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Chemical constituents of *Ulmus pumila* L. and their chemotaxonomic significance

Deri Hu [a,1], Zhenyu Liu [b,1], Yue Yu [a,1], Chenghao Wu [a], Jinze Liu [a], Dongzhou Kang [a], Junzhe Min [a,**], Mingshan Zheng [a,c,*]

[a] School of Pharmaceutical Sciences, Yanbian University, Yanji, 133002, PR China
[b] Medical College of Yanbian University, Yanji, 133002, PR China
[c] Key Laboratory of Natural Medicines of the Changbai Mountain, Ministry of Education, Yanbian University, Yanji, 133002, PR China

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ABSTRACT

A phytochemical study of the leaves of *Ulmus pumila* L. led to the isolation of 32 compounds, including fourteen flavonoids, which include flavonols (**1**–**6**), dihydroflavones (**7**–**11**), and dihydroflavonols (**12**–**14**), five terpenoids, which include megastigmane glycosides (**15**–**17**) and triterpenoids (**18**–**19**), four sugars (**20**–**23**), one phenylpropanoid (**24**), two phenolic glycosides (**25**–**26**), two aromatic glycosides (**27**–**28**), one phenolic (**29**), one lignan glycoside (**30**), one steroid glycoside (**31**), and one fatty acid (**32**). The structures of these isolated compounds were determined by analysis of their NMR spectroscopic (^{1}H and ^{13}C) data and by comparison with previously reported data. Compounds **4** and **8**–**10** were first reported from *U. pumila*; compound **12** was obtained from the genus *Ulmus* for the first time, while compounds **2**, **6**, **7**, **11**, **13**, **15**–**17**, **19**–**28**, **30**, and **32** have never been isolated from the Ulmaceae family. Chemotaxonomic studies have shown that the genus *Ulmus* may be closely related to the genera *Hemiptelea*, *Zelkova*, and *Holoptelea*.

1. Subject and source

The genus *Ulmus* L. is a typical member of the Ulmaceae family naturally distributed throughout the northern hemisphere in Eurasia, North America, and Northern Africa (Martin-Benito et al., 2005). According to the wordflora online/plant list 2024, 44 species are reported as accepted species, including *Ulmus pumila* L. that possesses 21 synonyms (http://www.worldfloraonline.org, accessed on August 30, 2024). In China, there are about 21 species of *Ulmus* plants that are widely distributed (Flora of China Editorial Committee, 2003). The fruit, bark, and leaves of *Ulmus pumila* L. can be used as medicine, and have been reported to possess antioxidant (Gu et al., 2019), anti-inflammatory (Lee et al., 2018), and anti-adipogenic activities (Ghosh et al., 2012).

In the present study, the leaves of *U. pumila* were collected in the Changbai Mountain area, Jilin Province, China, in June 2021 and were identified by Prof. Ming-shan Zheng (School of Pharmaceutical Sciences, Yanbian University, China). The voucher specimen (YSY-991106) was deposited at Pharmacognosy Laboratory of the College of Pharmacy, Yanbian University.

2. Previous work

Previous phytochemical investigations of *U. pumila* have mainly focused on the bark of this plant, revealing the presence of flavonoids (Ma et al., 2019; Cheng et al., 2020), triterpenoids (Wang et al., 2006), sesquiterpenoids (Wang et al., 2004), monosaccharides (Lee et al., 2018), and sterols (Melek et al., 2021). To the best of our knowledge, there has been limited research on the chemical composition of the leaves of *U. pumila*.

3. Present study

The air-dried leaves of *U. pumila* (8.8 kg) were extracted with 75% ethanol (3 × 60 L) by heating under reflux. The crude extract (2.3 kg)

* Corresponding author. School of Pharmaceutical Sciences, Yanbian University, Yanji, 133002, PR China.
** Corresponding author.
E-mail addresses: 15149910329@163.com (D. Hu), liuzy@ybu.edu.cn (Z. Liu), 574278239@qq.com (Y. Yu), 2023010925@ybu.edu.cn (C. Wu), 1193029934@qq.com (J. Liu), kangdz@ybu.edu.cn (D. Kang), junzhemin23@163.com (J. Min), zhengmingshan@ybu.edu.cn (M. Zheng).
[1] These authors contributed equally to this work.

