisture, protein, total lipid, carbohydrate, total dietary fiber and ash contents in New Zealand SunGold were 82, 1, 0.3, 15, 1.4 and 0.5%, respectively (USDA, 2017). The contents of moisture, carbohydrates, proteins and lipids were 85, 11, 1.3 and 0.52%, respectively; in *A. deliciosa* fruit pulp (Chakraborty et al., 2020). Stems of *A. arguta* contained 5.45% moisture, 0.63% crude lipid, 2.46% crude protein and 2.25% ash (Pinto et al., 2020). New Zealand *A. deliciosa* ‘Hayward’ flour was composed of 4.27% protein, 2.3% lipid and 4.7% ash. *A. chinensis* ‘Gold3’ flour was composed of 4.75% protein, 1.7% lipid and 3.9% ash (Li & Zhu, 2019).

2.2. Carbohydrates

2.2.1. Starch

Total starch content (TSC) of kiwifruit, varied among cultivars, and was also depended on maturation during storage (Li & Zhu, 2018b). *A. deliciosa* ‘Hayward’ and *A. chinensis* ‘Gold3’ had TSC of 41 and 52%, dry weight (DW), respectively (Li & Zhu, 2019). TSC of kiwifruit flours was lower than that of potato (65%), maize (84%) and wheat (77%) flours (Li & Zhu, 2019). Starch accumulates during kiwifruit development. Depending on DW, *A. deliciosa* ‘Hayward’ had the lowest TSC of 1.76% at 31 days of growth (DG), and highest TSC of 45.87% at 129 DG. *A. chinensis* ‘Gold3’ had the lowest TSC of 2.95% at 40 DG and highest TSC of 58.45% at 137 DG. Outer pericarp of ‘Gold3’, ‘Gold9’ and

A



B

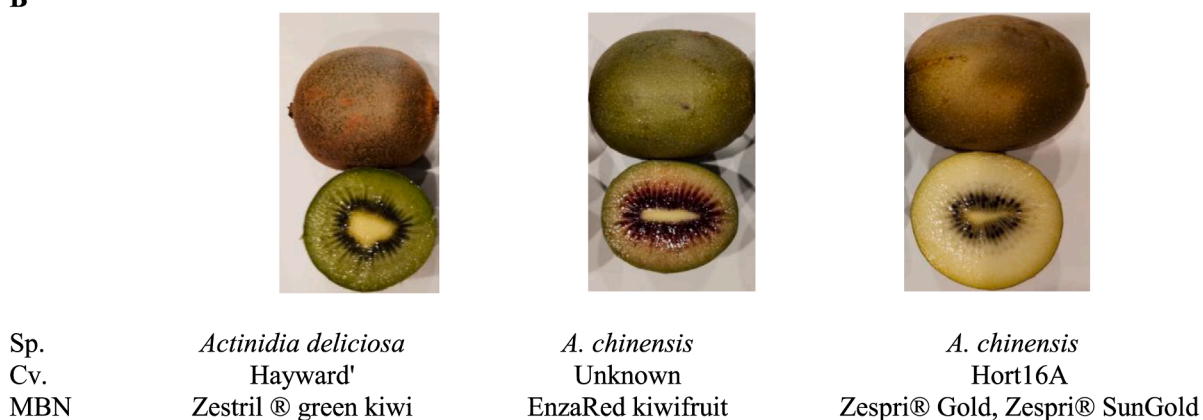


Fig. 1. Morphological characteristics of representative kiwifruits collected in A) China (Li et al., 2018) (Reprinted with permission from MDPI). B) New Zealand (Photos taken at Auckland, New Zealand); Sp., species; Cv., cultivar; MBN, marketed brand name.

'Hort16A' had higher TSC than core tissue (Li & Zhu, 2017). Starch converts to sugars during storage. Ripe kiwifruit contained little starch (USDA, 2017).

Kiwifruit starch exhibited B-type X-ray diffraction pattern. The starch granules were flattened and spheroid in shape with a size of 4–10 µm. The morphology of the starch depended on fruit varieties, parts (outer pericarp versus core) and development stages (Li & Zhu, 2017). Starches of *A. chinensis* 'Gold3', 'Gold9' and 'Hort16A' had similar

composition and physiochemical properties such as amylose leaching, swelling power, water soluble index, and rheology (Li & Zhu, 2017). Outer pericarp starches of *A. deliciosa* 'Hayward' and *A. chinensis* 'Gold3' exhibited similar granule morphology (Li & Zhu, 2018b). New Zealand *A. deliciosa* 'Hayward' (19.6%) and *A. chinensis* 'Gold3' (9.9%) flours varied in amylose content (Li & Zhu, 2019). Compared to potato and maize starch pastes, kiwifruit starches had higher enthalpy change for gelatinization and yield stresses. Rheological properties of kiwifruit

Table 2
Chemical composition of kiwifruits.

Chemical composition	Concentrations									
	<i>A. deliciosa</i> (fuzzy kiwifruit)			<i>A. chinensis</i> (golden kiwifruit)		<i>Actinidia</i> spp. (red kiwi)	<i>A. arguta</i> (hardy kiwifruit)	<i>A. macrosperma</i>	<i>A. polygama</i>	
Proximate composition	Pulp	Peel	Seed	Pulp	Seed	Pulp	Peel	Pulp	Pulp	Pulp
Moisture (g/100 g FW)	81.3–85.1 ^{3,5,7,17}			82.44 ¹⁷	5.26 ¹⁵	82.3 ⁵		82.8–84.7 ²¹		
Crude protein (g/kg DM)	53 ¹			68 ¹						
(g/100 g FW)	1.06–1.31 ^{5,7,17}			1.02 ¹⁷		1.54 ⁵				
(N × 6.25)					15.67 ¹⁵					
Total lipid (g/kg DM)	50 ¹			27 ¹						
(g/100 g FW)	0.42–0.52 ^{5,7,17}			0.28 ¹⁷		0.031 ⁵				
(% DW)			98.50 ¹⁶		35.54 ¹⁵					
Total carbohydrate (g/100 g FW)	10.9–14 ^{5,7,17}			15.79 ¹⁷	40.77 ¹⁵	15.4 ⁵				
Total ash (g/kg DM)	40 ¹			44 ¹						
(g/100 g FW)	0.63–0.69 ^{5,17}			0.47 ¹⁷		0.78 ⁵				
(% DW)					2.65 ¹⁵					
Physicochemical parameters										
Soluble solids content (% or Brix°)	13.1–19.1 ^{9,14,18}			13.6–17.5 ^{9,14}		6.1–13.9 ^{9,10}		14.0 ⁹	15.4 ⁹	
Reducing sugar (g/L)	125.29 ¹⁸			98.53 ¹⁸						
pH	3.27 ¹⁸			3.39 ¹⁸						
Titrate acidity (%)						1.0 ¹⁰				
(mg/L juice, expressed as malic acid)	5.9–20.5 ¹⁴			10.1–12.7 ¹⁴						
(g/L juice, expressed as malic acid)	12.16 ¹⁸			12.06 ¹⁸						
Firmness (N)	3.5–9.6 ¹⁴			5.5–26.9 ¹⁴		19.7–29.9 ¹⁰				
FW (g)						7.8–10.9 ¹⁰				
Nitrogen-free extractives (g/kg DM)	857 ¹			861 ¹						
Gross energy (kJ/g DM)	17.6 ¹			16.7 ¹						
(kcal/100 g FW)	58–64.2 ^{5, 17}			63 ¹⁷		67.4 ⁵				
(kJ/100 g FW)	259.8 ⁷									
Carbohydrates										
Total sugars (g/kg DM)	492 ¹			533 ¹						
(g/100 g FW)	8.30 ⁷									
(g/100 g FW, including NLEA)				12.3 ¹⁷						
Total free sugar	8.90–8.99 ^{5,17}			7.11–7.76 ³		10.49 ⁵		7.34–8.20 ³		
Fructose (g/100 g FW)	3.83–4.35 ^{5,17}			5.80 ¹⁷		3.39 ⁵		1.19–2.13 ³		
Glucose (dextrose, g/100 g FW)	3.52–4.11 ^{5,17}			5.28 ¹⁷		3.09 ⁵		0.95–1.89 ³		
Sucrose (g/100 g FW)	0.15–1.44 ^{5,17}			1.22 ¹⁷		1.44 ⁵		4.19–5.86 ³		
Trehalose (g/100 g FW)	0.110 ⁵					0.080 ⁵				
Lactose (g/100 g FW)	0.02 ¹⁷									
Maltose	0.19 ¹⁷									
Galactose	0.17 ¹⁷									
Total starch (g/kg DM)	3.1 ¹			3.7 ¹						
(g/100 g FW)				0.12 ¹⁷						
(% DW)	45.87			58.45						
Total dietary fiber (g/kg DM)	170 ¹			134 ¹						
(g/100 g FW)	3 ¹⁷			1.4 ¹⁷						
Soluble fiber (g/100 g FW)	0.7 ¹⁷									
Insoluble (g/100 g FW)	2.3 ¹⁷									
Lipids										
Fatty acid (FA) composition (g/100 g FW)										
Total saturated FAs	0.029–6.955 ^{5,17}			0.065 ¹⁷		19.77 ⁵				
Butyric acid (C4:0)				0.001 ¹⁷						
Caproic acid (C6:0)	0.008 ⁵					0.03 ⁵				

(continued on next page)

Table 2 (continued)

Chemical composition	Concentrations									
	<i>A. deliciosa</i> (fuzzy kiwifruit)			<i>A. chinensis</i> (golden kiwifruit)		<i>Actinidia</i> spp. (red kiwi)		<i>A. arguta</i> (hardy kiwifruit)	<i>A. macrosperma</i>	<i>A. polygama</i>
Proximate composition	Pulp	Peel	Seed	Pulp	Seed	Pulp	Peel	Pulp	Pulp	Pulp
Caprolic acid (C8:0)	0.016 ⁵			0.001 ¹⁷		0.04 ⁵				
Capric acid (C10:0)	0.003 ⁵			0.001 ¹⁷		0.03 ⁵				
Undecylic acid (C11:0)	0.024 ⁵					0.099 ⁵				
Lauric acid (C12:0)	0.025 ⁵			0.003 ¹⁷		0.38 ⁵				
Tridecylic acid (C13:0)	0.018 ⁵					0.017 ⁵				
Myristic acid (C14:0)	0.044 ⁵			0.003 ¹⁷		0.8 ⁵				
Pentadecylic acid (C15:0)	0.015 ⁵					0.165 ⁵				
Palmitic acid (C16:0)	0.017–4.6 ^{5,17}		5.42 ¹⁶	0.048 ¹⁷		14.3 ⁵				
Margaric acid (C17:0)	0.048 ⁵					0.23 ⁵				
Stearic acid (C18:0)	0.012–2.05 ⁵		3.34 ¹⁶	0.006 ¹⁷		2.9 ⁵				
Arachidic acid (C20:0)	0.037 ⁵			0.001 ¹⁷		0.44 ⁵				
Heneicosylic acid (C21:0)	0.011 ⁵					0.113 ⁵				
Behenic acid (C22:0)	0.043 ⁵					0.27 ⁵				
Total monounsaturated FAs	0.047–9.9 ⁵					10.29 ⁵				
Myristoleic acid (14:1)				0.005 ¹⁷						
Palmitoleic acid (C16:1)	0.106 ⁵			0.004 ¹⁷		1.05 ⁵				
(C16:1C)				0.004 ¹⁷						
<i>cis</i> -10-heptadecenoic acid (C17:1)	0.020 ⁵					0.10 ⁵				
Oleic acid (C18:1)	8.9 ⁵			0.014 ¹⁷		7.94 ⁵				
Oleic acid (C18:1C)	0.047–0.81 ^{5,17}			0.014 ¹⁷		0.96 ⁵				
(% of total fatty acids)			14.42 ¹⁶							
Eicosenoic acid (C20:1)	0.015 ⁵					0.205 ⁵				
Erucic acid (C22:1)	0.081 ⁵					0.04 ⁵				
Total polyunsaturated FAs	83.13 ⁵			0.111 ¹⁷		69.93 ⁵				
Linoleic acid (C18:2, n-6, undifferentiated)	0.246–14.44 ^{5,17}			0.06 ¹⁷		28.3 ⁵				
C18:2n-6c,c				0.058 ¹⁷						
C18:2 CLAs				0.001 ¹⁷						
(% of total fatty acids)			13.51 ¹⁶							
α -Linolenic acid (C18:3, n-3, undifferentiated)	68.0 ⁵			0.043 ¹⁷		35.0 ⁵				
C18:3n-3c,c,c				0.043 ¹⁷						
(% of total FAs)			63.40 ¹⁶							
γ -Linolenic acid (C18:3, n-6)	0.024–0.042 ⁵					0.012 ⁵				
(% of total fatty acids)			0.36 ¹⁶							
Eicosadienoic acid (C20:2);	0.254 ⁵					1.59 ⁵				
Eicosatrienoic acid (C20:3)				0.008 ¹⁷						
(20:3n-3)				0.008 ¹⁷						
(20:3n-6)				0.001 ¹⁷						
Erachidonic acid (C20:4, n-6)	0.334 ⁵					4.71 ⁵				
Protein										
Amino acids										
Tryptophan (g/100 g FW)	0.013 ¹⁷									
(mg/100 g FW)	5.25–17.40 ²⁰			9.20–16.85 ²⁰						
Threonine (g/100 g FW)	0.043 ¹⁷									
(mg/100 g FW)	22.20–26.00 ²⁰			19.85–29.15 ²⁰						
Isoleucine (g/100 g FW)	0.046 ¹⁷									
(mg/100 g FW)	18.70–24.05 ²⁰			16.00–25.30 ²⁰						
Leucine (g/100 g FW)	0.059 ¹⁷									
(mg/100 g FW)	20.95–30.05 ²⁰			21.10–35.20 ²⁰						

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Table 2 (continued)

Chemical composition		Concentrations									
		<i>A. deliciosa</i> (fuzzy kiwifruit)			<i>A. chinensis</i> (golden kiwifruit)		<i>Actinidia</i> spp. (red kiwi)		<i>A. arguta</i> (hardy kiwifruit)	<i>A. macrosperma</i>	<i>A. polygama</i>
Proximate composition		Pulp	Peel	Seed	Pulp	Seed	Pulp	Peel	Pulp	Pulp	Pulp
Lysine	(g/100 g FW)	0.055 ¹⁷			27.70–69.05 ²⁰						
Methionine	(mg/100 g FW)	31.20–63.30 ²⁰									
	(g/100 g FW)	0.022 ¹⁷									
Cystine	(mg/100 g FW)	10.95–24.40 ²⁰			12.20–22.15 ²⁰						
	(g/100 g FW)	0.028 ¹⁷									
Phenylalanine	(mg/100 g FW)	60.50–69.85 ²⁰			57.10–72.45 ²⁰						
	(g/100 g FW)	0.039 ¹⁷									
Tyrosine	(mg/100 g FW)	28.25–60.30 ²⁰			37.95–61.45 ²⁰						
	(g/100 g FW)	0.03 ¹⁷									
Valine	(mg/100 g FW)	54.95–79.35 ²⁰			59.35–78.50 ²⁰						
	(g/100 g FW)	0.052 ¹⁷									
Arginine	(mg/100 g FW)	31.85–37.50 ²⁰			31.35–40.40 ²⁰						
	(g/100 g FW)	0.073 ¹⁷									
Histidine	(mg/100 g FW)	20.55–64.450 ²⁰			49.00–181.05 ²⁰						
	(g/100 g FW)	0.024 ¹⁷									
Alanine	(mg/100 g FW)	12.25–20.05 ²⁰			12.80–25.00 ²⁰						
	(g/100 g FW)	0.048 ¹⁷									
Aspartic acid	(mg/100 g FW)	36.75–45.80 ²⁰			46.60–53.15 ²⁰						
	(g/100 g FW)	0.113 ¹⁷									
Glutamic acid	(mg/100 g FW)	51.80–61.50 ²⁰			50.80–97.50 ²⁰						
	(g/100 g FW)	0.165 ¹⁷									
Glycine	(mg/100 g FW)	80.50–99.30 ²⁰			88.75–143.50 ²⁰						
	(g/100 g FW)	0.054 ¹⁷									
Proline	(mg/100 g FW)	22.15–27.30 ²⁰			18.2–29.65 ²⁰						
	(g/100 g FW)	0.04 ¹⁷									
Serine	(mg/100 g FW)	11.25–15.25 ²⁰			10.90–18.10 ²⁰						
	(g/100 g FW)	0.047 ¹⁷									
TFAA/protein (%)		20.70–24.95 ²⁰			20.95–29.40 ²⁰						
		55.56–60.11 ²⁰			40.02–54.82 ²⁰						
Minor constituents											
Minerals											
Calcium (Ca, mg/100 g FW)		35 ¹⁷			17 ¹⁷						
Iron (Fe, mg/100 g FW)		0.24 ¹⁷			0.21 ¹⁷						
Magnesium (Mg, mg/100 g FW)		15.7 ¹⁷			12 ¹⁷						
Phosphorus (P, mg/100 g FW)		34 ¹⁷			25 ¹⁷						
Potassium (K, mg/100 g FW)		198–312.53 ^{7,17}			315 ¹⁷						
Sodium (Na, mg/100 g FW)		2.81–5 ^{7,17}			3 ¹⁷						
Zinc (Zn, mg/100 g FW)		0.14 ¹⁷			0.08 ¹⁷						
Copper (Cu, mg/100 g FW)		0.134 ¹⁷			0.151 ¹⁷						
Manganese (Mn, mg/100 g FW)		0.064 ¹⁷			0.048 ¹⁷						
Selenium (Se, mg/100 g FW)		0.2 ¹⁷			0.4 ¹⁷						
Vitamins											
Vitamin C	(mg/g DW)	5.63 ²									
	(g/100 g FW)	0.0625–0.0891 ⁷			0.103 ⁵						
	(mg/100 g FW)	53.42–390.68 ^{9,14,17}			59.32–169.54 ^{9,14,17}		0.037 ⁵ 0.0529 ⁵		51.3–130.0 ^{9,13}	85.94 ⁹	51.32 ⁹
Thiamin (mg/100 g FW)		0.027 ¹⁷									
Riboflavin (mg/100 g FW)		0.025 ¹⁷			0.074 ¹⁷						
Niacin (mg/100 g FW)		0.37 ¹⁷			0.231 ¹⁷						
Pantothenic acid (mg/100 g FW)		0.206 ¹⁷			0.12 ¹⁷						

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Table 2 (continued)