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was suspended with distilled water and successively partitioned into petroleum ether (PE, 3 × 1.4 L), ethyl acetate (EtOAc, 3 × 1.4 L), and *n*-butyl alcohol (*n*-BuOH, 3 × 1.4 L) sequentially, to give PE (90.0 g), EtOAc (199.0 g), *n*-BuOH (430.0 g), and aqueous fractions (930.0 g), respectively.

The EtOAc fraction (181.1 g) was subjected to silica gel column chromatography (CC) and eluted with PE–EtOAc (100:1–0:1, v/v) to afford seven fractions, including Fr. 1 (5.2 g), Fr. 2 (16.2 g), Fr. 3 (30.6 g), Fr. 4 (23.2 g), Fr. 5 (13.0 g), Fr. 6 (22.0 g), and Fr. 7 (52.0 g). Fr. 2 (15.2 g) was fractionated by silica gel CC by gradient elution with PE–EtOAc (50:1–0:1), v/v) to give ten subfractions, including Fr. 2–1 (1.0 g), Fr. 2-2 (1.2 g), Fr. 2–3 (1.6 g), Fr. 2–4 (1.2 g), Fr. 2–5 (1.3 g), Fr. 2–6 (1.1 g), Fr. 2–7 (1.2 g), Fr. 2–8 (1.3 g), Fr. 2–9 (1.0 g), and Fr. 2–10 (3.2 g). Fr. 2-2 (1.1 g) was purified using a Sephadex LH-20 column by eluting with CH_2Cl_2–MeOH (3:7, v/v) to afford compound **1** (20.3 mg). Fr. 2–5 (1.2 g) was subjected to reverse-phase (RP) CC by gradient elution with MeOH–H_2O (8:2–1:0, v/v) to yield compounds **3** (34.3 mg). Fr. 2–6 (1.0 g) subjected to RP CC by eluting with MeOH–H_2O (6:4–1:0, v/v) to yield compounds **2** (10.2 mg), **4** (6.6 mg), and **5** (4.3 mg), successively. Fr. 2–7 (1.1 g) was purified by recrystallization from MeOH to afford compound **18** (4.9 mg). Fr. 2–8 (1.2 g) was subjected to RP CC by gradient elution with MeOH–H_2O (7:3–1:0, v/v) to yield compound **9**

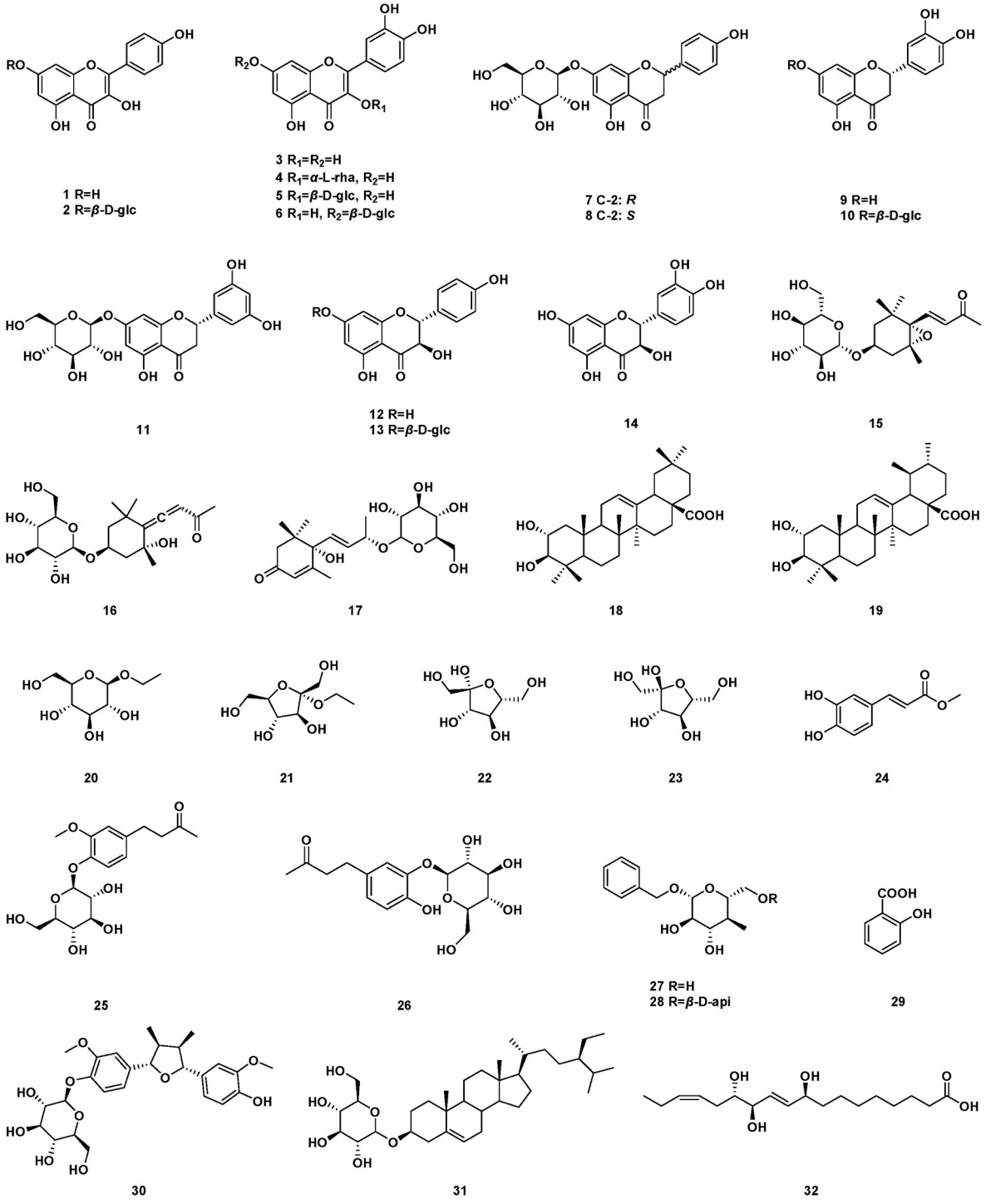

Fig. 1. Chemical structures of compounds **1**–**32** isolated from the leaves of *Ulmus pumila* L.

(8.1 mg). Fr. 3 (29.6 g) was fractionated by silica gel CC by gradient elution with CH_2Cl_2–MeOH (30:1–0:1, v/v) to give five subfractions, including Fr. 3–1 (1.2 g), Fr. 3–2 (5.3 g), Fr. 3-3 (5.1 g), Fr. 3–4 (6.8 g), and Fr. 3–5 (9.3 g). Fr. 3-3 (3.0 g) was subjected to RP CC by eluting with MeOH–H_2O (1:1–1:0, v/v) to yield a mixture of compounds **7** and **8** (188.3 mg). Fr. 3–4 (1.7 g) was purified by recrystallization from MeOH to afford compound **19** (4.2 mg). Fr. 4 (22.2 g) was fractionated using silica gel CC by gradient elution with CH_2Cl_2–MeOH (20:1–0:1, v/v) to give six subfractions, including Fr. 4–1 (4.2 g), Fr. 4–2 (3.3 g), Fr. 4–3 (4.1 g), Fr. 4-4 (2.8 g), Fr. 4–5 (3.2 g), and Fr. 4–6 (2.3 g). Fr. 4–1 (2.3 g) was subjected to silica gel CC using CH_2Cl_2–MeOH (30:1–2:1, v/v) to obtain compounds **29** (6.1 mg), **15** (9.2 mg), **16** (3.6 mg), and **17** (6.3 mg), successively. Fr. 4–2 (1.9 g) was fractionated using silica gel CC by gradient elution with CH_2Cl_2–MeOH (5:1–1:0, v/v) to give six subfractions, including Fr. 4-2-1 (0.1 g), Fr. 4-2-2 (0.5 g), Fr. 4-2-3 (0.1 g), Fr. 4-2-4 (0.1 g), Fr. 4-2-5 (0.1 g), and Fr. 4-2-6 (0.4 g). Fr. 4-2-2 (400.1 mg) subjected to RP CC by eluting with MeOH–H_2O (2:8–1:0, v/v) to yield compounds **10** (11.1 mg), **11** (10.6 mg), and **12** (20.9 mg), successively. Fr. 4–3 (1.7 g) was purified using a Sephadex LH-20 column by eluting with 100% MeOH to afford compounds **13** (9.9 mg) and **14** (7.1 mg). Fr. 4-4 (1.1 g) was separated successively using a Sephadex LH-20 column by eluting with CH_2Cl_2–MeOH (2:8, v/v) and an RP column by eluting with MeOH–H_2O (10:1–1:0, v/v) to give compounds **30** (6.3 mg) and **32** (4.1 mg). Fr. 4–5 (2.2 g) was subjected to RP CC by eluting with MeOH–H_2O (1:9–1:0, v/v) to yield compounds **25** (18.8 mg), **26** (7.5 mg), and **27** (16.9 mg), successively. Fr. 5 (12.0 g) was subjected to silica gel CC using CH_2Cl_2–MeOH (10:1–0:1, v/v) as the mobile phase to give nine subfractions, including Fr. 5–1 (1.0 g), Fr. 5–2 (1.9 g), Fr. 5–3 (1.0 g), Fr. 5–4 (1.0 g), Fr. 5-5 (1.2 g), Fr. 5–6 (1.3 g), Fr. 5–7 (1.9 g), Fr. 5–8 (1.2 g), and Fr. 5–9 (1.0 g). Fr. B5-2 (1.0 g) was subjected to RP CC by gradient elution with MeOH–H_2O (1:9–1:0, v/v) to yield compounds **28** (8.0 mg) and **31** (38.6 mg). Fr. 5–7 (1.8 g) was subjected to RP CC by gradient elution with MeOH–H_2O (1:9–1:0, v/v) to yield a mixture of compounds **20** and **21** (7.3 mg), **22** (13.3 mg), and **23** (5.9 mg), successively. Fr. 5–8 (1.0 g) was purified using a Sephadex LH-20 column by eluting with 100% MeOH to afford compounds **6** (20.1 mg) and **24** (3.1 mg).