Chemical composition	Concentrations									
	<i>A. deliciosa</i> (fuzzy kiwifruit)			<i>A. chinensis</i> (golden kiwifruit)		<i>Actinidia</i> spp. (red kiwi)		<i>A. arguta</i> (hardy kiwifruit)	<i>A. macrosperma</i>	<i>A. polygama</i>
Proximate composition	Pulp	Peel	Seed	Pulp	Seed	Pulp	Peel	Pulp	Pulp	Pulp
Vitamin B ₆ (mg/100 g FW)	0.061 ¹⁷			0.079 ¹⁷						
Folate (μg/100 g FW)	26 ¹⁷			31 ¹⁷						
Choline (mg/100 g FW)				1.9 ¹⁷						
Vitamin B ₁₂				0.08 ¹⁷						
Vitamin A (μg/100 g FW, RAE)	4 ¹⁷			1 ¹⁷						
(mg/100 g FW)	20.0 ⁷									
Vitamin K (phylloquinone) (μg/100 g FW)	40.3 ¹⁷			6.1 ¹⁷						
Vitamin E (α-Tocopherol (mg/100 g FW)	1.3–1.7 ^{5,17}	3.57 ⁵		1.4 ¹⁷		2.40 ⁵	7.4 ⁵			
β-Tocopherol (mg/100 g FW)				0.04 ¹⁷						
γ-Tocopherol (mg/100 g FW)	0.03–0.04 ^{5,17}	1.01 ⁵		0.07 ¹⁷		0.060 ⁵	1.70 ⁵			
δ-Tocopherol (mg/100 g FW)	ND ⁵	ND ⁵				1.86 ⁵	1.75 ⁵			
Total tocopherols (mg/100 g FW)	1.7 ⁵	4.58 ⁵				4.3 ⁵	10.8 ⁵			
γ-Tocotrienol (mg/100 g FW)	0.1 ¹⁷									
Organic acids										
Total organic acids (g/100 g FW)	2.90 ⁵	3.7 ⁵				3.88 ⁵	3.67 ⁵			
Quinic acid	0.70 ⁵	1.91 ⁵				1.5 ⁵	1.6 ⁵			
Malic acid	0.58 ⁵	0.60 ⁵				0.82 ⁵	0.62 ⁵			
Citric acid	1.56 ⁵	1.27 ⁵				1.310 ⁵	1.38 ⁵			
Chlorophylls										
Total chlorophylls (μg/g DW)	72.13 ²									
Chlorophyll <i>a</i>	56.15 ²									
Chlorophyll <i>b</i>	15.98 ²									
Chlorophyll derivatives										
Pheophytin <i>a</i>	408 ¹²									
Pheophytin <i>b</i>	75 ¹²									
Carotenoids										
Total carotenoids (μg/100 g DM)	531 ¹²									
(mg/100 g FW)	0.18 ¹⁴			0.18–0.35 ¹⁴						
Lutein + zeaxanthin (μg/100 g FW)	122 ¹⁷			24 ¹⁷						
Xanthophyll + carotene (μg/g DW)	26.14 ²									
Lutein (μg/100 g DM)	362 ¹²									
β-carotene (μg/100 g DM)	79 ¹²									
(μg/100 g FW)	52 ¹⁷			14 ¹⁷						
Neolutein A + B (μg/100 g DM)	50 ¹²									
Neoxanthin (μg/100 g DM)	33 ¹²									
Violaxanthin (μg/100 g DM)	6.3 ¹²									
Phenolic compounds										
Total phenolics (mgGAE/g DW)	3.75–8.19 ^{2,4,9}			4.7–16.52 ⁹			8.15 ⁹	5.57 ⁹		4.71 ⁹
(mgGAE/100 g FW)	71.2–94.7 ^{8,14}			101–169 ¹⁴			65.69–140.00 ¹⁰			
(μg/g DW)	479.02 ¹¹			231.32 ¹¹				586.9 ¹¹		
(mg/g peel)		5.881 ⁶								
Phenolic acids and derivatives										
Total hydroxycinnamic derivatives (mg/g peel)		0.459 ⁶								
Gallic acid (mg/100 g DW)	29.406 ⁴									
(μg/g DW)	5.64–9.74 ⁹			12.17–53.74 ⁹			ND ⁹	ND ⁹		9.90 ⁹
3,4-dihydroxybenzoic acid (mg/100 g DW)	34.120 ⁴									

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Table 2 (continued)

Chemical composition		Concentrations									
		<i>A. deliciosa</i> (fuzzy kiwifruit)			<i>A. chinensis</i> (golden kiwifruit)		<i>Actinidia</i> spp. (red kiwi)		<i>A. arguta</i> (hardy kiwifruit)	<i>A. macrosperma</i>	<i>A. polygama</i>
Proximate composition		Pulp	Peel	Seed	Pulp	Seed	Pulp	Peel	Pulp	Pulp	Pulp
Syringic acid (mg/100 g DW)		2.585 ⁴									
<i>p</i> -coumaric acid (mg/100 g DW)		0.06 ⁴									
Protocatechuic acid (µg/g DW)		ND ⁹			6.55–15.76 ⁹				ND ⁹	ND ⁹	12.19 ⁹
Chlorogenic acid (µg/g DW)		0.28 ¹¹ –235.75 ⁹			0.39 ¹¹ –75.25 ⁹				7.70 ⁹	27.12 ⁹	1.97 ¹¹ –63.50 ⁹
Neochlorogenic acid (µg/g DW)		ND ⁹			6.29–133.72 ⁹				21.14 ⁹	ND ⁹	ND ⁹
Ferulic acid (µg/g DW)		0.60 ¹¹			0.42 ¹¹					4.70 ¹¹	
<i>trans</i> -ferulic acid (mg/100 g DW)		0.363 ⁴									
Isoferulic acid (µg/g DW)		28.17 ¹¹			15.12 ¹¹					32.71 ¹¹	
Ferulic acid glucoside (mg/g peel)			0.174 ⁶								
Ferulic acid dehydrodimer (mg/g peel)			0.042 ⁶								
Caffeic acid (mg/100 g DW)		1.592 ⁴									
(µg/g DW)		ND ⁹ –0.08 ¹¹			ND ⁹ –0.04 ¹¹			22.56 ⁹	40.97 ⁹	1.64 ¹¹ –2.69 ⁹	
Caffeic acid hexosides (mg/g ext)		Traces–1.65 ⁵	ND–3.35 ⁵				ND–13.60 ⁵	ND–2.22 ⁵			
Caffeic acid dihexosides (mg/g ext)		0.52 ⁵	ND ⁵				ND ⁵	ND ⁵			
Caffeic acid derivatives (mg/g ext)		ND–0.38 ⁵	ND–1.23 ⁵				ND–8.6 ⁵	ND–2.14 ⁵			
Caffeic acid derivative (mg/g peel)			0.243 ⁶								
Dimethyl caffeic acid hexoside (mg/g ext)		0.35 ⁵	ND ⁵				1.35 ⁵	0.85 ⁵			
Acetyl-dimethyl caffeic acid hexoside (mg/g ext)		ND ⁵	ND ⁵				3.33 ⁵	0.136 ⁵			
Dimethyl caffeic acid hexoside (mg/g peel)			Trace ⁶								
Flavonoids											
Total flavonoids	(mg CE/g DW)	2.11–2.47 ²									
	(mg CE/100 g FW)	2.08–4.23 ^{8,14}			3.97–17.09 ^{8,14}						
Flavanols											
Total flavanols (µg CE/g DW)		0.14–0.16 ²									
(mg CE/100 g FW)		103.8–159.4 ⁸			81.5–119.4 ⁸						
Isorhamnetin (mg/100 g DW)		8.503 ⁴									
Kaempferol (mg/100 g DW)		8.096 ⁴									
Kaempferol-3-Orutinoside (mg/g ext)		0.347 ⁵	0.464 ⁵				ND ⁵	ND ⁵			
Quercetin (mg/100 g DW)		1.865 ⁴									
Quercetin (µg/g DW)		0.17 ¹¹			ND ¹¹					2.56 ¹¹	
Quercetin-3-O-glucoside (mg/g ext)		ND ⁵	0.64 ⁵				0.406 ⁵	0.42 ⁵			
(µg/g DW)		0.14 ¹¹ –5.10 ⁹			0.45 ¹¹ –6.16 ⁹				11.02 ⁹	4.16 ¹¹	108.60 ⁹
Quercetin-3-O-galactoside (µg/g DW)		441.39 ¹¹			205.19 ¹¹					470.9 ¹¹	
Quercetin arabinoglucoside (µg/g DW)		0.21 ¹¹			0.06 ¹¹					2.53 ¹¹	
Quercetin-3-O-rhamnoside (mg/g ext)		0.360 ⁵	2.59 ⁵				0.74 ⁵	0.295 ⁵			
(µg/g DW)		0.31 ¹¹	0.61 ¹¹							2.99 ¹¹	
Quercetin-3-O-rutinoside (mg/g ext)		0.358 ⁵	0.53 ⁵				ND ⁵	ND ⁵			
(µg/g DW)		0.55 ¹¹	0.29 ¹¹							1.96 ¹¹	
Rutin (µg/g DW)									8.27 ⁹	17.58 ⁹	48.23 ⁹
Rutin trihydrate (mg/100 g DW)		0.387 ⁴									
Favanols (Flavan-3-ols)											
Epigallocatechin (µg/g DW)		0.46 ¹¹			0.61 ¹¹					1.55 ¹¹	
Epigallocatechingallate (µg/g DW)		0.40 ¹¹			ND ¹¹					0.75 ¹¹	
(+) -catechin (µg/g DW)		0.30 ¹¹ –14.71 ⁹			0.75 ¹¹ –32.08 ⁹				132.08 ⁹	28.72 ⁹ –54.31 ¹¹	43.30 ⁹
(mg/100 g DW)		46.91 ⁴									
(–) -epicatechin (µg/g DW)		0.74 ¹¹ –27.96 ⁹			5.15 ¹¹ –162.61 ⁹				ND ⁹	0.91 ¹¹ –31.48 ⁹	26.12 ⁹
(mg/g ext)		11.8 ⁵	0.59 ⁵				163 ⁵	110 ⁵			
B-type (<i>epi</i>) CA dimer (mg/g ext)		5.4 ⁵	ND ⁵				35 ⁵	23.3 ⁵			
B-type (<i>epi</i>) CA trimers (mg/g ext)		ND ⁵	ND ⁵				14.9–24.6 ⁵	7.4–17.6 ⁵			

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Table 2 (continued)

Chemical composition	Concentrations									
	<i>A. deliciosa</i> (fuzzy kiwifruit)			<i>A. chinensis</i> (golden kiwifruit)		<i>Actinidia</i> spp. (red kiwi)		<i>A. arguta</i> (hardy kiwifruit)	<i>A. macrosperma</i>	<i>A. polygama</i>
Proximate composition	Pulp	Peel	Seed	Pulp	Seed	Pulp	Peel	Pulp	Pulp	Pulp
B-type (<i>epi</i>) CA tetramer (mg/g ext)	ND ⁵	3.6 ⁵				30.4 ⁵	18.8 ⁵			
B-type (<i>epi</i>) CA pentamers (mg/g ext)	ND ⁵	ND ⁵				12.4–12.9 ⁵	6.6–7.7 ⁵			
Procyanidins										
Procyanidin B1 (μg/g DW)	91.03–118.58 ⁹			64.60–446.81 ⁹				58.72 ⁹	107.98 ⁹	ND ⁹
Procyanidin B2 (μg/g DW)	17.88–146.28 ⁹			20.91–182.11 ⁹				65.17 ⁹	112.73 ⁹	81.42 ⁹
Procyanidin dimer (mg/g peel)		0.696 ⁶								
Procyanidin trimers (mg/g peel)		0.665–1.193 ⁶								
Procyanidin tetramer (mg/g peel)		0.142 ⁶								
Total procyanidins (mg/g peel)		5.422 ⁶								
Flavones										
Apigenin 7-glucoside (mg/100 g DW)	0.347 ⁴									
Flavanones										
Naringenin (mg/100 g DW)	2.479 ⁴									
Dihydrochalcones										
Phloridzin (μg/g DW)	5.08 ¹¹	2.03 ¹¹							3.12 ¹¹	
Phloritin (μg/g DW)	0.14 ¹¹	0.21 ¹¹							0.14 ¹¹	
Anthocyanins										
Total anthocyanins (mg CGE /g DW)	20.21 ²									
(mg CGE /100 g FW)	1.37–3.34 ⁸			2.43–4.05 ⁸						
Cyanidin-3-sambubioside (mg/g ext.)	ND ⁵	ND ⁵				12.9 ⁵	ND ⁵			
Stilbenoids										
Resveratrol (mg/100 g DW)	0.386 ⁴									

Notes: ¹ Fresh ripe de-skinned kiwifruits (*A. deliciosa* ‘Hayward’ and *A. chinensis* ‘Hort16A’ (Henare et al., 2012). ² Water and methanol extracts of fresh kiwi fruit ‘Hayward’ cultivated in Korea (Park et al., 2016). ³ *A. arguta* Ananasnaya, *A. arguta* – seedling, *A. arguta* ‘Issai’, *A. chinensis* ‘Soreli’, *A. deliciosa* ‘Hayward’ (Horák et al., 2019); ⁴ *A. deliciosa* purchased in Turkey (Özcan et al., 2020); ⁵ Pulp and peel of *A. deliciosa* ‘Hayward’ (green kiwi) and *Actinidia* spp. (red kiwi) from Portugal (Dias et al., 2020); ⁶ Peel of *A. deliciosa* ‘Hayward’ from Italy (D’eliseo et al., 2019); ⁷ Fresh kiwifruits (*A. deliciosa*) (Chakraborty et al., 2020); ⁸ Four varieties, namely Hayward (green flesh) (*A. deliciosa*), Qinmei (green flesh) (*A. deliciosa*), Hongyang (green flesh and red in the middle) (*A. chinensis*) and Huayou (yellow flesh) (*A. chinensis*) harvested in China (Ma et al., 2019); ⁹ Eight different *A. chinensis* cultivars, three different *A. deliciosa* cultivars, *A. macrosperma*, *A. polygama*, and *A. arguta* (Li et al., 2018); ¹⁰ Hardy kiwifruit ‘Cheongsan’ grown in Korea and harvested in August (SSC 6%) and September (SSC 8%). ¹¹ *A. macrosperma*, *A. deliciosa* and *A. chinensis* from New Zealand (Hettihewa et al., 2018). ¹² *A. deliciosa* ‘Hayward’ (Benlloch-Tinoco et al., 2015); ¹³ Three different hardy kiwifruits (*A. arguta* × *A. deliciosa* ‘Mansu’, *A. arguta* ‘Haeyeon’, and *A. arguta* ‘Chiak’) from Korea (Jeong et al., 2020); ¹⁴ Four of yellow-fleshed (*A. chinensis* var. *chinensis* – ‘Dori’, ‘G3’, ‘Jintao’ and ‘Soreli’) and two green-fleshed (*A. chinensis* var. *deliciosa* – ‘Hayward’ and ‘Summer’) from Italy (Cozzolino et al., 2020); ¹⁵ Dried *A. chinensis* seeds (Deng et al., 2014); ¹⁶ Seed oil of *A. deliciosa* grown in Brazil by compressed propane extraction (Renata Coelho et al., 2016); ¹⁷ USDA National nutrient database release, NDB Number 9148 kiwifruit, green, raw., fruit source not stated; and NDB Number 9520 kiwifruit, ZESPRI SunGold, raw, grown in New Zealand (USDA, 2017); ¹⁸ Fruit juices from *A. deliciosa* ‘Hayward’ and *A. chinensis* ‘Hort16A’, respectively, harvested in China (Zhao et al., 2020). ¹⁹ New Zealand grown *A. deliciosa* ‘Hayward’ at 129 days of the growth and *A. chinensis* ‘Gold3’ at 137 days of the growth (Li & Zhu, 2018b); ²⁰ New Zealand *A. deliciosa* ‘Hayward’ and *A. chinensis* ‘Hort16A’, and Chinese *A. deliciosa* (‘Hayward’, ‘Qinmei’, ‘Cuixiang’, ‘Jinxiang’, ‘Xuxiang’) and *A. chinensis* (‘Hort16A’, ‘Jintao’, ‘Hongyang’, ‘Huayou’) (Ma et al., 2017); ²¹ (Latocha, 2017). *A. deliciosa*, *Actinidia deliciosa*; CA, catechin; CE, catechin equivalent; CGE, cyanidin-3-glucoside equivalent; CLA, conjugated linoleic acid; DW, dry weight; ext, extract; GAE, gallic acid equivalent; ND: non-detected; NLEA, Nutrition Labeling and Education Act; FW, fresh weight; RAE, retinol activity equivalent, IU, international unit, 1 IU equals to 0.3 μg of retinol, 1.8 μg of β-carotene, or 3.6 μg of other provitamin-A carotenoids; TFAA, total free amino acids.

Table 3

Representative biological activities detected in different varieties of kiwifruit.