Phytochemical study of the EtOAc extract of *U. pumila.* led to the isolation of 32 compounds (**1**–**32**, Fig. 1). By comparing their NMR spectroscopic data with those reported in the literature, the isolated compounds were identified as kaempferol (**1**) (Yu et al., 2024), kaempferol 7-*O*-glucoside (**2**) (Wang et al., 2023), quercetin (**3**) (Yu et al., 2024), quercitrin (**4**) (Yu et al., 2024), quercetin 3-*O*-glucoside (**5**) (Yu et al., 2024), quercetin 7-*O*-glucoside (**6**) (Wang et al., 2024), (2*R*)-naringenin 7-*O*-*β*-D-glucopyranoside (**7**) (Xu et al., 2017), (2*S*)-naringenin 7-*O*-*β*-D-glucopyranoside (**8**) (Xu et al., 2017), eriodictyol (**9**) (Schilbert et al., 2024), eriodictyol 7-*O*-*β*-D-glucopyranoside (**10**) (Schilbert et al., 2024), 3′,5′,5-trihydroxyflavanone 7-*O*-*β*-D-glucopyranoside (**11**) (Wang et al., 2023), (2*R*,3*R*)-dihydrokaempferol (**12**) (Chang et al., 2004), (2*R*,3*R*)-dihydrokaempferol 7-*O*-glucoside (**13**) (Iwashina et al., 2022), taxifolin (**14**) (Kim et al., 2000), icariside B2 (**15**) (Vu et al., 2022), staphylionoside D (**16**) (Tian et al., 2024), roseoside (**17**) (Kaweetripob et al., 2023), maslinic acid (**18**) (Wang et al., 2006), corosolic acid (**19**) (Yu et al., 2021), ethyl *β*-D-glucopyranoside (**20**) (Dai et al., 2018), ethyl *β*-D-fructofuranoside (**21**) (Dai et al., 2018), *β*-D-fructofuranose (**22**) (Yu et al., 2023), *α*-D-fructofuranose (**23**) (Chen et al., 2022), caffeic acid methyl ester (**24**) (Hu et al., 2023), zingerone *β*-D-glucopyranoside (**25**) (Nagatani et al., 2001), myzodendrone (**26**) (Nagatani et al., 2001), benzyl-*β*-D--glucopyranoside (**27**) (Zhang et al., 2022), icariside F_2 (**28**) (Zhang et al., 2022), salicylic acid (**29**) (Yang et al., 2024), (−)-nectandrin B-*β*-D-glucopyranoside (**30**) (Bu et al., 2013), daucosterol (**31**) (Zheng et al., 2024), and (9*S*,10*E*,12*R*,13*S*,15*Z*)-9,12,13-trihydroxy-10,15-octadecadienoic acid (**32**) (Lopes et al., 2022).