Plant parts	Varieties (cultivation origin)	<i>In vitro/in vivo</i> model systems		Observations	Tentative key bioactive components	References
Anti-oxidative						
Fruit extracts (ethanol and water)	6 cultivars, including 'Hort 16A' (New Zealand), 'Hayward', 'Daheung', 'Haenam', 'Bidan' and 'SKK12'	Assay Model Doses Admi. Time	<i>In vitro</i> chemistry-based FRAP, CUPRAC, and β -carotene Model-dependent Model-dependent Model-dependent	The FRAP, CUPRAC, and β -carotene values depended on cultivar types and extract solvents. Among 6 cultivars, the water extracts of 'SKK12' had the highest FRAP, CUPRAC, and β -carotene values (24.6 μ M TE/g DW, 43.3 μ M TE/g DW, and 27.6%, respectively).	Phenolic compounds	Park, Leontowicz et al. (2015)
Leaf extracts (water, ethanol, water–ethanol 50:50 v/v)	<i>A. arguta</i> (Portugal)	Assay Model Doses Admi. Time	<i>In vitro</i> chemistry-based FRAP, DPPH, ROS ($O_2^{\cdot-}$, H_2O_2 , HOCl, ROO $\cdot$) and RNS (NO $\cdot$, ONOO $^-$) scavenging assays Model-dependent Model-dependent Model-dependent	Depending on DW, aqueous leaf extracts exhibited the highest $O_2^{\cdot-}$ (IC ₅₀ = 24.4 μ g/mL) and HOCl (IC ₅₀ = 82.3 μ g/mL) scavenging abilities. Hydroalcoholic leaf extracts exhibited the highest ONOO $^-$ (with NaHCO ₃ , IC ₅₀ = 5.2 μ g/mL) scavenging ability. Alcoholic leaf extracts exhibited the highest H_2O_2 (IC ₅₀ = 192.7 μ g/mL), NO $\cdot$ (IC ₅₀ = 0.8 μ g/mL) and ONOO $^-$ (without NaHCO ₃ , IC ₅₀ = 4.7 μ g/mL), DPPH (IC ₅₀ = 54.0 μ g/mL) scavenging abilities, and FRAP (6628.4 μ mol of ferrous sulphate/g) values.	Polyphenols	Almeida et al. (2018)
Fruit peel and flesh polyphenols	<i>A. chinensis</i> (China)	Assay Model Doses Admi. Time	<i>In vitro</i> chemistry-based DPPH, ABTS, hydroxyl ion reduction, ion chelating Model-dependent Model-dependent Model-dependent	The peel polyphenols exhibited the higher DPPH and ABTS, hydroxyl ion reduction, ion chelating values than the flesh polyphenols, but lower than EDTA and vitamin C.	Polyphenols	Alim et al. (2019)
Mature and thinned young fruits (thinned at 20 and 60 days after fruit-set, respectively)	<i>A. chinensis</i> 'Zesy002', <i>A. chinensis</i> $\times$ <i>A. deliciosa</i> 'Zesh004', and <i>A. deliciosa</i> 'Hayward' (New Zealand)	Assay Model Doses Admi. Time	<i>In vitro</i> chemistry-based ABTS, DPPH, FRAP Model-dependent Model-dependent Model-dependent	Thinned young fruits exhibited higher ABTS, DPPH and FRAP values comparing with mature fruits. Thinned young fruit (thinned at 20 days after fruit-set) from 'Zesy002' had the highest ABTS, DPPH and FRAP values of 483.17, 324.88 and 341.65 μ mol TE/g FDW, respectively. Mature fruits from 'Hayward' had the lowest ABTS, DPPH and FRAP values of 27.29, 20.98, 26.08 μ mol TE/g FDW, respectively.	Polyphenols	Jiao et al. (2019)
Phenolic extracts of thinned young kiwifruits	<i>A. deliciosa</i> 'Hayward' (New Zealand)	Assay Model Doses Admi. Time	<i>In vitro</i> chemistry-based ABTS, DPPH, FRAP, TBARS Model-dependent Model-dependent Model-dependent	Phenolic extracts had ABTS, DPPH and FRAP values of 10.60, 6.76 and 2.89 μ mol TE/g, respectively. After 7 days refrigeration at 4 $^{\circ}$ C, the TBARS values (0.25 mg MDA/kg) of the raw round beef treated with phenolic extracts were similar to the TBARS value of the beef treated with epicatechin (0.22 mg MDA/kg), being lower than that of the beef with potassium sorbate (0.77 mg MDA/kg) and the control (0.69 mg MDA/kg).	Polyphenols containing epicatechin, quercitrin and catechin	Jiao et al. (2020)
Fermented fruit pulp	<i>Actinidia</i> Lindl. (China)	Assay Model Doses Admi. Time	<i>In vitro</i> chemistry-based DPPH, ABTS Model-dependent Model-dependent Model-dependent	<i>Lactobacillus plantarum</i> fermented fruit pulp had increased antioxidant compounds and DPPH and ABTS values.	Polyphenolics	Zhou et al. (2020)
Fruits	<i>A. deliciosa</i> (Turkey)	Assay Model Doses Admi. Time	<i>In vitro</i> chemistry-based DPPH Model-dependent Model-dependent Model-dependent	Microwave dried sample (92.3%) exhibited the highest DPPH scavenging ability, followed by oven dried (79.3%) and fresh sample (16.2%).	Phenolic acids, flavonoids	Özcan et al. (2020)
Fruit poly-saccharides	<i>A. chinensis</i> 'Hongshi' (China)	Assay Model	<i>In vitro</i> chemistry-based DPPH, ABTS, reducing power	Microwave-assisted extracted fruit polysaccharides had the highest DPPH, ABTS and reducing	Polysaccharides with low molecular weight and	Han et al. (2019)

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Table 3 (continued)

Plant parts	Varieties (cultivation origin)	<i>In vitro/in vivo</i> model systems		Observations	Tentative key bioactive components	References
Fruit pomace extracts	<i>A. deliciosa</i> 'Hayward' (New Zealand)	Doses Admi. Time Assay Model Doses Admi. Time	1, 1.5, 2, 2.5, 3 mg/mL Model-dependent Model-dependent <i>In vitro</i> chemistry-based DPPH, FRAP and ABTS Model-dependent Model-dependent Model-dependent	power, followed by ultrasonic-assisted and hot water extracted fruit polysaccharides. DPPH, FRAP and ABTS of pomace extracts from subcritical water extraction (170–225 °C, 90 min) were higher than those of pomace extracts from solid-solvent extraction using 100% ethanol, 80% methanol and 70% acetone as solvents, respectively.	high unmethylated galacturo-nic acids Phenolics	Kheirkhah et al. (2019)
Fruits	<i>A. chinensis</i> (8 cultivars), <i>A. deliciosa</i> (3 cultivars) and <i>A. arguta</i> , <i>A. macrosperma</i> , and <i>A. polygama</i> (China)	Assay Model Doses Admi. Time	<i>In vitro</i> chemistry-based ABTS, DPPH, FRAP Model-dependent Model-dependent Model-dependent	ABTS, DPPH, FRAP values of <i>A. chinensis</i> ranged 38.16–160.9 µmol TE/g DW, 13.12–87.38 mg GAE/g DW and 25.42–149.979 µmol TE/g DW, respectively. ABTS, DPPH, FRAP values of three <i>A. deliciosa</i> cultivars ranged 32.95–55.71 µmol TE/g DW, 15.67–28.10 mg GAE/g DW, 26.43–54.11 µmol TE/g DW, respectively. <i>A. arguta</i> had the highest ABTS, DPPH and FRAP value, followed by <i>A. macrosperma</i> , and <i>A. polygama</i> .	Phenolics	Li and Zhu (2019)
Wine fermented from fresh fruit juice with/without pomace	<i>A. deliciosa</i> 'Xuxiang' (China)	Assay Model Doses Admi. Time	<i>In vitro</i> chemistry-based DPPH, OH ⁻ , O ²⁻ and TRP Model-dependent Model-dependent Model-dependent	Glutathione-enriched inactive dry yeast addition improved the antioxidant abilities of wine fermented with fruit juice with pomace in different extent.	Phenolics	Liu et al. (2020)
Anticancer Pulp and peel extracts	<i>A. deliciosa</i> 'Hayward' and <i>Actinidia</i> spp. (red kiwi) (Portugal)	Assay Model Doses Admi. Time	<i>In vitro</i> cell culture-based MCF-7, NCI-H460, HeLa, HepG2 Model-dependent Model-dependent Model-dependent	<i>A. deliciosa</i> 'Hayward' peel extracts 'were antiproliferative against selected cancerous cells (MCF-7, NCI-H460, HeLa, and HepG2) with a GI ₅₀ < 400 µg/mL.	Phenolics	Dias et al. (2020)
Peel and flesh polyphenols	<i>A. chinensis</i> (China)	Assay Model Doses Admi. Time	<i>In vitro</i> cell culture-based HepG2 100, 200, 300, 400 µg/mL Co-inoculation 24 and 72 h	Peel polyphenols (IC ₅₀ = 170.0 µg/mL), being stronger than the fresh polyphenols (IC ₅₀ = 291.0 µg/mL) dose- and time-dependently against HepG2 cell proliferation.	Polyphenols	Alim et al. (2019)
Roots	<i>A. chinensis</i> Planch (China)	Assay Model Doses Admi. Time	<i>In vitro</i> cell culture-based HGC-27 0, 45, 90, 180, 360 mg/mL Co-incubation 24 h	Root extracts dose-dependently inhibited proliferation of gastric cancer cells HGC-27, via promoting cell apoptosis and suppressing mesenchymal phenotype.	Ursolic and Oleanolic acids	Gao et al. (2020)
2β, 3β, 23-trihydroxy-urs-12-ene-28-olic acid (TUA) of root	<i>A. chinensis</i> (China)	Assay Model Doses Admi.	<i>In vitro</i> cell culture-based NCI-H460 10, 20 and 30 mg/mL 24 or 48 h	TUA exhibited dose- and time-dependently cytotoxic to human lung carcinoma NCI-H460 cells. Anticancer of TUA was via inhibiting NF-κB signaling pathway.	TUA	Cheng et al. (2015)
Root extracts	<i>A. chinensis</i> Planch (China)	Assay Model Doses Admi.	<i>In vitro</i> cell culture-based SMMC7721, MHCC97L, MHCC97H, HCCLM3, Hep3B, HepG2, and L02 1, 5, 10, 15, 30, 50 mg/mL 24, 48 and 72 h	Root extracts were dose- and time-dependently anti-proliferative against all hepatocellular carcinoma cells via downregulating DLX2 gene expression. Root extracts (below 10 mg/mL) were non-toxic to the normal liver epithelial L02 cells.	A mixture of triterpenoids, polysaccharides, flavonoids, steroids, terpenes, phenolic acids	Fang et al. (2019)
Root extracts	<i>A. chinensis</i> Planch (China)	Assay Model Doses Admi. Time	<i>In vivo</i> preclinical trial zebrafish embryos 90, 180 mg/mL Abdominal perivitelline space injection 48 h	Root extracts reduced the tumor growth of HGC-27 cells induced zebrafish xenograft model. Root extracts increased ROS levels by inhibiting glutathione peroxidase 4 (GPx4) and xCT (SLC7A11) proteins.	Ursolic and oleanolic acids	Gao et al. (2020)
Root extracts	<i>A. chinensis</i> Planch (China)	Assay Model Doses	<i>In vivo</i> animal trial Male athymic BALB/c nude mice 2 g/kg daily	Root extracts (2 g/kg per day) suppressed the malignant biological behaviors of HCC cells in nude mice bearing orthotopic	Bioactive mixture of triterpenoids, polysaccharides,	Fang et al. (2019)

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Table 3 (continued)

Plant parts	Varieties (cultivation origin)	In vitro/in vivo model systems		Observations	Tentative key bioactive components	References
		<i>Admi.</i> <i>Time</i>	Intragastrically 6 weeks	xenografts via regulating the epithelial mesenchymal transition by DLX2.	flavonoids, steroids, terpenes, phenolic acids	
Antihypertensive						
Flavonoid-rich extracts from fruit	<i>A. macrosperma</i> , <i>A. deliciosa</i> 'Hayward', <i>A. chinensis</i> 'Hort 16A' (New Zealand)	<i>Assay</i> <i>Model</i> <i>Doses</i> <i>Admi.</i> <i>Time</i>	<i>In vitro</i> chemistry based angiotensin-converting enzyme (ACE) inhibition Not applicable Not applicable Not applicable	Flavonoid-rich extracts from <i>A. macrosperma</i> (IC ₅₀ = 0.49 mg/mL), <i>A. deliciosa</i> (IC ₅₀ = 30.49 mg/mL), <i>A. chinensis</i> (IC ₅₀ = 12.81 mg/mL) varied in ACE inhibition activities.	Flavonoids	Hettihewa et al. (2018)
Antimicrobial (antibacterial, antifungal)						
Pulp and peel extracts	<i>A. deliciosa</i> 'Hayward' (green kiwi) and <i>Actinidia</i> spp. (red kiwi) (Portugal)	<i>Assay</i> <i>Model</i> <i>Doses</i> <i>Admi.</i> <i>Time</i>	<i>In vitro</i> microbe based 4 bacteria (<i>Escherichiacoli</i> , <i>Enterobacter cloacae</i> , <i>Bacillus cereus</i> , <i>Listeria monocytogenes</i>), and 4 fungi (<i>Aspergillus ochraceus</i> , <i>A. niger</i> , <i>A. versicolor</i> , <i>Penicillium funiculosum</i>) Not applicable Not applicable Not applicable	Green kiwi pulp extracts had the lowest MIC for <i>B. cereus</i> . Red kiwi pulp extracts had the lowest MIC for <i>E. coli</i> . Red kiwi peel extracts had the lowest MIC for <i>L. monocytogenes</i> and <i>E. cloacae</i> . The red kiwi peel extracts had the lowest MIC for <i>A. ochraceus</i> . The green kiwi peel extracts had the lowest MIC for <i>P. funiculosum</i> .	Phenolics	Dias et al. (2020)
Peel and flesh polyphenol extracts	<i>A. chinensis</i> (China)	<i>Assay</i> <i>Model</i> <i>Doses</i> <i>Admi.</i> <i>Time</i>	<i>In vitro</i> disk diffusion <i>E. coli</i> , <i>S. aureus</i> and <i>L. monocytogenes</i> 100, 200, 300 µg/mL Co-incubation 18–24 h	Peel polyphenol extracts were more dose-dependently antibacterial against both gram-negative <i>E. coli</i> and gram-positive <i>S. aureus</i> and <i>L. monocytogenes</i> than fresh polyphenol extracts.	Polyphenols	Alim et al. (2019)
Leaf extracts (water, ethanol, water-ethanol 50:50 v/v)	<i>A. arguta</i> (Portugal)	<i>Assay</i> <i>Model</i> <i>Doses</i> <i>Admi.</i> <i>Time</i>	Embedding, surface scattering, and agar diffusion assay Gram-positive (<i>S. aureus</i>) gram-negative bacteria (<i>E. coli</i> and <i>Pseudomonas aeruginosa</i>) and yeasts (<i>Candida albicans</i>) 20, 50 mg/mL Co-incubation Not applicable	At 50 mg/mL, hydroalcoholic and alcoholic extracts were antimicrobial against <i>S. aureus</i> .	Phenolic acids and flavonoid compounds	Almeida et al. (2018)
Anti-inflammatory						
Peel extracts	<i>A. deliciosa</i> 'Hayward' (Italy)	<i>Assay</i> <i>Model</i> <i>Doses</i> <i>Admi.</i> <i>Time</i>	<i>In vitro</i> cell culture-based Human THP-1 monocytes 50 µg/mL Co-incubation 24 h	Peel extracts stimulated autophagy and inhibited inflammatory mediators, including pro-inflammatory cytokines (IL-6, IL-1β, TNF-α), HMGB1 danger signal and granzyme B serine protease, and signal transducer and activator of transcription 3 (STAT3) in LPS stimulated THP-1 monocytes.	Polyphenols	D'eliseo et al. (2019)
Polyphenolextracts	<i>A. melanandra</i> , <i>A. arguta</i> 'purpurea', red <i>A. macrosperma</i> × <i>A. melanandra</i> , and yellow <i>A. macrosperma</i> × <i>A. melanandra</i> (New Zealand)	<i>Assay</i> <i>Model</i> <i>Doses</i> <i>Admi.</i> <i>Time</i>	<i>In vitro</i> cell culture-based Human alveolar epithelial A549 cells 1–25 µg/mL Co-incubation 24 h	Polyphenol extracts of the ripe purple-fleshed kiwifruits (<i>A. melanandra</i> , <i>A. arguta</i> 'purpurea', and red <i>A. macrosperma</i> × <i>A. melanandra</i>) effectively modulated the secretion key inflammatory signals (CCL11 and NF-κB) stimulated by TNFα and IL-4 in A547 cells.	Cyanidin- and delphinidin- based anthocyanins	Peng et al. (2020)
Organic acid derivatives	<i>A. arguta</i> (Korea)	<i>Assay</i> <i>Model</i> <i>Doses</i> <i>Admi.</i> <i>Time</i>	<i>In vitro</i> cell culture-based LPS-stimulated RAW 264.7 macrophages Not applicable Co-incubation Not applicable	Quinic acid derivatives inhibited NF-κB transcriptional activity IC ₅₀ = 4.0 µM in LPS- stimulated RAW 264.7 macrophages.	Organic acids conjugates such as quinic acid derivatives	Ahn et al. (2020)
Pulp and peel extracts	<i>A. deliciosa</i> 'Hayward' and <i>Actinidia</i> spp. (Portugal)	<i>Assay</i> <i>Model</i> <i>Doses</i> <i>Admi.</i> <i>Time</i>	<i>In vitro</i> cell culture-based RAW 264.7 cells Not applicable Co-incubation Not applicable	Only peel extracts of <i>A. deliciosa</i> 'Hayward' was cytotoxic to RAW 264.7 cells, with an IC ₅₀ of 316 µg/mL. Anti-inflammatory drug dexamethasone had an IC ₅₀ of 16 µg/mL.	Phenolics	Dias et al. (2020)

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Table 3 (continued)

Plant parts	Varieties (cultivation origin)	In vitro/in vivo model systems		Observations	Tentative key bioactive components	References
Roots	<i>A. kolomikta</i> Maxim. (China)	Assay Model	<i>In vitro</i> cell culture-based LPS-stimulated RAW 264.7 macrophages	Salidroside, D-threo-guaiacylglycerol 7-O- β -D-glucopyranoside, and <i>epi</i> -afzelechin isolated from roots inhibited NO, TNF- α , and IL-6 production in LPS-induced RAW264.7 cells via inhibiting COX-2 and iNOS expression.	Salidroside, D-threo-guaiacyl-glycerol 7-O- β -D-glucopyrano-side, and <i>epi</i> -afzelechin	Ye et al. (2020)
Freeze-dried fruit powder	<i>A. arguta</i> (China)	Doses Admi. Time	Not applicable Co-incubation Not applicable			
		Assay Model	<i>In vitro</i> cell culture-based LPS-stimulated RAW 264.7 macrophages	<i>In vitro</i> , freeze-dried powders dose-dependently reduced the NO content and iNOS expression.	Unknown	Lian et al. (2019)
		Doses Admi. Time	100, 200, and 400 μ g/ mL Co-incubation 26 h			
		Assay Model	<i>In vivo</i> animal trial Dextran sulfate sodium (DSS)-induced colitis in Balb/c mice	<i>In vivo</i> , freeze-dried powders ameliorated physiological index and histological changes and reduced the oxidative stress levels in DSS-induced colitis mice. Anti-inflammatory activity was through targeting mitogen-activated protein kinases (MAPKs) pathway.		
Neuroprotective Fruits	<i>A. arguta</i> $\times$ <i>A. deliciosa</i> 'Mansu' <i>A. arguta</i> 'Haeyeon', <i>A. arguta</i> 'Chiak'	Doses Admi. Time	Not applicable Co-incubation Not applicable			
		Assay Model	<i>In vitro</i> cell culture-based Neuronal PC-12 and SH-SY5Y cells	Hardy kiwifruits protected neuronal PC-12 and SH-SY5Y cells from H ₂ O ₂ damage by increasing cell viability and reducing intracellular oxidative stress. 'Mansu' exhibited the highest total phenolic, total flavonoid, and vitamin C contents and antioxidant capacity. Hardy kiwifruits were acetylcholinesterase and butyrylcholinesterase inhibitors	Antioxidants (phenolics and vitamin C)	Jeong et al. (2020)
Fruit chloroform fractions	<i>A. arguta</i> 'Autumn Sense' (Korea)	Doses Admi. Time	Not applicable Co-incubation 24 h			
		Assay Model	<i>In vitro</i> cell culture-based MC-IXC cells	Chloroform fractions (better than vitamin C) protected MC-IXC cells from high glucose-induced neurotoxicity.	Pentacyclic triterpenoids such as asiatic acid, madecassic acid	Ha et al. (2020)
		Doses Admi. Time	10, 20 μ g/mL Co-incubation 24 h			
		Assay Model	<i>In vivo</i> animal trial Male C57BL/6 mice	<i>In in vivo</i> , chloroform fractions improved insulin resistance-induced cognitive dysfunction of C57BL/6 mice with high-fat diet by suppressing the c-Jun NH2-terminal kinase (JNK) signaling pathway		
Fruit extracts, extract fractions (Mw > 3 kDa and < 3 kDa, respectively) diluted 1:5 and 1:10	<i>A. deliciosa</i> 'Hayward' and <i>A. chinensis</i> 'Hort 16A' (Italy)	Doses Admi. Time	20 and 40 mg/kg BW Intragastrically 12 weeks			
		Assay Model	<i>In vivo</i> animal trial <i>Caenorhabditis elegans</i> spinal muscular atrophy (SMA) model	Fruit extract fractions (with bioactive) Mw > 3 kDa of <i>A. deliciosa</i> 'Hayward' were neuroprotective via inhibiting the degeneration and death of motor neurons and the locomotion impairment in <i>C. elegans</i> SMA model. Mechanisms underlying neuroprotection are still unclear.	Macromolecules (Mw > 3 kDa)	Mazzarella et al. (2019)
Promoting gut health Fruits	<i>A. deliciosa</i> 'Hayward'	Doses Admi. Time	final dilution of 1:10, 1:20, 1:40, and 1:100 1 day pretreatment, followed by incubation 24 h			
		Assay Model	<i>In vivo</i> human trial 20 healthy controls, 20 patients with FC, and 20 patients with IBS-C	Compared to psyllium (7.5 g/ day), kiwifruit consumption is more effectively improved complete spontaneous bowel movement of patients with IBS-C or FC.	Dietary fibers	Cremon et al. (2018)
Fruit digestive and soluble bacteria-free fermentation products	<i>A. chinensis</i> 'Hort16A' and <i>A. deliciosa</i> 'Hayward' (New Zealand)	Doses Admi. Time	2 fruits /day Oral consumption 16 weeks			
		Assay Model	<i>In vitro</i> cell culture-based HT-29 cells	Green kiwifruit soluble bacteria-free fermentation products dose- and time-dependently increased IFN γ -stimulated IL-7 secretion in HT-29 cells after a 24 h incubation via activating TLR9 by DNA nucleotides (possibly	Dietary fibers, combines with polyphenolic compounds	Paturi et al. (2020)
		Doses Admi. Time	0.001–10 μ g/mL Co-incubation 24 h			

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Table 3 (continued)

Plant parts	Varieties (cultivation origin)	In vitro/in vivo model systems		Observations	Tentative key bioactive components	References
Fruit pulp (deseeded, peeled, freeze-dried)	<i>A. deliciosa</i> 'Hayward' (New Zealand)	Assay Model Doses Admi. Time	In vivo animal trial Male Sprague–Dawley rats 25 g/day Food allocation 7 days	containing CpG motifs) from the soluble fermenta. Freeze-dried kiwifruit pulp (less effective than dietary fiber mixtures) slightly dose-dependently increased faecal bulk and water holding capacity, while minimal altering the disappearance of fermentable fiber during hind gut passage in rats.	Dietary fibers	Monro et al. (2017)
Whole fruit with and without peels (freeze-dried)	<i>A. chinensis</i> (China)	Assay Model Doses Admi. Time	In vivo animal trial Healthy 8-week old male Sprague–Dawley rats 2 fruits without peels and fruits with peels, respectively Gavage feeding 4 weeks	Two whole fruits with peel (better than fruits without peels) improved the gut microbial richness and diversity, increased proportions of beneficial bacteria (<i>Lactobacillus</i> and <i>Barnesiella</i>) and reduced harmful bacteria (<i>Enterococcus</i> , <i>Escherichia</i> , <i>Staphylococcus</i> species), in healthy rats.	Polyphenol and fibers (i.e., pectin, hemi-celluloses)	Alim et al. (2020)
Antiobesity Seed oil	<i>A. chinensis</i> (China)	Assay Model Doses Admi. Time	In vivo animal trial HFD-induced obese C57BL/6 mice 1.0 and 3.0 mL/kg BW, daily Orally 12 weeks	Seed oil diet 1) reduced the BW gain, inguinal fat tissue weight, blood glucose, and HOMA-IR index, 2) increased serum HDL-C levels and decreased the levels of TC, TG, and LDL-C, 3) decreased the <i>Firmicutes</i> -to- <i>Bacteroidetes</i> ratio in HFD-induced C57BL/6 obese mice. Seed oil diet down-regulated mRNA expression of inflammatory cytokines (TNF- α , IL-6, IL-1 β , COX-2, and iNOS), while up-regulating the expressions of thermogenesis-related genes (PPAR- γ , UCP1, PGC1- α , and PRDM16).	Essential fatty acid (α -linolenic acid)	Qu et al. (2019)
Anti-allergic Water soluble extracts	<i>A. arguta</i>	Assay Model Doses Admi. Time	In vivo animal trial BALB/c mice with <i>dermatophagoides farinae</i> extracts (DfE) induced AD 2.5 and 25 mg/kg, daily Orally 8 weeks	Water soluble extracts ameliorated AD related symptoms, such as ear swelling and clinical score in DfE induced AD mice. Anti-allergic activity of water soluble extracts was through targeting CD4 + FOXP3 + regulatory T cells (Treg) related mTOR signaling pathway.	Unknown	Bae et al. (2016)

Notes: AD, atopic dermatitis; Admi. administration DPPH, 2,2-diphenyl-1-picryl-hydrazyl; DW, dry weight; BW, body weight; EDTA, ethylenediaminetetraacetic acid; FC, functional constipation; FDW, freeze-dried weight; FRAP, Ferric reducing antioxidant power assay; GI₅₀, concentration achieving 50% of growth inhibition in cell lines; HeLa, cervical carcinoma; HepG2, hepatocellular carcinoma; HGC-27, human gastric cancer cells; MC-IXC, human neuroblastoma MC-IXC cells; H₂O₂, hydrogen peroxide; HFD, high-fat diet; HOCl, hypochlorous acid; IC₅₀, concentration achieving 50% of inhibition *in vitro*; IBS-C, irritable bowel syndrome with constipation; LPS, lipopolysaccharide; O₂^{•−}, superoxide radical; PLP2, porcine liver cell; MCF-7, breast adenocarcinoma; MDA, malondialdehyde; Mw, molecular weight; MIC, minimum inhibitory concentration; MBC, minimum bactericidal concentration; NCI-H460, non-small cell lung cancer; NO[•], nitric oxide; ONOO[•], peroxynitrite; OxHLIA, oxidative hemolysis inhibition assay; RAW 264, mouse macrophage-like cell; RNS, reactive nitrogen species; ROS, reactive oxygen species; ROO[•], peroxy radical; TBARS, thiobarbituric acid reactive substances; TE, Trolox equivalents.

starch were similar to those of potato starch (Li & Zhu, 2017).

Kiwifruit core starch had higher apparent contents (32–37% and 25–28%, respectively), true amylose contents (21–23% and 16–18%, respectively) and larger granules than outer pericarp starch (Li & Zhu, 2017). Longer unit chains of both amylopectins and their ϕ , β -limit dextrins (LDs), and less short B-chains of the ϕ , β -LDs of amylopectins in core starch than outer pericarp starch (Li & Zhu, 2018a). Core starch presented lower degree of crystallinity and gelatinization parameters. Outer pericarp starch presented lower amylose content and enzyme susceptibility (Li & Zhu, 2017).

2.2.2. Mono and disaccharides

Kiwifruit starch hydrolysis produces monosaccharides (simple

sugars) during post-harvest storage. New Zealand SunGold (63 kcal/100 g) contained 12.3% of total sugar content and green kiwifruit had 9%, depending on FW (USDA, 2017). Total pulp sugar content varied in *A. deliciosa* 'Hayward' (green kiwi) (9%) and *Actinidia* sp. (red kiwi) (11%) (Dias et al., 2020). New Zealand *A. deliciosa* 'Hayward' flour had higher total sugar content (10.2%) than *A. chinensis* 'Gold3' flour (9.2%) (Li & Zhu, 2019). Soluble sugars are involved in the growth and development of yellow-fleshed 'Jinshi 1' (Xiong et al., 2020).

Based on FW, SunGold contains fructose (5.8%), glucose (5.3%) and sucrose (1.2%). Green kiwifruit contains sucrose (0.15%), glucose (4.1%), fructose (4.4%), maltose (0.19%) and galactose (0.17%) (USDA, 2017). *A. deliciosa* 'Hayward' and red kiwi pulps contained different levels of fructose (3.8 and 3.4%, respectively), glucose (3.5 and 3.1%,

Table 4
Effect of processing on properties of selected kiwifruit products.

Kiwifruit commodity (Car., COO)	Purpose	Processing	Processing conditions		Observed effects	References
			Parameters (range studied)	Optimized parameters		
Kiwifruit (<i>A. chinensis</i> Planch. 'Hongshi', China)	Extraction optimization	Microwave -assisted extraction	Microwave power (240–480 W)	440	Under conditions optimized by response surface methodology, microwave and ultrasonic assisted extractions achieved a yield of 2.92, and 2.82%, respectively.	Han et al. (2019)
			Ratio of water to raw material (20–52.9 mL/g)	53		
			Extraction time (2–8 min)	8		
		Ultrasonic-assisted extraction	Ultrasonic amplitude (25–70%)	70		
			Ratio of water to raw material (20–30 mL/g)	30		
			Extraction time (2–10 min)	10		
Fresh cut kiwifruits (<i>A. deliciosa</i> 'Hayward', China)	Shelf life extension	Ultrasonic + nanoZnO coating, ultrasonic + NaClO, NaClO + ZnO coating	NaClO conc. (50 µL/L)	1.2	Combining ultrasound treatment and nano-ZnO (1.2 g/L) coating lower production of ethylene (1.86 µL/ kg h) and carbon dioxide (10.01 mg /kg h), water loss (0.46%), while increasing firmness (7.87 N).	Meng et al. (2014)
			Ultrasonic power (350 W)			
			Ultrasonic frequency (40 kHz)			
Unpeeled whole kiwi-fruit (<i>A. deliciosa</i> 'Hayward', India)	Shelf life extension	Ultrasonic + NaOCl	Time (10 min)	368	Under an optimized condition, treated kiwifruits had total bacterial count and total yeast and mold count of 3.48 and 2.34 log CFU/cm ² , respectively, as well as the firmness and RR being 56.77 N and 27.71 mg CO ₂ / kg h FW, respectively.	Vivek et al. (2016)
			Nano-ZnO conc. (0.4–1.2 g/L)			
			Ultrasonic intensity (184–368 W/cm ²)			
			Temperature (25–40 °C)			
Fresh-cut kiwifruits (<i>A. deliciosa</i> 'Hayward', India)	Shelf life extension	Chitosan coating + ultrasonic + NaOCl solution	Time (8–15 min)	8	Chitosan (0.8 and 1.0%) coating reduced the mass loss, RR, micro growth, and improved the sensory quality of fresh-cut kiwifruits with ultrasonic and NaOCl treatments, during 10 days of storage at 5 °C.	Vivek and Subbarao (2018)
			NaOCl conc. (30–60 ppm)			
			Chitosan conc. (06–10%)			
			Ultrasonic intensity (368 W/cm ²)			
Kiwifruit juice from ripe green kiwifruits (N/A, Canada)	Enhancing bioactive and antioxidant capacity	Ultrasonic	Temperature (25 °C)	0.8, 10	Compared to the control, juice with 16-min ultrasonic treatment had increased TPC (108.65%), flavonoids (105.56%), and antioxidant capacity (65.67%), while decreasing total protein and ascorbic acid.	Wang, Vanga, Mccusker, and Raghavan (2019)
			Ultrasonic Time (8 min)			
			NaOCl conc.(30 ppm)			
			Ultrasonic power (400 W)			
Mature kiwifruit (<i>A. deliciosa</i> 'Yate', China)	Post-harvest diseases control	Curcumin	Ultrasonic frequency (25 kHz)	16	Curcumin dose-dependently inhibited <i>Diaporthe phaseolorum</i> induced postharvest decay of kiwifruits by inhibiting the vegetative growth and cell viability, promoting apoptosis and cell death, and decreasing pathogenicity of the pathogen. Curcumin minimal altered fruit quality (firmness, SSC, or TA) over 14-days storage at 25 °C.	Kai et al. (2020)
			Time (min) (4–16 min)			
			Curcumin conc. (100–300 mg/L)			
			≥ 200			
Kiwifruits slices (2–3 mm diameter, 10 mm thick-nesses) (<i>A. deliciosa</i> , Turkey)	Effects on anti-oxidant activity, TPC	Oven and microwave drying	Oven drying (70 °C, 20 h) microwave (720 W, 3 min)	N/A	Microwave drying increased TPC (by 469%) and DPPH (by 79%). Oven drying increased TPC (by 389%) and DPPH (by 66%). Microwave and oven drying induced different changes in phenolic level. Microwave drying reduced the amount of 3, 4-dihydroxybenzoic acid (by 248.4%).	Özcan et al. (2020)
Kiwifruits (<i>A. chinensis</i> Hayward' Canada)	Effects on physio-chemical properties	Ultrasonic treatment	Ultrasonic (400 W, 20 kHz, 4–16 min)	N/A	Ultrasonic treatment improved color attributes (<i>a</i> *, <i>b</i> *, and YI), stability, pectin yield, cloudiness, carbohydrates (fructose and glucose) level, and flow and viscoelastic behaviors	Wang, Wang, Vanga, and Raghavan (2020)
Wine fermented from fresh kiwifruit juice with/ without pomace	Effects on color and antioxidant capacity	GIDY addition	GIDY (100, 300, and 500 mg/L) Juice with/without pomace	N/A	GIDY at 300 mg/L increased GSH, glutathione disulfide, total GSH concentrations, and the total phenolic content of kiwi wine. GIDY at 300 mg/L improved color parameters and	Liu et al. (2020)

(continued on next page)

Table 4 (continued)

Kiwifruit commodity (Car., COO)	Purpose	Processing	Processing conditions		Observed effects	References
			Parameters (range studied)	Optimized parameters		
(<i>A. deliciosa</i> 'Xuxiang', China) Fruit pomace (<i>A. deliciosa</i> 'Hayward', New Zealand)	Extraction optimization	Subcritical water extraction	Temperature (170–225 °C) Time (10–180 min) Pressure (50 bar).	<200 °C 90 min	antioxidant activities of wines fermented with pomace. Under optimized conditions, kiwifruit pomace had maximum phenolic compounds recovery and minimum undesired Maillard reaction products such as melanoidins, 5-hydroxymethylfurfural.	Kheirkhah et al. (2019)

Notes: *A. deliciosa*, *Actinidia deliciosa*; Conc, concentration; COO, country of origin; Car, cultivar; CFU, colony-forming unit; DPPH, 2,2-diphenyl-1-picrylhydrazyl; FW, fresh weight; GIDY, glutathione-enriched inactive dry yeast; GSH, glutathione; N/A, not available; NaOCl, sodium hypochlorite; SSC, soluble solids content; RR, respiration rate; TA, titratable acidity; TPC, total phenolic content; YI, yellowness index.

respectively), sucrose (1.4 and 3.9%, respectively), and trehalose (0.11 and 0.08%, respectively) (Dias et al., 2020). *Lactobacillus plantarum* fermentation decreased fructose, and sucrose contents of kiwifruit pulp (Zhou et al., 2020).

2.2.3. Dietary fiber

Kiwifruit contained more insoluble dietary fibre (IDF) than soluble dietary fibre (SDF). For example, the contents of total dietary fiber (TDF), IDF and SDF of green kiwifruit were 3, 2.3 and 0.7%, FW respectively. New Zealand ZESPRI SunGold contained TDF of 1.4% FW (USDA, 2017). TDF, SDF and IDF of *A. chinensis* 'Gold3' (20, 5, and 15% DW respectively) differed from those of *A. deliciosa* 'Hayward' flour (21, 7, and 14% DW, respectively) (Li & Zhu, 2019). SDF and IDF and of *A. arguta* was 0.8–1.0 and 2.1–3.1% (FW), respectively (Pinto et al., 2020). Insoluble NSP (cellulose and hemicellulose) and water-soluble NSP (pectin) were the major components of IDF and SDF, respectively, in kiwifruit (Li & Zhu, 2019; Yuliarti et al., 2015).

2.2.4. Non-starch polysaccharides (NSP)

NSP composition of different kiwifruit cultivars depends on genetic and environmental factors, extraction techniques (acid, hot water, enzyme, microwave and ultrasound based ones) conditions (time, temperature and concentrations) (Han et al., 2019; Yuliarti et al., 2015). Golden kiwifruit pectins were high-methoxylated and rich in galacturonic acid. NSP isolated from *A. chinensis* were extracted using microwave-assisted (MA, yield of 2.92%), ultrasound-assisted (UA, yield of 2.82%), and hot water (HW, yield of 2.86%) techniques (Han et al., 2019). MA, UA, and HW extracted kiwifruit polysaccharides varied in the levels, listed respectively, of total carbohydrates (78.2, 74.8 and 76.2%), uronic acid (43.9, 43.3 and 45.7%), protein contents (3.5, 6.1 and 4.3%), molecular weights (MWs) (168.9, 176.9 and 195.5 kDa) and degree of esterification (43.3, 48.4, and 55.0%) (Han et al., 2019). The molar ratio of constituent monosaccharides of MA, UA, and HW extracted kiwifruit polysaccharides differs (mannose: rhamnose: galacturonic acid: glucose: galactose: xylose: arabinose, 0.36: 0.23: 3.28: 1.00: 1.69: 0.24: 0.93, and 0.77: 0.47: 5.16: 1.00: 2.91: 0.36: 1.86, and 0.25: 0.35: 4.07: 1.00: 1.24: 0.24: 1.01, respectively) (Han et al., 2019).

2.3. Proteins

2.3.1. Amino acids

Kiwifruit varieties contained different levels of eighteen amino acids, including glutamic and aspartic acids, arginine, leucine, lysine, glycine, valine, alanine, serine, isoleucine, threonine, phenylalanine, cysteine, histidine, methionine, tryptophan, proline, and tyrosine (Table 2) (Ma et al., 2017; USDA, 2017). Two New Zealand cultivars (*A. deliciosa* 'Hayward' and *A. chinensis* 'Hort16A') and nine Chinese cultivars (*A. deliciosa* 'Hayward', 'Qinmei', 'Cuixiang', 'Jinxiang' and Xuxiang, and *A. chinensis* 'Hort16A', 'Jintao', 'Hongyang' 'Huayou'), investigated by Ma et al. (2017), had a range of total free amino acid/protein values of 44–60%.