4. Chemotaxonomic significance

In this study, a total of 32 compounds, including six flavonols (**1**–**6**), five dihydroflavones (**7**–**11**), three dihydroflavonols (**12**–**14**), three megastigmane glycosides (**15**–**17**), two triterpenoids (**18**–**19**), four sugars (**20**–**23**), one phenylpropanoid (**24**), two phenolic glycosides (**25**–**26**), two aromatic glycosides (**27**–**28**), one phenolic (**29**), one lignan glycoside (**30**), one steroid glycoside (**31**), and one fatty acid (**32**) were isolated from *U. pumila*. The isolation of four flavonoids (**4** and **8**–**10**) was reported for the first time from this plant; the flavonoid (2*R*,3*R*)-dihydrokaempferol (**12**) was first identified from the genus *Ulmus*; and twenty compounds (**2**, **6**, **7**, **11**, **13**, **15**–**17**, **19**–**28**, **30**, and **32**) were originally isolated from the family Ulmaceae. These findings improved our understanding of the family Ulmaceae and genus *Ulmus*.

Fourteen flavonoids were purified from *U. pumila*, being flavonols (**1**–**6**) predominant, followed by dihydroflavones (**7**–**11**), and dihydroflavonols (**12**–**14**) ones. Among the flavonoids of *U. pumila*, glycosylation at C-7 of the flavonoids nucleus has been found to be the most common feature (Cheng et al., 2020), and compounds **2**, **6**–**8**, **10**–**11**, and **13** isolated from the leaves of *U. pumila* were in good agreement with the above previous statement. Flavonoids **2**, **6**, **11**, and **13** have been obtained in a variety of plants; however, they were first identified as novel constituents of the family Ulmaceae that could serve as potential chemotaxonomic biomakers to distinguish *U. pumila* from other species of the Ulmaceae family. (2*R*)-Naringenin 7-*O*-*β*-D-glucopyranoside (**7**) was previously obtained from *Helichrysum arenarium* (Asteraceae) (Yang et al., 2021), *Viburnum macrocephalum* (Viburnaceae) (Xu et al., 2017), and *Paeonia lactiflora* (Paeoniaceae) (Shi et al., 2016). It was the first to be recorded from the family Ulmaceae. Thus, the biosynthetic processes may be the same in *U. pumila* and the plants mentioned above. To the best of our knowledge, (2*S*)-naringenin 7-*O*-*β*-D-glucopyranoside (**8**) and eriodictyol 7-*O*-*β*-D-glucopyranoside (**10**) have only been reported from *U. macrocarpa* in the Ulmaceae family. The first discovery of these two compounds from this plant may serve as a potential chemotaxonomic maker for *Ulmus*, in view of the fact that they have not been isolated from other genera of the Ulmaceae family. It is also possible to distinguish the genus *Ulmus* and most genera in the Ulmaceae family. (2*R*,3*R*)-Dihydrokaempferol (12) was previously isolated only from the genera *Hemiptelea* and *Zelkova* in the Ulmaceae family (Table 1); however, it has never been reported in *Ulmus*. Compound 12 may be useful in distinguishing *U. pumila* from other species of the genus *Ulmus*, as well as providing additional evidence of the close relationship between *Hemiptelea*, *Zelkova*, and *Ulmus*. Quercitrin (4) was previously obtained in the genus *Ulmus* and *Zelkova* among in the family Ulmaceae, such as *U. minor*, *U. parvifolia*, and *Zelkova serrata*, and eriodictyol (**9**) was also formerly derived in the genus *Ulmus* solely in *U. macrocarpa* among the Ulmaceae family. Both compounds were the first time isolated from *U. pumila*, providing fresh information on the chemistry of *U. pumila.* This evidence suggests a chemical correlation within the same genus. Kaempferol (**1**) and quercetin (**3**) have been found in numerous plant species. By contrast, quercetin 3-*O*-glucoside (**5**) and taxifolin (**14**) have only been found in the genus *Ulmus* within the Ulmaceae family. Notably, the narrow distribution of compounds **5** and **14** in the genus might have chemotaxonomic significance in the Ulmaceae family.