2.3.2. Proteases

2.3.2.1. Crude extracts. Among ninety commercial fruits/vegetables in China, kiwifruit (*A. deliciosa* 28.8 U/g, pH 3.0) ranked second [leek 32.7 U/g, pH 10.5 (being first)] in top five protease rich foods, followed by broccoli (16.9 U/g, pH 3.0), ginger (16.6 U/g, pH 7.5), and red pepper (15.8 U/g, pH 7.5) (Sun, Zhang, Yan, & Jiang, 2016). At pH 3.0, *A. deliciosa* had the highest protease activity of 28.8 U/g, followed by 21.0 U/g (pH 7.5) and 7.8 U/g (pH 10.5) (Sun et al., 2016). Iodoacetamide (a cysteine-protease inhibitor) can inhibit kiwifruit protease activities. In *A. deliciosa* protein extracts, SDS-PAGE and zymographic analysis revealed 21, 23 and 29 kDa proteases in acidic pH, and 28 kDa protease in neutral pH (Sun et al., 2016).

Among three cultivars, *A. deliciosa* ('Xuxiang', 'Jinxiang', and 'Hayward') and four Chinese cultivars of *A. chinensis* ('Jinlong I', 'Qihong', 'Jinyan' and 'Hongyang'), *A. deliciosa* crude extracts had higher proteases and milk-clotting activity than *A. chinensis* crude extracts (Zhang, Sun, Liu, Li, & Jiang, 2017). Except for 'Jinyan', crude extracts of 'Hongyang', 'Jinlong I' and 'Qihong' were unable to coagulate milk. Actinidin (~29 kDa) was detected in all seven cultivars. *A. deliciosa* 'Xuxiang' had the most actinidin comparatively. Except for *A. chinensis* 'Hongyang', all tested cultivars contained kiwellin (~20 kDa). Only *A. deliciosa* 'Xuxiang' and 'Hayward' contained thaumatin-like protein (~22 kDa) (Zhang et al., 2017).

2.3.2.2. Actinidin. Actinidin, a cysteine protease, accounted for 50–60% of soluble proteins in kiwifruit (Sun et al., 2016; Zhang et al., 2017). Actinidin (~29 kDa) purified from *A. deliciosa* 'Xuxiang' had an optimal pH of 3.5 and temperature of 40 °C. Thermal treatment (30 min, 50 °C) completely deactivates actinidin (Zhang et al., 2017). 'Xuxiang' actinidin activity can be completely inhibited [asiodoacetic acid or iodoacetamide (4 mmol/L)], minimally influenced [pepstain A or PMSF (1 or 4 mmol/L)], or promoted [ethylenediaminetetraacetic acid (4 mmol/L) or dithiothreitol (1 or 4 mmol/L)] (Zhang et al., 2017). *A. deliciosa* 'Hayward' extracts (0.089 µmol/mg/min) had higher actinidin activity than *A. chinensis* 'Hort16A' extracts (0.031 µmol/mg/min) (Gong, Morton, Bhat, Mason, & Bekhit, 2020). *A. arguta* (1.6–10.7 mg/mL of fruit juice) had higher amount of actinidin than *A. deliciosa* and *A. chinensis* (Latocha, 2017). Kiwifruit crude and purified actinidin was used in production of ACE-inhibitory peptides from protein hydrolysates of soy, rice, walnut, rapeseed and oats (Zhang et al., 2017). Kiwifruit actinidin *in vitro* digested human salivary amylase, but not human gastric lipase (Martin, Cordiner, & McGhie, 2017).

2.3.3. Allergenic proteins

Thirteen kiwifruit allergenic proteins were identified (Table 5). The major (>50% of the tested population affected) kiwifruit allergens includes Act d1 (actinidin, 27 kDa), Act d2 (thaumatin-like protein, 24 kDa), Act d8 (pathogenesis-related protein PR-10, 17 kDa), Act d11 (major latex protein, 17 kDa) and Act d12 (11S globulin, 50.2 kDa). Minor allergens includes Act d3 (glycoprotein of unknown function, 42

Table 5
Allergens identified in kiwifruits.

Kiwifruit variety	Allergen	Allergen protein family/ biochemical designation	Molecular weight (kDa)	Cross-reactivity with birch and grass pollen and latex	Properties	Sensitivity to food processing
<i>A. deliciosa</i>	Act d 1	Actinidin	27	Unknown	Major allergen, ripening-related	Slightly sensitive to enzymatic (pepsin) treatment, thermally unstable proteins
<i>A. deliciosa</i>	Act d 2	Thaumatin-like protein	24	Unknown	Major allergen, ripening-related	Highly sensitive to enzymes (pepsin), thermally unstable proteins
<i>A. deliciosa</i>	Act d 3	Glycoprotein of unknown function	42	Birch and grass pollen, latex	Minor allergen	Unknown
<i>A. deliciosa</i>	Act d 4	Phytocystatin	11	Unknown	Minor allergen	Unknown
<i>A. deliciosa</i> ; <i>A. chinensis</i>	Act d 5	Kiwellin	26	Unknown	Minor allergen, ripening-related	Unknown
<i>A. deliciosa</i>	Act d 6	Pectin methylesterase inhibitor	18	Unknown	Minor allergen	Unknown
<i>A. deliciosa</i>	Act d 7	Pectin methylesterase	35	Birch and grass pollen, latex	Minor allergen	Sensitive to ethylene treatment
<i>A. deliciosa</i> ; <i>A. chinensis</i>	Act d 8	Pathogenesis-related protein PR-10 (Bet v 1 homologues)	17	Birch pollen	Major allergen	Sensitive to ethylene treatment
<i>A. deliciosa</i> ; <i>A. chinensis</i>	Act d 9	Profilin (Bet v 2 homologues)	14	Birch and grass pollen, latex	Minor allergen	Unknown
<i>A. deliciosa</i>	Act d 10	Non-specific lipid-transfer proteins (nsLTPs)	9	Unknown	Minor allergen	Unknown
<i>A. deliciosa</i>	Act d 11	Major latex protein	17	Birch pollen	Minor allergen ripening-related	Unknown
<i>A. deliciosa</i> seeds	Act d 12	Cupin, 11S globulin	50.2	Unknown	Major allergen, storage proteins, seed-related	Highly resistant to thermal treatment
<i>A. deliciosa</i> seeds	Act d 13	2S albumin	113.6	Unknown	Minor allergen, storage proteins, seed-related	Stable

Adapted with slight modifications from Bublin, 2013; Le & Knulst, 2015; Wang, Vanga, McCusker et al., 2019.

kDa), Act d4 (phytolectin 11 kDa), Act d5 (kiwellin, 26 kDa), Act d6 (pectin methylesterase inhibitor, 18 kDa), Act d7 (pectin methylesterase, 35 kDa), Act d9 (profilin14), Act d10 (nonspecific lipid-transfer protein, 9 kDa) and Act d13 (2S albumin, 113.6 kDa). 2S albumin and 11S globulins (primarily in kiwifruit seeds) belong to storage proteins and are relatively stable against heat and digestion (Calamelli et al., 2019; Le & Knulst, 2015).

2.4. Lipids

Pulp lipids from *A. deliciosa* 'Hayward' and red kiwi were highly unsaturated with a total saturated fatty acids (FA) of 7 and 20% FW, respectively (Dias et al., 2020). The percentages of their total mono-unsaturated (9.9 and 10.3% FW, respectively) and polyunsaturated FA (83 and 70% FW, respectively) varied (Dias et al., 2020). 'Hayward' and red kiwi varied in concentration of fourteen saturated, six mono-unsaturated and five polyunsaturated FAs (Table 2). Saturated palmitic (C16:0), monounsaturated oleic acid (C18:1) and polyunsaturated linolenic acid (C18:3) predominated in red kiwi (14.3, 8.0 and 35.0 g/100 g, FW, respectively) and *A. deliciosa* 'Hayward' (4.6, 8.9 and 68.0 g/100 g, FW, respectively). Three *A. arguta* cultivars contained 14–31% saturated FAs (predominated by palmitic acid) and 70–86% unsaturated FAs (predominated by α -linoleic acid) (Latocha, 2017).

Based on FW, in ZESPRI SunGold, 0.065 g/100 g of FA were saturated, 0.023 g/100 g of FA were monounsaturated, and 0.111 g/100 g of FA were polyunsaturated (USDA, 2017). Saturated FA (4:0, 8:0, 10:0, 12:0, 14:0, 16:0, 18:0, and 20:0) detected in SunGold had concentrations of 0.001, 0.001, 0.001, 0.003, 0.003, 0.048, 0.006, and 0.001 g/100 g FW, respectively (USDA, 2017). In fresh green kiwifruit, 0.287 g/100 g of FA were polyunsaturated, 0.047 g/100 g of FA are monounsaturated, and 0.029 g/100 g of FA are saturated. The FA of 18:2 (0.246 g/100 g) is most abundant, followed by 18:1 (0.047 g/100 g), 18:3 (0.042 g/100 g), and 16:0 (0.017 g/100 g) and 18:0 (0.012 g/100 g) (USDA, 2017).

Lipids are mostly concentrated in kiwifruit seeds. Soxhlet *n*-hexane extraction (34%) obtained higher yield than compressed propane extraction (32%) for Brazilian *A. deliciosa* seed oil. The different extractions led to similar FA composition and lipid contents. For example,

the propane extracted seed oils had 96% of total lipids and were highly unsaturated with the concentrations of C18:3n3, C18:3n6, C18:2n6c, C18:1n9c, C18:0 and C16:0 being 63.4, 0.36, 13.5, 14.4, 3.34, and 5.24%, respectively (Coelho, Kanda, Hamerski, Masson, & Corazza, 2016). Compared to seed oils of Italian kiwifruit extracted using Soxhlet, those extracted using supercritical CO₂ extractions, ultrasound, microwave contained more omega-3 FAs (Cravotto et al., 2011). Therefore, extraction methods should be optimized for oil composition and contents.

2.5. Minerals

Fresh ZESPRI SunGold and green kiwifruit (unstated cultivar/country) varied in concentration of potassium, phosphorus, calcium, magnesium, sodium, iron, copper, zinc, manganese, and selenium (Table 2). Comparatively, the SunGold kiwifruit had more potassium (315 mg/100 g, FW) (USDA, 2017). *A. arguta* had more potassium, calcium, magnesium, manganese, and zinc than *A. deliciosa* 'Hayward' (Latocha, 2017).

2.6. Vitamins

Variations in vitamin C (VC) content depends on kiwifruit variety. Eleven cultivars, investigated by Ma et al. (2017), had a VC content range of 54.86–159.08 mg/100 g FW, with *A. chinensis* Jintao showing the highest VC content. Eight *A. chinensis* cultivars and three *A. deliciosa* cultivars had a VC content ranges of 53–391 and 59–169 mg/100 g, respectively. *A. polygama* (86 mg/100 g) had higher VC content than *A. macrosperma* (61 mg/100 g) and *A. arguta* (51.32 mg/100 g) (Li et al., 2018). VC contents of Korean *A. arguta* × *A. deliciosa* 'Mansu', *A. arguta* 'Haeyon' and 'Chiak' ranged from 55 to 130 mg/100 g (Jeong et al., 2020). Among Chinese grown kiwifruits, *A. macrosperma* (768 mg/100 g) had higher VC content than *A. arguta*, *A. chinensis* and *A. deliciosa* (Wang et al., 2018).

Fresh ZESPRI SunGold and green kiwifruit (unstated cultivar/country) varied in concentrations of vitamins and pro-vitamins, including vitamins (C, A, B₆, B₁₂, and K), riboflavin, niacin, pantothenic acid,

folate, choline, α , β and γ -tocopherols (Table 2). Comparatively, Sun-Gold contained higher VC and folate (161.3 mg/100 g and 31 μ g/100 g FW, respectively) (USDA, 2017). Based on FW, *A. deliciosa* 'Hayward' peels contained higher total tocopherols, α , γ and δ -tocopherols (4.3, 2.40, 0.06, and 1.86 mg/100 g respectively) than pulps (1.7, 1.7, 0.04, and 0 mg/100 g, respectively). Similarly comparative pattern in red kiwi peels (10.8, 7.4, 1.70, and 10.8 mg/100 g, respectively) and pulps (4.58, 3.57, 1.01, and 0 mg/100 g, respectively) was obtained (Dias et al., 2020). VC degrades the most in thermal-processed kiwifruit products, such as dried-slices than using other processing methods (Ma, Lan, Geng et al., 2019). Combining ultrasonic treatment and NaOCl solution minimally influenced VC content of unpeeled whole *A. deliciosa* 'Hayward' (Vivek, Subbarao, & Srivastava, 2016). Improved processing technologies are required for minimizing VC loss.

2.7. Organic acids

Organic acid levels, depending on varieties, plant parts and processing, are important for kiwifruit nutrition/flavor (i.e., acidity). *A. deliciosa* 'Hayward' contained quinic, malic, citric and ascorbic acids, and total organic acids that differs from red kiwi fruits (Table 2). Ten succinic acid derivatives, eleven quinic acid derivatives, two shikimic acid derivatives, and six citric acid derivatives were identified in *A. arguta* (Ahn et al., 2020). *L. plantarum* fermentation increased lactic acid contents, while decreasing that of phosphoric acid in kiwifruit pulp (Zhou et al., 2020).

2.8. Chlorophylls

For six cultivars, including New Zealand 'Hort 16A' and five Korean cultivars ('Hayward', 'Daheung' 'Haenam' 'Bidan' and 'SKK12') investigated by Park, Leontowicz et al. (2015), total chlorophyll contents ranged from 2.9 to 140 μ g/g DW. The contents of chlorophyll *a* and chlorophyll *b* ranged from 4.4 to 101 and 0.7–39.1 μ g/g DW, respectively (Park, Leontowicz et al., 2015). Korean 'Hayward' contained 72 μ g/g DW of chlorophylls (Park et al., 2016). Chlorophyll *a* and *b* accounted for 56 and 16 μ g/g DW, respectively, in *A. deliciosa* fruits, a source of pheophytin *a* and *b* (40872, and 75 μ g/g DW, respectively) (Benlloch-Tinoco et al., 2015). Microwave (1000 W, 340 s) and conventional pasteurisation (97 °C, 30 s) reduced total chlorophyll content by 42–100% (Benlloch-Tinoco et al., 2015).

2.9. Phenolic compounds

Total phenolic content (TPC), types and concentrations of individual phenolic compounds are affected by several factors. They included species and cultivars, fruit parts (flesh vs peel), maturation stages, and processing methods (such as extraction, fermentation and dehydration) as described below.

2.9.1. TPC

2.9.1.1. Species and cultivars. TPC of eight *A. chinensis* and three *A. deliciosa* cultivars ranged from 4.7–16 and 5.3–6.6 mg GAE/g DW, respectively. *A. arguta*, *A. macrosperma*, and *A. polygama* had TPC of 8.15, 5.57, and 4.71 mg GAE/g DW, respectively (Li & Zhu, 2019). Eleven cultivars, investigated by Ma et al. (2017), had a TPC range of 58.45 to 152 mg GAE/100 g FW, with *A. chinensis* 'Huayou' containing the highest TPC. Extracts (70% aqueous acetone) of *A. deliciosa* 'Hayward', *A. chinensis* 'Hort 16A' and *A. macrosperma* varied in TPC (479, 231 and 587 μ g/g DW, respectively) (Hettihewa, Hemar, & Rupasinghe, 2018). Fresh Korean 'Hayward' had a TPC of 8.19 mg GAE/g (Park et al., 2016). The TPC of *A. arguta* 'Chiak' and 'Darae No. 2' ranged from 88 to 113 mg GAE/100 g FW. The TPC of *A. chinensis* 'Haegum' and 'Haehyang' ranged from 86 to 133 mg GAE/100 g FW. The TPC of *A. arguta*

$\times$ *A. deliciosa* 'Mansoo' ranged from 118 to 131 mg GAE/100 g FW (Lee et al., 2015). *A. eriantha* 'Bidan' peeled fruit methanol extracts had higher TPC than *A. arguta*, and *A. deliciosa* 'Hayward' extracts (57.4, 12.9, and 6.4 mg GAE/g DW, respectively) (Abdul Hamid et al., 2017).

2.9.1.2. Maturity stages. At different maturity stages, Korean *A. eriantha* 'Bidan' had a range of TPC of 433–775 mg GAE/100 g FW. Changes in TPC of *A. chinensis* occurred during fruit maturation. In early maturation stages, polyphenoloxidase induced oxidation of polyphenols, decreasing the TPC. In late maturation stages, more ascorbic acid possibly reacted with Folin-Ciocalteu reagent, increasing the TPC (Nie et al., 2020). Among six TYK [25 and 60 days after fruit-set (DAF), respectively] and three mature fruits of New Zealand cultivars *A. chinensis* 'Zesy002', *A. chinensis* $\times$ *A. deliciosa* 'Zesh004' and *A. deliciosa* 'Hayward' investigated by Jiao, Chen, Fan, and Quek (2019), *A. chinensis* 'Zesy002' TYK (25 DAF) exhibited the highest levels of TPC (82.84 mg GAE/g FDW). 'Hayward' TYK (25 DAF) extract exhibited a TPC of 0.53 g epicatechin equivalent/g DW (Jiao et al., 2020).

2.9.1.3. Fruit parts. *A. chinensis* peel polyphenolic extracts (12.8 mg GAE/g DW) had higher TPC than flesh polyphenolic extracts (9.5 mg GAE/g DW) (Alim et al., 2019). The polyphenols ultrasonically extracted from 'Hayward' TYK (25 DAF) exhibited a TPC of 0.53 g epicatechin equivalent/g DW (Jiao et al., 2020).

2.9.1.4. Processing techniques. Extraction methods and solvent type affect the TPC. Subcritical water (175–225 °C, 90 min) temperature-dependently increased the TPC of kiwifruit pomace extracts. The extraction gave higher phenolic yield than solid-solvent extractions (using 100% ethanol, 80% methanol and 70% acetone as solvents) (Kheirkhah, Baroutian, & Quek, 2019). Subcritical water had lowered dielectric constant and polarity of water and increased solubility of polar to medium-polar pomace extract compounds (Kheirkhah et al., 2019). TPC of ethanol Portuguese *A. arguta* leaf ethanol extracts (440.7 mg CAE/g DW) was higher than water (189.4 mg GAE/g DW) and hydroalcoholic (50% ethanol, 140.7 mg GAE/g DW) extracts (Almeida et al., 2018). The TPC of six cultivars was in a range of 4.2–14.5 for ethanol extracts, and 5.3–16.3 mg GAE/g for water extracts (Park, Leontowicz et al., 2015).

L. plantarum fermentation (28 h) increased TPC in kiwifruit pulp by 63%. Fermentation promoted phenolic releases from the pulp (Zhou et al., 2020). Microwave-dried *A. deliciosa* (1117 mg/100 g DW) had the higher TPC than oven-dried samples (1034 mg/100 g DW) (Özcan et al., 2020). Phenolics are commonly used indicators for extraction and processing optimization (Kheirkhah et al., 2019; Wang, Vanga, Raghavan, 2019; Özcan et al., 2020; Liu et al., 2020).

2.9.2. Phenolic acids (PAs) and their derivatives

2.9.2.1. Species and cultivars. Fourteen kiwifruit varieties, including eight *A. chinensis* cultivars ('Hongshi', 'Jinshi', 'Jinlong', 'Jinyan' 'Hongyang', 'Jinhong', 'Honghua', and 'Hort16A'), three *A. deliciosa* cultivars ('Cuixiang', 'Xuxiang', and 'Hayward'), *A. macrosperma*, *A. polygama* and *A. arguta*, investigated by Li et al. (2018), varied in the contents of gallic, protocatechuic, chlorogenic, neochlorogenic and caffeic acids (Table 2), ranging from 9.8–53.8, 6.6–15.8, 7.7–235.8, 6.6–133.7 and 2.7–41.0 μ g/g DW, respectively. Among these varieties, 'Jinshi', 'Jinlong' and *A. macrosperma* exhibited the highest contents of gallic, neochlorogenic and caffeic acids, respectively. *A. chinensis* 'Hongshi' exhibited the highest content of both protocatechuic and chlorogenic acids (Li et al., 2018).

2.9.2.2. Extraction methods. *A. arguta* leaf aqueous extracts (60.2 μ g/mg, DW) had the highest hydroxycinnamic level, followed by the alcoholic extracts (44.6 μ g/mg, DW) and the hydroalcoholic extracts (31.0

µg/mg, DW). Neochlorogenic acid (23.2–43.1 µg/mg, DW), chlorogenic acid (2.9–4.9 µg/mg, DW), caffeic acid derivatives (0.4–7.1 µg/mg, DW) were tentatively identified from the aqueous, hydroalcoholic, and alcoholic extracts of *A. arguta* leaves (Almeida et al., 2018).

2.9.2.3. Plant parts. Italian *A. deliciosa* ‘Hayward’ peel extracts had higher contents of total hydroxycinnamic derivatives of 0.46 mg/g. Caffeic acid derivative (0.24 mg/g peel) was the most abundant, followed by ferulic acid glucoside (0.17 mg/g peel) and ferulic acid dehydromer (0.04 mg/g peel) and dimethyl caffeic acid hexoside (trace amount) (D’eliseo et al., 2019).

The concentration order of six PAs identified from *A. deliciosa* was 3,4-dihydroxybenzoic acid (33 mg/100 g) > gallic acid (18 mg/100 g) > syringic acid (8.4 mg/100 g) > caffeic acid (1.9 mg/100 g) > *trans*-ferulic acid (3.5 mg/100 g) > *p*-coumaric acid (0.53 mg/100 g) (Özcan et al., 2020). One caffeic acid dihexoside, one caffeic acid derivative, four caffeic acid hexosides, and one dimethyl caffeic acid hexoside were identified from *A. deliciosa* ‘Hayward’ pulp. Only one caffeic acid derivative (differed from ‘Hayward’) and one caffeic acid hexoside (concentration higher than ‘Hayward’) were identified from red kiwifruit pulp (Dias et al., 2020). *A. deliciosa* ‘Hayward’ peel contained more caffeic acid derivative (8.6 mg/g extract), caffeic acid hexoside (13.7 mg/g extract), dimethyl caffeic acid hexoside (1.4 mg/g extract), and acetyl-dimethyl caffeic acid hexoside (3.3 mg/g extract) than red kiwifruit peel (2.1 and 2.2, 0.9 and 0.1 mg/g extract, respectively) (Dias et al., 2020). Fruit pomace of *A. deliciosa* mainly contained protocatechuic acid, caffeic acid derivatives, chlorogenic and *p*-coumaric acids (Kheirkhaha et al., 2019). *A. macrosperma*, *A. chinensis*, and *A. deliciosa* varied in the contents of chlorogenic (0.28–1.97 µg/g DW), caffeic (0.04–1.64 µg/g DW), ferulic (0.42–4.70 µg/g DW) and isoferulic (15.12–32.71 µg/g DW) acids, with the highest levels present in *A. macrosperma* (Hettihewa et al., 2018).

2.9.2.4. Maturity stages. Changes in PAs of kiwifruit occurred during maturation (Jiao et al., 2019). Based on freeze-dried-weight (FDW), gallic (0.23–0.26 µg/g), protocatechuic (0.36–0.66 µg/g), vanillic (2.96–4.40 µg/g), caffeic (0.56–1.17 µg/g), chlorogenic (0.27–2.39 µg/g), ferulic (0.02–0.09 µg/g), and *p*-coumaric (0.06–0.17 µg/g) acids were reported in matured New Zealand *A. chinensis* ‘Zesy002’, *A. chinensis* × *A. deliciosa* ‘Zesh004’ and *A. deliciosa* ‘Hayward’ fruits. Except for vanillic acid (2.83–2.93 µg/g), higher levels of gallic (0.63–1.42 µg/g), protocatechuic (1.53–2.89 µg/g), caffeic (0.92–1.96 µg/g), chlorogenic (1.56–5.15 µg/g), ferulic (0.95–3.07 µg/g), and *p*-coumaric (0.42–0.71 µg/g) acids were found in TYK (20 DAF) (Jiao et al., 2019). TYK contained more PAs than matured fruits.

2.9.2.5. Processing techniques. Changes in PA composition occur over processing. After 28 h of *L. plantarum* fermentation, gallic acid and chlorogenic acid contents decreased and protocatechuic acid and *p*-coumaric acid contents increased in kiwifruit pulp (Zhou et al., 2020). Oven-drying (70 °C, 20 h) increased the contents of 3, 4-dihydroxybenzoic, gallic, syringic, caffeic and *p*-coumaric acids, while decreasing *trans*-ferulic acid level. Microwave-drying (720 W, 3 min) reduced gallic acid and 3,4-dihydroxybenzoic acid contents, and increased syringic acid, caffeic acid, *p*-coumaric acid and *trans*-ferulic acid contents in kiwifruits (Özcan et al., 2020).

2.9.3. Flavonoids

2.9.3.1. Total flavonoid content

2.9.3.1.1. Species and cultivars. Different extraction solvents led to variations in total flavonoid content (TFC). TFC of fresh Korean ‘Hayward’ water extracts was 2.47 mg catechin equivalent (CE)/g DW, which was higher than that of methanol extracts (2.11 mg CE/g DW) (Park et al., 2016). For six different cultivars, investigated by Park,

Leontowicz et al. (2015), the TFC of ethanol and water extracts ranged from 1.2–4.3 and 0.6–1.8 mg CE/g DW, respectively. Alcoholic Portuguese *A. arguta* leaves extract had the highest TFC (318.1 mg CE/g DW) than aqueous (136.7 mg CE/g DW) and hydroalcoholic (50% ethanol, 173.8 mg CE/g DW) extracts. Extraction solvents possibly influenced the solubility of kiwifruit flavonoids (Almeida et al., 2018).

2.9.3.1.2. Fruit parts. *A. chinensis* peel polyphenolic extracts (2.7 mg rutin/g) had higher TFC than flesh polyphenolic extracts (1.8 mg rutin/g) (Alim et al., 2019).

2.9.3.1.3. Maturity. *A. chinensis* ‘Zesy002’ TYK (25 DAF) exhibited the highest TFC (30 CE/g DW) among six TYK and three matured fruits investigated by Jiao et al. (2019).

2.9.3.1.4. Processing techniques. Zhou et al. (2020) reported a 69% of increase in TFC of pulp after 28 h fermentation by *L. plantarum*. Fermentation induces enzymatic conversions among phenolic substances. Kheirkhaha et al. (2019) reported that subcritical water extraction (175–225 °C, 90 min) temperature-dependently increased kiwifruit pomace extract TFC. Park et al. (2016) observed that adding white sugar (10, 15, 20 and 25%) concentration-dependently decreased TFC of water and methanol extracts in Korean ‘Hayward’ smoothies.

2.9.3.2. Flavonols. Cultivar and maturity of kiwifruit determine total flavonols content. Jiao et al. (2019) found that TYK exhibited higher total flavonols content than matured kiwifruits. ‘Hayward’ TYK (25 DAF) contained the highest levels of rutin and quercitrin (170 and 454 µg/g, respectively), and matured ‘Zesy002’ contained the lowest levels of rutin and quercitrin (2.8 and 2.2 µg/g, DW respectively) (Jiao et al., 2019). In ultrasonic-extracted polyphenols from ‘Hayward’ TYK (25 DAF), quercetin accounted for 36 mg/g of the extract (Jiao et al., 2020). Quercetin glycosides were predominately found in polyphenolic extracts of ripe *A. macrosperma* × *A. melanandra* Yellow (yellow skin/flesh) (Peng et al., 2020). In fresh *A. deliciosa*, isorhamnetin (8.5 mg/100 g, DW) was predominate, followed by kaempferol (8.1 mg/100 g, DW), quercetin (1.9 mg/100 g, DW) and rutin trihydrate (0.387 mg/100 g, DW) (Özcan et al., 2020).

Oven-dried (70 °C, 20 h) kiwifruits had less kaempferol (15.3 mg/100 g DW) and rutin trihydrate (1.1 mg/100 g DW) than microwave-dried (720 W, 3 min) samples (19.9 and 2.1 mg/100 g DW, receptivity). The former had more isorhamnetin (18.5 mg/100 g DW) and quercetin (3.3 mg/100 g DW) than the latter (16.2 and 1.3 mg/100 g DW, respectively) (Özcan et al., 2020). Among fourteen cultivars, *A. chinensis* ‘Hongshi’ contained the highest content of quercetin-3-rhamnoside (41.9 µg/g DW). Quercetin-3-rhamnoside was absent in *A. chinensis* ‘Jinlong’ and *A. deliciosa* ‘Hayward’. Rutin was found in *A. polygama* (48.2 µg/g DW), *A. macrosperma* (17.6 µg/g DW), and *A. arguta* (8.3 µg/g DW). Quercetin-3-O-glucoside was detected in *A. macrosperma*, *A. arguta*, *A. chinensis* ‘Hongshi’, and *A. deliciosa* ‘Xuxiang’ (109, 11.0, 6.2 and 5.10 µg/g DW, respectively) (Li et al., 2018).

The hydroalcoholic extracts (46.4 µg/mg DW) exhibited the highest content of flavonols, followed by aqueous (37.1 µg/mg DW) and alcoholic (28.8 µg/mg DW) extracts of Portuguese *A. arguta* leaves (Almeida et al., 2018). Contents of glycosylated quercetin and glycosylated kaempferol derivatives in Portuguese *A. arguta* leaf extracts varied between extraction solvents used (Almeida et al., 2018). Korean ‘Hayward’ water extracts (0.16 mg CE/g DW) contained more flavanols than methanol extracts (0.14 mg CE/g DW) (Park et al., 2016).

2.9.3.2.1. Flavan-3-ols. Total flavan-3-ols contents in fourteen kiwifruit cultivars ranged from 96–824 µg/g DW (Li et al., 2018). Hydroalcoholic extracts (147.8 µg/mg DW) had more total flavan-3-ols than alcoholic (48.3 µg/mg DW) and aqueous (18.8 µg/mg DW) Portuguese *A. arguta* leaf extracts (Almeida et al., 2018).

Flavan-3-ols profiles depend on kiwifruit variety. Among fourteen cultivars investigated by Li et al. (2018), ‘Hongshi’ had the highest (-)-epicatechin (163 µg/g DW) and procyanidin B1 (447 µg/g DW) and procyanidin B2 (182 µg/g DW) contents. *A. arguta* had the highest

(+)-catechin content (132 µg/g DW). Gallocatechin was dominant in ripe yellow-fleshed *A. macrosperma* × *A. melanandra* polyphenolic extracts (Peng et al., 2020). Among eleven cultivars, Chinese *A. chinensis* ‘Hongyang’ had the highest (+/–)-catechin (8.66 mg/100 g), and *A. chinensis* ‘Jinshi 1’ had the highest epicatechin (0.56 mg/100 g) (Ma et al., 2017).

Flavan-3-ols profiles of different kiwifruit parts varied. Catechin accounted for 26.1% in Chinese ‘Guichang’ pulp (Zhou et al., 2020). Italian *A. deliciosa* ‘Hayward’ peels contained total procyanidins content of 5.4 mg/g. Specifically, one dimeric (0.697 mg/g), five trimeric (0.665–1.194 mg/g) and one tetrameric (0.143 mg/g) procyanidins were identified (D’eliseo et al., 2019). Catechin derivatives were the most predominant flavan-3-ols in *A. arguta* leaves (Almeida et al., 2018).

Profile of flavan-3-ols depended on maturity (Jiao et al., 2019). ‘Zesy002’ TYK had the highest amounts of epicatechin (FDW) and catechin (49 µg/g FDW) among 6 TYK and 3 matured fruits (Jiao et al., 2019). Processing also influenced flavan-3-ols profiles. *L. plantarum*-fermented kiwifruit pulp exhibited decreased contents of epicatechin and catechin (Zhou et al., 2020). Oven (70 °C, 20 h) and microwave (720 W, 3 min) drying increased the content of (+)-catechin of *A. deliciosa* by 84 and 90%, respectively (Özcan et al., 2020).

2.9.3.2.2. Flavanones. *A. deliciosa* (100 g) contained 2.48 mg of naringenin. Compared to microwave-dried (720 W, 3 min) *A. deliciosa* (6.67 mg), oven-dried (70 °C, 20 h) sample had less naringenin (6.06 mg) (Özcan et al., 2020).

2.9.3.2.3. Flavones. *A. deliciosa* (100 g) contained 0.347 mg of apigenin 7-glucoside. The content of apigenin 7-glucoside in oven-dried (70 °C, 20 h) *A. deliciosa* (1.50 mg) was higher than that of microwave-dried (720 W, 3 min) samples (1.07 mg) (Özcan et al., 2020).

2.9.3.3. Dihydrochalcones. New Zealand *A. macrosperma*, *A. deliciosa* and *A. chinensis* contained phloridzin (2.03–5.08 µg/g DW) and phloritin (0.14–0.21 µg/g DW). *A. deliciosa* and *A. chinensis* had the highest contents of phloridzin and phloritin, respectively (Hettihewa et al., 2018).

2.9.3.4. Anthocyanins. Total anthocyanin content (TAC) of fresh Korean ‘Hayward’ water extracts was 20 mg cyanidin-3-glucoside equivalents (CGE)/g DW (Park et al., 2016). TAC of Chinese *A. deliciosa* (‘Hayward’ and ‘Qinmei’) and *A. chinensis* (‘Hongyang’ and ‘Huayou’), ranged from 1.4 to 3.3 mg CGE/100 g FW (Ma, Lan, Ju et al., 2019). Jiao et al. (2019) found that *A. chinensis* ‘Zesy002’ TYK (25 DAF) had the highest TAC of 20 CE/g DW among six TYK and three matured kiwifruits. Eleven cultivars investigated by Ma et al. (2017) had TAC of 1.06–5.31 mg CGE/100 g FW, with *A. deliciosa* ‘Jinxiang’ having the highest TAC.

Anthocyanins, namely delphinidin-3-O-(xylosyl) galactoside, delphinidin-3-O-galactoside, cyanidin-3-O-(xylosyl) galactoside, cyanidin-3-O-galactoside, cyanidin-3-O-sambubioside and cyanidin-3-O-glucoside contributed to the colour of red kiwifruit’s pulp (Wojdyło et al., 2017). Cyanidin-based anthocyanins mainly contributed to purple colors of skin and flesh of ripe *A. melanandra* and *A. purpurea*. Delphinidin-based anthocyanins were associated with purple pigmentation of peels and flesh in *A. macrosperma* × *A. melanandra* Red (Peng et al., 2020). TAC increased as kiwifruit ripened and/or were stored in prolonged low-temperatures (Li et al., 2018; Peng et al., 2020). Adding white sugar (10, 15, 20 and 25%) concentration-dependently decreased TAC of water extracts of ‘Hayward’ smoothies (Park et al., 2016).

2.9.4. Stilbenoids

Resveratrol in *A. deliciosa* was 0.386 mg/100 g. Oven (70 °C, 20 h) and microwave (720 W, 3 min) dried *A. deliciosa* contained the resveratrol levels of 0.632 and 0.494 mg/100 g, DW, respectively (Özcan et al., 2020).

2.10. Carotenoids

Total carotenoid contents (TCC) ranged from 1.5 to 7.5 µg/g DW in six cultivars (Park, Leontowicz et al., 2015). Different kiwifruits varied in carotenoid composition. Based on FW, ZESPRI SunGold had 14 µg/100 g of β-carotene and 24 µg/100 g of lutein and zeaxanthin (USDA, 2017). Lutein, β-carotene, neolutein A + B, neoxanthin and violaxanthin represent the major carotenoids in *A. deliciosa* ‘Hayward’ (Benlloch-Tinoco et al., 2015). Bright-yellow-fleshed *A. chinensis* ‘Jinshi 1’ contained predominantly β-cryptoxanthin, followed by lutein, zeaxanthin, and β-carotene. Bright-yellow-fleshed *A. chinensis* ‘Jinyan’ contains predominantly β-carotene, followed by lutein and zeaxanthin (Xia et al., 2020).

Storage temperature positively correlated to TCC in kiwifruit. More carotenoids were found in kiwifruit stored at 20 °C than that at 4 °C. Carotenoid biosynthetic genes (PSY, CCD1 and NCED1 genes) contributed to the increased content of carotenoids during storage at 20 °C (Xia et al., 2020). Unigene11266 and Unigene23885 are the major genes for carotenoid synthesis in *A. chinensis* (Zhang et al., 2015). Metabolisms of individual carotenoids respond to temperature changes differently. Increases of lutein, β-carotene, and β-cryptoxanthin contents, and decreases of zeaxanthin content occurred in *A. chinensis* ‘Jinshi 1’ stored at 20 °C. Increase of zeaxanthin and β-carotene contents, decrease of lutein content, and appearance of two new carotenoids (β-cryptoxanthin and α-carotene) occurred in *A. chinensis* ‘Jinyan’ stored at 20 °C (Xia et al., 2020). Microwaving (1000 W, 340 s) reduced 62–91% of carotenoids in kiwifruit (Benlloch-Tinoco et al., 2015). Factors, including cultivar, processing, and storage conditions determined variations of kiwifruit carotenoid profiles (Xia et al., 2020).

2.11. Volatiles

Volatile profiles of kiwifruits depended on various factors, including species and varieties, stage of fruit maturity and ripening, storage conditions and technological treatments. Volatile biomarkers have been identified and are likely to be sensory-relevant (Cheng, Seal, Macrae, & Wang, 2011; Cozzolino et al., 2020; Garcia et al., 2012; Garcia, Stevenson, Atkinson, Winz, & Quek, 2013; Santoni, Barboni, Paolini, & Costa, 2013; Wang, MacRae, Wohlers, & Marsh, 2011; Young & Pater-son, 1985; Zhang, Zhang, Zhong, & Guo, 2019; Zhao, Zhang, Liu, & Zhang, 2020).

2.11.1. Species and varieties

Aroma notes from volatiles differentiate kiwifruit varieties. Seventy-two volatiles in four yellow-fleshed (*A. chinensis* ‘Dorì’, ‘G3’, ‘Jintao’ and ‘Soreli’) and two green-fleshed (*A. deliciosa* ‘Hayward’ and ‘Summer’) Italian kiwifruits were identified. Twenty-two esters, fifteen terpenes, fourteen aldehydes, nine alcohols, five ketones, and four furans were identified. ‘Dorì’ was differentiated from the other cultivars by its unique composition of six esters of ethyl isobutyrate, propyl butyrate, ethyl pentanoate, ethyl trans-2-butenate, methyl octanoate, ethyl benzoate. 2-Pentylfuran with green and vegetable notes discriminated green-fleshed kiwifruit from yellow-fleshed cultivars (Cozzolino et al., 2020). The fresh, green and grassy notes identified by the consumers in kiwifruit aroma were mainly attributed to hexanal, trans-2-hexenal, trans-3-hexenal and ethyl butanoate (Cozzolino et al., 2020; Nieuwenhuizen et al., 2016; Zhang et al., 2019). Ethyl butyrate, hexanal, and (E)-hex-2-enal were the key odour-active contributors of sweet, intense herbaceous and herbaceous/almond notes, respectively (Young, Pater-son, & Burns, 1983). Hexanal (1.06 mg/kg) was the most abundant, followed by (E)-hex-2-enal (0.639 mg/kg), hexan-2-ol (0.277 mg/kg), ethyl butyrate (0.104 mg/kg) and hexanol (0.094 mg/kg) in lyophilised Corsican *A. deliciosa* ‘Hayward’ (Santoni et al., 2013). Zhao et al. (2020) identified 37 and 39 bound aroma compounds in ‘Hort16A’ and ‘Hayward’ pomace, respectively. Myrtenol and geraniol were the most abundant in ‘Hort16A’ and ‘Hayward’, respectively. Two unique

A. deliciosa 'Cuiyu' volatile biomarkers (1-methoxy-2-methyl-benzene, (E, E)-2,4-heptadienal) differentiated *A. deliciosa* 'Cuiyu' from *A. chinensis* 'Jintao' and *A. eriantha* 'Tuguomaohua' (Zhang et al., 2019). Bound decanals, unique to 'Hayward', imparted the fatty flavor (Zhao et al., 2020).

2.11.2. Fruit maturity, ripening, and storage

A. chinensis 'Jintao' had four unique maturity-independent volatile biomarkers, including formic acid octyl ester, 2-methylbicyclo[4.3.0]non-1(6)-ene, 1-ethoxy-2,4-hexadiene, and 2-methyl-5-(1-methyl-ethyl)-bicyclo[3.1.0]hex-2-ene (Zhang et al., 2009). Decreases in volatile levels occurred during ripening and/or storage of the fruit (Sanoni et al., 2013).

2.11.3. Technological treatments

The process of fermentation in kiwifruit winemaking changed the volatile profiles of kiwifruit juice and wine. Kiwifruit wines contained various esters (ethyl eicosanoate, ethyl acetate, diethyl butanedioate, ethyl hexadecanoate, ethyl decanoate, ethyl 9-decenoate, methyl octanoate, methyl benzoate, isoamyl acetate, ethyl octanoate, isobutyl acetate, and ethyl hexanoate), four alcohols (2-methyl-1-butanol, isoamyl alcohol, 1-hexanol and (E)-3-hexen-1-ol), two acids (hexanoic and octanoic acids), one ketone (6-methyl-5-hepten-2-one) and one furan (2,3-dihydrobenzofuran). These compounds were rare in kiwifruit juices. 'Hayward' wine displayed higher intensity of sweet aroma than 'Hayward' juice (Zhao et al., 2020). 'Hort16A' juice had more 2-heptanol, 4-methyl-3-penten-2-one, 4-hydroxy-4-methyl-2-pentanone, 3-carene, terpinolene, citral, myrtenol, and 4-ethylguaiaicol than 'Hayward' juice (Zhao et al., 2020).

2.12. Chemical contaminants

Potential chemical contaminants (e.g. mycotoxins, pesticides and heavy metals) in kiwifruits have been identified, while investigation of the contaminant origins, and methods of monitoring, enforcement, and other intervention methods to minimize these chemical contaminants in kiwifruit is much less studied so far.

2.12.1. Mycotoxins

Kiwifruit is susceptible to postharvest fungal contaminations such as *Penicillium expansum*, which produces mycotoxin patulin (Reddy, Spadaro, Lore, Gullino, & Garibaldi, 2010). Patulin may end up in finished kiwifruit products such as juice. Encouragingly, magnetic chitosan (1:1 ratio of Fe₃O₄ particles to chitosan), a superior patulin adsorbent, reduced patulin levels in kiwifruit juice without altering juice flavor and quality (Luo et al., 2016). Prevention of mycotoxin contamination of kiwifruit is more practical than mycotoxin removal.

2.12.2. Pesticide residues

Adverse effects from neonicotinoid insecticide, nitenpyram [(E)-N-(6-Chloro-3-pyridylmethyl)-N-ethyl-N'-methyl-2-nitrovinylidenediamine], are of great concern. In a field trial, nitenpyram (25–50 mg active ingredient/kg) was sprayed three-times with 7-day intervals. Final nitenpyram residues (0.01–0.54 mg/kg, 7–21 days after spraying) were detected in the kiwifruits at six Chinese planting regions (Ge et al., 2020). The maximum allowable levels of pesticide residues in agriculture products, such as kiwifruits, vary among countries. Toxicological significance of residue level in the edible portion of kiwifruit is not clear.

2.12.3. Heavy metals

Ma et al. (2017) found that New Zealand *A. chinensis* 'Hort16A' and Chinese *A. deliciosa* 'Jinxiang' had the lowest and highest contents of Pb (lead) (2.7 and 11.5 µg/100 g FW, respectively), without stating contamination sources.

2.13. Comparative discussion of chemical properties of kiwifruit

Factors influencing the chemical variations (Table 2) included species, maturity stage, fruit parts, geographical and environmental conditions, and agricultural practices. Some studies compared different kiwifruit cultivars, species or plant parts. In different studies, the methods used tended to be inconsistent. Differences in sample sources, extraction methods, analytical procedures, and means of result expression using different standard equivalents and/or weight bases contribute to the variations between studies, and rendering data interpretation difficult.

Comparative studies also emphasized the differences between kiwifruit and other fruits. The results of these comparative studies suggested the difference-derived potential application and market values of kiwifruits. However, the appropriate properties studied and comparable samples selected are limited and inconsistency in different comparative reports. Kiwifruit (unknown species) had more VC (84 mg/100 g FW) than grapefruit (30–70 mg/100 g), raspberry (19–37 mg/100 g), apple (0.5–20 mg/100 g), pear (4 mg/100 g), plum (5 mg/100 g), and banana (7–14 mg/100 g) (Janda, Kasprzak, & Wolska, 2015). Among different fruits, DF content ranked in the order of *A. deliciosa* (24.7 g/kg) > red plum (22.2 g/kg) > strawberry = peach (20.7 g/kg) > banana (15.5 g/kg) > red grapefruit = white grape (13.2 g/kg) > orange (13.0 g/kg) > mango (12.9 g/kg) > apple (12.2 g/kg), based on DW (Park, Im et al., 2015). The TPC of *A. kolomikta* and *A. arguta* were higher than green grape, cherry, green delicious apple, banana, avocado, pineapple, blueberry, papaya, grapefruit, red plum, lemon, Hainan mango, peach, and South African orange (Baranowska-Wójcik & Szwajgier, 2019).

Pérez-Burillo et al. (2018) found that kiwifruit (*Actinidia* spp.) had lower energy (49 kcal/100 g) than persimmon (*Diospyros kaki*) (114 kcal/100 g). Kiwifruit (70 g/100 g) had lower water content than persimmon (129 g/100 g). It had less protein, lipids, carbohydrates and fiber and more calcium; however, persimmon contained less iron, magnesium, zinc, sodium, potassium, phosphorus and selenium. Kiwifruit had higher contents of niacin equivalents and lower contents of thiamine, riboflavin, and vitamin B6 than persimmon. It had higher VC (91 mg/100 g) and folate (25 mg/100 g) contents than persimmon (19 and 12 mg/100 g, respectively). Persimmon contained vitamin A of 191 µg retinol activity equivalents (RAE)/100 g, which greatly surpassed kiwifruit (1.8 µg RAE /100 g) (Pérez-Burillo et al., 2018). According to Özcan et al. (2020), kiwifruit (*A. deliciosa*) (81%) had lower moisture content than pepino fruits (*Solanum muricatum* Aiton) (93%). Kiwifruit had a lower TPC (623 mg/100 g DW) than pepino (1511 mg/100 g DW). Focusing on phenolics, kiwifruits contained predominantly (+)-catechin (47 mg/100 g), followed by 1, 2-dihydroxybenzene (45 mg/100 g), 3,4-dihydroxybenzoic acid (34 mg/100 g) and gallic acid (29 mg/100 g). Pepino fruits contained predominantly 1, 2-dihydroxybenzene (53 mg/100 g) followed by 3,4-dihydroxybenzoic acid (33 mg/100 g), (+)-catechin (32 mg/100 g) and gallic acid (18 mg/100 g) (Özcan et al., 2020). Such comparative data is useful for targeted and personalized nutrition applications.

3. Biological activities of kiwifruit

The major research interest included assessment of antioxidative and antimicrobial properties (potentially used in food safety or in human health), effects on inflammation, neuroprotection, and antihypertensive biomarkers, cytotoxic activities toward selected cancer cells, effects on hypercholesterolemia and obesity conditions, effects on gut microbiome and implications for human health (Table 3). Much of the work in these respective areas has been conducted *in vitro* using chemistry-based or cell culture systems. Few animal studies and human trials have been done.

3.1. Antioxidative property

3.1.1. *In vitro* antioxidative

Fresh and processed kiwifruits exhibited a broad spectrum of *in vitro* antioxidant activities (AAs). The chemistry-based assays applied included 2,2-diphenyl-1-picrylhydrazyl (DPPH), ferric reducing antioxidant power (FRAP), 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonate) (ABTS), cupric reducing antioxidant capacity (CUPRAC), β -carotene, thiobarbituric acid reactive substances (TBARS), hemolysis inhibition assay (OxHLIA), total reducing power (TRP), ion-chelating, hydroxyl radical ($\text{OH}^\bullet$) and superoxide anion radical ($\text{O}_2^{\bullet-}$) scavenging assays (Table 3). Variations in AAs existed among different kiwifruit varieties, parts, or samples of developmental stages.

ABTS, DPPH and FRAP values of eight *A. chinensis* cultivars ranged from 38 to 161 μmol Trolox equivalent (TE)/g DW, 13–87 mg GAE/g DW, and 25–150 μmol TE/g DW, respectively. *A. arguta* had higher AAs than *A. macrocarpa* and *A. polygama* (Li & Zhu, 2019). Antioxidant capacities of *A. kolomikta* and *A. arguta* were higher than those of *A. chinensis* and *A. deliciosa* determined by ABTS, DPPH, ORAC, and FRAP assays (Wang et al., 2018).

Kiwifruits varied in combinations of six cultivars and three extraction solvents exhibited different AAs. Water extracts had higher FRAP, CUPRAC, and β -carotene values than ethanol extracts of six cultivars (Park, Leontowicz et al., 2015). 'Hayward' water extracts had higher FRAP, ABTS, CUPRAC and DPPH values than methanol extracts (Park, Im et al., 2015). *A. eriantha* 'Bidan' extracts had higher DPPH, ABTS, FRAP and CUPRAC values than *A. arguta*, and *A. deliciosa* 'Hayward' (Leontowicz, H., Leontowicz M. et al., 2016; Abdul Hamid et al., 2017). Extraction solvents and evaluation assays affect AAs of Portuguese *A. arguta* leaves (Almeida et al., 2018) (Table 3).

Underutilized kiwifruit resources were also antioxidative. *A. chinensis* peel polyphenol extracts exhibited higher AAs than flesh polyphenol extracts (Alim et al., 2019). TYK of *A. chinensis* 'Zesy002', *A. chinensis* $\times$ *A. deliciosa* 'Zesh004' and *A. deliciosa* 'Hayward' had higher ABTS, DPPH and FRAP values than the matured ones, due to higher TPC and TFC of TYK (Jiao et al., 2019).

3.1.2. *In vivo* antioxidative activity

Kiwifruit consumptions (regardless of the number of kiwifruits consumed) provided protection against oxidative damage on DNA and increased antioxidant levels in health individuals. Kiwifruit consumptions (1–3 per day, 3 weeks) protected fourteen healthy volunteers (8 women and 6 men, 26–54 years) against oxidative DNA damage, as measured using lymphocytes (Collins, Harrington, Drew, & Melvin, 2003). Twenty-four healthy volunteers (men and women, 20–57 years, BMI of 20–30 kg/m^2) supplemented with a normal diet containing *A. chinensis* 'Hort 16A' (either one or two per day) for 4 weeks had decreased H_2O_2 -induced DNA damage and increased plasma vitamin C (Brevik et al., 2011).

3.1.3. Effect of processing on AAs

Subcritical water (175–225 $^\circ\text{C}$) temperature-dependently increased the AAs of *A. deliciosa* 'Hayward' fruit pomace extracts (Kheirkhah et al., 2019). Subcritical water improved phenolics extraction yield (Kheirkhah et al., 2019). *L. plantarum* fermentation increased AA of kiwifruit pulp by increasing the amount of phenolics (Zhou et al., 2020). Adding glutathione-enriched inactive dry yeasts improved the AA of *A. deliciosa* 'Xuxiang' wines made from fermenting pomace (Liu et al., 2020). Microwave-extracted polysaccharides showed the highest AA, followed by ultrasonic and hot water-extracted polysaccharides. More unmethylated galacturonic acid and lower MW of microwave-extracted polysaccharides possibly contributed to the higher AAs (Han et al., 2019). Compared to butylated hydroxytoluene, microwave-extracted polysaccharides had lower DPPH and ABTS values and reducing power (Han et al., 2019). Özcan et al. (2020) also reported that microwave-dried samples had the highest DPPH scavenging activity, followed by oven-

dried and fresh *A. deliciosa*.

3.2. Antiinflammatory property

Freeze-dried *A. arguta* fruit powder was anti-inflammatory in lipopolysaccharides (LPS) stimulated RAW 24.7 macrophages (*in vitro*) and Balb/c mice (*in vivo*) with colitis induced by dextran sulfate sodium (DSS) (Lian et al., 2019) (Table 3). *In vitro*, two hour pre-treatment of freeze-dried *A. arguta* fruit powder (100, 200, and 400 $\mu\text{g}/\text{ml}$) reduced proinflammatory factors (NO content and iNOS expression) in LPS (1 $\mu\text{g}/\text{mL}$) RAW 264 cells. *In vivo*, freeze-dried *A. arguta* fruit powder ameliorated DSS-induced changes in physiological indices, and histological observations (i.e. colonic mucosal ulcer, necrotic crypt, severe loss of goblet cells, and inflammatory cell infiltration), and oxidative stress levels in the Balb/c mice. Mechanically, the fruit powder inhibited overexpression of proinflammatory cytokines [interleukin-6 (IL-6), interleukin-1 β (IL-1 β), and tumor necrosis factor (TNF- α)] via mitogen-activated protein kinases pathway in mice colonic tissues (Lian et al., 2019).

Polyphenols rich *A. deliciosa* 'Hayward' peel extracts regulated IL-6, IL-1 β and TNF- α pro-inflammatory cytokines, HMGB1 danger signalling, granzyme B serine protease, signal transducer and activator of transcription 3 (STAT3) signaling in LPS stimulated THP-1 monocytes (D'eliseo et al., 2019). *A. deliciosa* 'Hayward' peel extracts were cytotoxic to RAW 264.7 cells with an IC_{50} of 316 $\mu\text{g}/\text{mL}$. IC_{50} of anti-inflammatory drug dexamethasone was 16 $\mu\text{g}/\text{mL}$ (Dias et al., 2020). Therefore, kiwifruit was not particularly strong in *in vitro* anti-inflammatory activities.

LPS-induced RAW264.7 cells, salidroside, D-threo-guaiacylglycerol 7-O- β -D-glucopyranoside, and *epi*-afzelechin isolated from *A. kolomikta* roots were anti-inflammatory against NO, TNF- α and IL-6 production and inhibited COX-2 and iNOS expressions (Ye et al., 2020).

Ripe purple *A. melanandra*, *A. purpurea*, and *A. macrocarpa* $\times$ *A. melanandra* polyphenolic extracts regulated secretion of CCL11 and the NF- κB signalling pathway in human alveolar cells stimulated by TNF α and IL-4 (Peng et al., 2020). Delphinidin- and cyanidin-based anthocyanins were anti-inflammatory bioactives in polyphenolic extracts (Peng et al., 2020). Organic acid conjugated phenolics in kiwifruit were also anti-inflammatory. Quinic acid derivatives, in particular, inhibited NF- κB transcriptional activity in LPS-stimulated RAW 264.7 macrophages (Ahn et al., 2020).

3.3. Anticancer property

Chinese *A. chinensis* root extracts dose/time-dependently antiproliferated six hepatocellular carcinoma cells (SMMC7721, MHCC97L, MHCC97H, HCCLM3, Hep3B and HepG2) via downregulating DLX2 gene expression (Fang et al., 2019) and activating the JNK/AKT signaling pathway (Fang et al., 2020). *A. chinensis* root extracts dose-dependently antiproliferated gastric cancer cells HGC-27 via promoting cell apoptosis and suppressing mesenchymal phenotype (Gao et al., 2020). 2 β , 3 β , 23-trihydroxy-urs-12-ene-28-olic acid (TUA) from *A. chinensis* was dose/time-dependently cytotoxic to human lung cancer cells (NCI-H460) and induced apoptosis via inhibiting NF- κB (p65) expression level and activating I $\kappa\text{B}\alpha$ in cancer cells. TUA reduced NF κB , p-I $\kappa\text{B}\alpha$ and p65 expression, and NF κB DNA-binding and increased I $\kappa\text{B}\alpha$ expression (Cheng, Li, Huang, Chen, & Liu, 2015). Portuguese *A. deliciosa* 'Hayward' peel extracts inhibited proliferation of MCF-7 (breast carcinoma), NCI-H460, HeLa (human cervical carcinoma) and HepG2 (Dias et al., 2020). Kiwifruit peels were antiproliferative against HepG2, due to high contents of phenolics and flavonoids (Alim et al., 2020).

In vivo administration of Chinese *A. chinensis* root extracts reduced HGC-27 cell growth in zebrafish xenograft mode via inhibition of GPx4 and SLC7A11 proteins (Gao et al., 2020). Chinese *A. chinensis* root extract also suppressed the malignant biological behavior of

hepatocellular carcinoma cells in nude mice bearing orthotopic xenografts via regulating the epithelial-mesenchymal transition by DLX2 (Fang et al., 2019). Nishimura et al. (2016) reported 50% MeOH-fraction of *A. arguta* fruits reduced mouse (ICR) skin tumors induced by 7,12-dimethylbenz(a)anthracene (DMBA)-12-O-tetradecanoylphorbol-13-acetate (TPA).

Tentatively, phenolics, ursolic and oleanolic acids, TUA and a combination of various components (triterpenoids, polysaccharides, flavonoids, steroids, terpenes and PAs) have been linked to the anticancer potential of kiwifruit products (Table 3). Most recently, Lippi and Mattiuzzi (2020) pointed out that anticancer activity of kiwifruit was associated with their intervention against endogenous oxidative damages *in vivo*. Molecular interactions between kiwifruit bioactives and *in vivo* biomarkers, metabolomic approaches to anticancer responses, and clinical benefits of anticancer agents derived from kiwifruit remain unclear.

3.4. Antimicrobial property

A. chinensis peel and flesh polyphenol extracts (100, 200 and 300 µg/mL) dose-dependently inhibited growth of gram-positive (*Staphylococcus aureus*, *Listeria monocytogenes* and gram-negative bacteria (*Escherichia coli*) (Alim et al., 2019). The bacteria were more susceptible to peel polyphenol extracts than flesh polyphenol extracts. Higher antibacterial activity may be due to higher contents of phenolics and flavonoids (Alim et al., 2019). Gram-positive bacteria were more sensitive to kiwifruit polyphenol treatment than gram-negative bacteria. Cell-wall lipopolysaccharides protected gram-negative bacteria from polyphenol attack (Alim et al., 2019). In a comparative antimicrobial potential study of Portuguese *A. deliciosa* 'Hayward' and red kiwi, *Bacillus cereus* and *E. coli* were more sensitive to pulp extracts from 'Hayward' and red kiwi, respectively. *L. monocytogenes* and *Enterobacter cloacae* were more sensitive to red kiwi peel extracts. *Aspergillus ochraceus* and *Penicillium funiculosum* were more susceptible to the peel extracts than the pulp extracts (Dias et al., 2020). According to Almeida et al. (2018), 50 mg/mL of Portuguese *A. arguta* hydroalcoholic and alcoholic leaf extracts were antimicrobial against *S. aureus* with a minimum inhibitory concentration of 3.12 and 1.56 mg/mL, respectively. Kiwifruit phenolics possibly represented the most active antimicrobial components (Alim et al., 2019; Dias et al., 2020). Key antimicrobial components in kiwifruit remain to be characterised.

3.5. Antihypertension

Hypertension prevention can be achieved by inhibiting angiotensin-converting enzyme (ACE) activity. The *in vitro* chemistry-based ACE inhibitory activity assay was applied for screening antihypertensive potentials of kiwifruit. Using an *in vitro* fluorescence-based biochemical assay, flavonoid-rich *A. macrocarpa* extracts exhibited higher *in vitro* ACE inhibition activity (IC₅₀, 0.49 mg/mL of extracts) than those of *A. chinensis* 'Hort 16A' and *A. deliciosa* 'Hayward', with an IC₅₀ of 12.81 to 30.49 mg/mL of extracts, respectively (Hettihewa et al., 2018). Hettihewa et al. (2018) proposed that the antihypertensive potential of *A. macrocarpa* was attributed to its prominent phenolics, such as quercetin, quercetin-3-galactoside, quercetin-3-glucoside, quercetin-3-rhamnoside, quercetin-3-rutinoside, quercetin-arabinoglucoside, catechin, epigallocatechin gallate, epigallocatechin, chlorogenic, ferulic, isoferulic, and caffeic acids. Actinidin from *A. deliciosa* 'Xuxiang' also presented ACE-inhibition activity (Zhang et al., 2017).

3.6. Neuroprotection

Neuroprotective effects of kiwifruit have been evaluated using *in vitro* model of neuroblastoma (MC-IXC), pheochromocytoma (PC-12), and human neuroblastoma (SH-SY5Y) cells (Jeong et al., 2020; Ha et al., 2020) and *in vivo* animal models of C57BL/6 mice (Ha et al., 2020) and

Caenorhabditis elegans (Mazzarella et al., 2019).

Ha et al. (2020) reported that chloroform fraction of *A. arguta* 'Autumn Sense' protected MC-IXC cells from high glucose-induced neurotoxicity. Jeong et al. (2020) proposed that antioxidants (e.g., VC and phenolics) in three *A. arguta* cultivars protected PC-12 and SH-SY5Y cells from hydrogen peroxide-induced damages.

Daily feeding of kiwifruit fraction for 12 weeks improved glucose tolerance and cognitive dysfunctions of C57BL/6 mice fed with a high-fat diet (HFD). It improved HFD-induced impaired cholinergic, antioxidant system and mitochondria functions in mouse brains. The kiwifruit fraction improved insulin resistance [by increasing serine phosphorylation of insulin receptor substrate] and inhibited neuronal apoptosis [by suppressing the c-Jun NH₂-terminal kinase-signaling pathway]. Pentacyclic triterpenoids (asiatic and madecassic acids) were possible contributors for the observed neuroprotective effects (Ha et al., 2020). Fruit extract fractions of *A. deliciosa* 'Hayward' (not *A. chinensis* 'Hort 16A') protected *C. elegans* spinal muscular atrophy model against degeneration, death of motor neurons, and locomotion impairment. Mazzarella et al. (2019) proposed that bioactive (MW > 3 kDa) in *A. deliciosa* 'Hayward' were *in vivo* neuroprotective, although underlying mechanisms were still unclear.

3.7. Promoting gut functions

3.7.1. In vitro studies

Kiwifruit digesta with/without interferon gamma (IFN γ) minimally influenced epithelial IL-7 secretion in human colorectal adenocarcinoma HT-29 cells (Paturi et al., 2020). In the absence of IFN γ , kiwifruit soluble fermenta increased epithelial IL-7 secretion in HT-29 cells (Paturi et al., 2020). In the presence of IFN γ , the soluble fermenta of *A. deliciosa* (not *A. chinensis*) increased epithelial IL-7 secretion in HT-29 cells. Kiwifruit DF and polyphenols are gut health promoters (Paturi et al., 2020).

3.7.2. In vivo studies

In Sprague-Dawley rats, dried deseeded *A. deliciosa* 'Hayward' pulp had little effect on faecal bulk and water holding capacity, and the disappearance of fermentable fibres during hindgut passage (Monro, Paturi, & Mishra, 2017). Four-week feedings of two unpeeled *A. chinensis* freeze-dried fruits to healthy male Sprague-Dawley rats exhibited probiotic effects in the gut. The treated rats had reduced serum saturated FA and increased hepatic and serum polyunsaturated FA (Alim et al., 2020). Polyphenols and DFs in kiwifruit peels contributed to these positive effects (Alim et al., 2019, 2020). Dietary actinidin of fresh *A. deliciosa* 'Hayward' fruits increased the rate of gastric emptying and the digestion of beef muscle proteins in male pigs (Montoya et al., 2014).

3.7.3. Clinical studies

A randomized, crossover, single blind and controlled human clinical trials involved 20 healthy controls, 20 patients with functional constipation and 20 patients with irritable bowel syndrome (Cremon et al., 2018). Daily consumption of two *A. deliciosa* 'Hayward' was more effective in relieving constipation (by improving complete spontaneous bowel movement in patients) than daily treatment with psyllium (7.5 g) (Cremon et al., 2018). In healthy volunteers, kiwifruit intake increased water content in the small bowel and stool frequency with improved stool consistency (Wilkinson-Smith et al., 2019). Kiwifruit DF reduced digestive discomfort and potentially acted as a dietary alternative in mild constipation.

3.8. Antiobesity

C57BL/6 mice with obesity induced by HFD were administered *A. chinensis* seed oil daily for 12 consecutive weeks. Obese mice had reduced bodyweight, inguinal fat tissue weight, blood glucose level, and HOMA-IR index. This seed oil diet altered the gut microbiota in obese mice by increasing the abundance of *Pseudo flavonifactor*, *Flavonifactor*,

Intestinimonas, *Romboutsia*, and *Olsenella*. The diet down-regulated mRNA expression of inflammatory cytokines (TNF- α , IL-6, IL-1 β , COX-2, and iNOS), while up-regulating expression of thermogenesis-related genes (PPAR- γ , UCP1, PGC1- α , and PRDM16) in inguinal fat tissue. Kiwifruit seed oils rich in α -linolenic acid exhibited antiobesity (Qu et al., 2019). Inhibitory abilities on the pancreatic lipase and α -glucosidase imparted *A. chinensis* 'Donghong' as a promising natural antiobesity agent source.

3.9. Antihypercholesterolemia

Male Wistar rats with 1% cholesterol-enriched diet induced hypercholesterolemia improved liver somatic index and lipid profiles after supplementing 5% lyophilized kiwifruit. Polish grown *A. arguta* 'Geneva', 'Anna', and 'Weiki' showed the most significant results (Leontowicz, M., Leontowicz, H. et al., 2016).

3.10. Toxicity and allergic reactions

3.10.1. In vitro and in vivo toxicity

In vitro short-term hepatotoxicity studies, pulp and peel extracts of *A. deliciosa* 'Hayward' and red kiwi were non-toxic to the porcine liver primary cells (PLP2) cells (Hettihewa et al., 2018). *A. chinensis* root extracts (≤ 10 mg/mL) were non-cytotoxic to normal liver epithelial cell line (L02). At a higher concentration (≥ 15 mg/mL), the extracts inhibited L02 cell proliferation (Fang et al., 2019). Aqueous (≤ 1000 μ g/mL), hydroalcoholic (ethanol: water = 50:50 v/v) and alcoholic (≤ 100 μ g/mL) extracts of Portuguese *A. arguta* leaves were non-cytotoxic to the Caco-2 clone type C2BBE1 and HT29-MTX cells (Almeida et al., 2018).

Results obtained from *in vitro* studies cannot often be used directly to predict biological responses *in vivo*. Using *in vitro* assay possibly reduced the number of animals used, and provided certain levels of predictions for toxicological information. However, limitations of *in vitro* methods should be clearly stated.

In vivo, fruit extracts of *A. deliciosa* 'Hayward' and *A. chinensis* 'Hort 16' (purchased in Italy) diluted 1:10, 1:20, 1:40, and 1:100 minimal influenced the growth and life cycle of wide-type *C. elegans* in the 24 h treatment (Mazzarella et al., 2019). Clinical assessments of cellular responses after short/long-term exposure to kiwifruit ingredients, in practicality non-edible plant parts, are necessary.

3.10.2. Allergic reactions

Epidemiological studies revealed approximately 0.75–2% of the population have certain sensitivity to kiwifruit in Central Europe (Wang, Vanga, McCusker et al., 2019). Approximately 12–17% of individuals allergic to natural rubber latex can be allergic to kiwifruit (Bublin, 2013). Symptoms of kiwifruit allergy can be mild (e.g., skin itching and rashes), severe (respiratory and digestive uncomfortableness, wheezing, diarrhea), and life threatening (e.g., anaphylactic shock and death) (Bublin, 2013; Wang, Vanga, McCusker et al., 2019). Immunoglobulin (Ig) E-mediated allergic reactions, pollen-fruit allergy and latex-fruit syndromes have been associated with consumption or peeling of kiwifruit among adults and children (Bublin, 2013; Le et al., 2013). In some cases, IgE antibodies of patients with grass, birch pollen, or peanut allergy were cross-reactive with kiwifruit allergens (van Odiijk, Sjolander, Brostedt, Borres, & Englund, 2017; Wang, Vanga, McCusker et al., 2019).

Processing tends to reduce kiwifruit allergenicity (Wang, Vanga, McCusker et al., 2019). Act d1 and Act d2, two key allergens in kiwifruit, exhibited different sensitivity to enzymatic treatments. Pepsin treatment decreased the allergenicity of Act d2 up to 70%. Act d1 was insensitive to pepsin treatment. Act d7 and Act d8 were sensitive to ethylene treatments. High-intensity ultrasound processing induced conformational and structural changes of kiwifruit allergens. Thermal processing denatures allergenic kiwifruit proteins (Wang, Vanga, McCusker et al., 2019). Allergenicity reduction processing and non-allergenic kiwifruit cultivars are desirable.

3.11. General discussions on biological properties of kiwifruit

3.11.1. In vitro, in vivo and clinical studies

Less *in vivo* animal and human trials were used in evaluating bioactivities of kiwifruits, while there were numerous *in vitro* chemistry-based and cell culture-based assays employed. *In vitro* antioxidant assays may hardly explain *in vivo* biological AAs (Wang & Zhu, 2017). For example, cancer-derived cell lines are the most widely used models to study anticancer potential of kiwifruit. The clinical relevance of *in vitro* cultured cancer cell lines remains in question. *In vitro* models should be used as an adjunct to animal studies in order to fully reveal physiological functions of kiwifruit bioactives, their combinations, and related mechanisms. *In vivo* and *in vitro* approaches to evaluate bioaccessibility and bioavailability of nutrients and bioactive compounds derived from kiwifruit have been scarcely reported. It is necessary to propose *in vitro*–*in vivo* correlations and potential clinically relevant bioactivity studies on kiwifruits. Randomized double blind, placebo-controlled clinical trials are necessary to determine if kiwifruit consumption reduces the major chronic diseases. In addition, comparison studies are needed to determine whether kiwifruit provides protective or treatment health benefits compared with other common fruits and vegetables.

3.11.2. Component-property relationships

TPC and TFC positively correlated with antioxidative, antimicrobial, and anti-proliferative activities of *A. chinensis* (Alim et al., 2019). In *A. arguta* cultivars, correlation values for total cellular AA with TPC were higher than those with TFC (An et al., 2016). Portuguese *A. arguta* leaf extracts had positive correlations between TPC and FRAP values (Almeida et al., 2018). VC content, TPC and TFC were positively correlated with the antioxidant capacity (ABTS, DPPH, ORAC, and FRAP values) of *A. chinensis*, *A. arguta*, *A. deliciosa* and *A. kolomikta* grown in China (Wang et al., 2018).

Improved lipid homeostasis, FA metabolism and gut microbiota in healthy rats were associated with 10 phenolics in unpeeled *A. chinensis* (Alim et al., 2020). Involvement of procyanidins of *A. deliciosa* 'Hayward' peels inhibited inflammatory molecules (IL-6, IL-1 β , TNF- α pro-inflammatory cytokines, HMGB1 danger signal and granzyme B serine protease), prevented STAT3 activation, and promoted autophagy (D'eliseo et al., 2019). Antioxidant, cytotoxicity and anti-inflammatory activities of *A. deliciosa* 'Hayward' were related to the content of phenolics, especially B-type (*epi*) catechin dimers (Dias et al., 2020). The AAs positively related to content of unmethylated galacturonic acid in *A. chinensis* polysaccharides (Han et al., 2019). Identification and isolation of pharmacological agents from kiwifruit for common diseases remain to be recognized.

3.11.3. Multiple-functional components

Kiwifruit phytochemicals exhibit multiple health potentials (Table 4). Kiwifruit polyphenols were antioxidative, antiproliferative against selected cancer cells, antimicrobial, anti-inflammatory and promoted gut health (Table 4). Each biological property may involve different *in vivo* functional pathways. Multifunctional kiwifruit-derived products can potentially multi-target complex diseases (such as cancer) with multiple disorders in gene mutations or pathways (Zheng, Wei, Zhao, & Ni, 2018). Studied mechanisms behind the biological effect of kiwifruits are primary based on single disease. Pathway-based screening approaches can be attempted to identify potential multi-target agents derived from kiwifruits.

Beneficial and adverse health outcomes coexist with certain kiwifruit-derived compounds. Actinidin, considered a major allergen in kiwifruit, potentially acts as an antihypertensive agent due to its ACE inhibitory effect (Zhang et al., 2017; Wang, Vanga, McCusker et al., 2019). Maximizing beneficial and minimizing detrimental contributions of kiwifruit actinidin are necessary. Overall, evidence of clinical benefits of kiwifruit-derived ingredients and products on reducing major chronic diseases are still relatively unclear.

4. Conclusions and outlooks

Actinidia species have diversified morphological characteristics, fruit qualitative traits, and chemical profiles. Kiwifruits of different species and varieties are a good source of bioactive phytochemicals including vitamins (C, E, K and folate), phenolic acids and their derivatives, flavonoids (flavanols, flavonols and anthocyanins), carotenoids, chlorophylls, non-starch polysaccharides, minerals and organic acids. Health-promoting effects of kiwifruits include antioxidative, antiinflammatory, antihypertensive, anticancer, antimicrobial, neuroprotective, antiobesity and gut health promotion. Kiwifruit-related mycotoxin contamination and allergic reactions are of concerns. Optimized processing (extraction, thermal, ultrasound, and chemical processing) can maximize safety, nutrition and bioactivity of kiwifruits.

Chemical differences present uniqueness between varieties of kiwifruit. Volatiles with unique sensory traits are identification biomarkers for different kiwifruit cultivars. Although species other than *A. deliciosa* and *A. chinensis* are underutilized, they have potential therapeutic and nutritional values that satisfy health-conscious consumers. Kiwifruit can be nutritionally and biologically complementary among different varieties and species. In addition, underutilized non-fruit plant parts (peels, seeds, leaves and roots) and fruit waste (i.e., TYK, peels) are sources of value-added ingredients. Kiwifruit multifunctional ingredients deserve diversification and innovation in food and non-food industries.

To exploit kiwifruit resources fully, the following aspects deserve attention: 1) Valorization of underutilized resources. 2) Recovering kiwifruit value-added ingredients, such as starch derived viscosity modifiers, texture modifiers and DF enhanced prebiotics. 3) Uses of kiwifruit-derived antioxidants and antimicrobials as food additives for food safety. 4) Developing non-allergenic cultivars and allergen-deactivation techniques. 5) Isolation and purification of the bioactives and validate their *in vivo* health-promoting physiological responses. 6) Identifying multi-targeted mechanisms of kiwifruit bioactive phytochemicals. 7) Evaluating *in vitro* toxicology of non-edible kiwifruit plant parts. 8) Establishing clinical pharmacology profiles of potential therapeutic agents derived from kiwifruits. 9) Conjugation of kiwifruit bioactive phytochemical and common used drugs for synergistic prevention or treatment purposes. 10) Diversification and innovation of food and non-food kiwifruit products. 11) Epidemiological studies on effects of kiwifruit consumption on human health. 12) Assessment of genetic resources of different genotypes and diverse *Actinidia* species for chemical and biological diversities.

Funding declaration

None.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.foodchem.2020.128469>.

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