Five terpenoids (**15**–**19**) were purified from this plant, comprising three megastigmane glycosides (**15**–**17**) and two triterpenoids (**18**–**19**). All of the isolated terpenoids, except maslinic acid (**18**), are novel to the family Ulmaceae. The discovery of these compounds has enriched the chemical composition of terpenoids in the family Ulmaceae and may be useful in distinguishing *U. pumila* from other species in the family. As for triterpenoid **18** has previously been reported in the bark of *U. pumila*, and this is the first time it has been found in the leaves of this plant.

Sugars (**20**–**23**), phenylpropanoid (**24**), phenolic glycosides (**25**–**26**), aromatic glycosides (**27**–**28**), lignan glycoside (**30**), and fatty acid (**32**) were identified as novel constituents of the family Ulmaceae. The

Table 1
Repartition of the compounds isolated from Ulmus pumila in the genus and family.

Phytochemical class	Compounds	*Ulmus* species	References	Ulmaceae genus	References
Flavonoids	kaempferol (**1**)	*U. americana* *U. davidiana* *U. davidiana var. japonica* *U. glabra* *U. laevis* *U. macrocarpa* *U. minor* *U. parvifolia* *U. pumila* *U. rubra*	Sherman and Giannasi (1987) Park et al. (2022) Lee et al. (2023) Varfalvyova et al. (2023) Drzewiecka et al. (2018) Li and Bao (2022) Schott et al. (2023) Cho et al. (2003) Li and Bao (2022) Sherman and Giannasi (1987)	*Hemiptelea* Zelkova	Chang et al. (2004) Won et al. (2018)
	quercetin (**3**)	*U. davidiana var. japonica* *U. parvifolia* *U. pumila* ……	Lee et al. (2023) Cho et al. (2003) Zhou et al. (2017)	*Holoptelea* Zelkova	Anju et al. (2020) Won et al. (2018)
	quercitrin (**4**)	*U. minor* *U. parvifolia*	D'Angiolo et al. (2022) Cho et al. (2003)	Zelkova	Sun et al. (2015)
	quercetin 3-*O*-glucoside (**5**)	*U. davidiana* *U. laciniata* *U. minor* *U. parvifolia* *U. pinnato-ramosa* *U. pumila* *U. rubra*	Park et al. (2022) Gu et al. (2019) D'Angiolo et al. (2022) Cho et al. (2003) Chumbalov et al. (1972) Gu et al. (2019) Saleem et al. (2009)		
	(2*S*)-naringenin 7-*O*-*β*-d-glucopyranoside (**8**)	*U. macrocarpa*	Kwon et al. (2022)		
	eriodictyol (**9**)	*U. macrocarpa*	Li and Bao (2022)		
	eriodictyol 7-*O*-*β*-d-glucopyranoside (**10**)	*U. macrocarpa*	Kwon et al. (2022)		
	(2*R*,3*R*)-dihydrokaempferol (**12**)			*Hemiptelea* *Zelkova*	Chang et al. (2004) Niklas and Giannasi (1977)
	taxifolin (**14**)	*U. davidiana* *U. glabra* *U. macrocarpa* *U. pumila*	Kim et al. (2000) Varfalvyova et al. (2023) Kim et al. (2000) Kim et al. (2000)		
Terpenoid	maslinic acid (**18**)	*U. davidiana* *U. davidiana var. japonica* *U. pumila*	Yang et al. (2011) Zheng et al. (2010) Wang et al. (2006)	Zelkova	Choi et al. (2019)
Phenolic	salicylic acid (**29**)	*U. davidiana* *U. minor* *U. pumila* ……	Ham and Kim (2020) Lortzing et al. (2024) Huang et al. (2016)	*Hemiptelea*	Yang et al. (2024)
Steroid glycoside	daucosterol (**31**)	*U. davidiana* *U. davidiana var. japonica* *U. parvifolia* *U. pumila* *U. punula*	Yang et al. (2011) Zheng et al. (2010) Moon and Rim (1995) Zheng et al. (2024) Wang et al. (2012)	*Holoptelea*	Nadella et al. (2012)

discovery of these compounds has enriched the knowledge of the chemical diversity of the Ulmaceae, and may serve as potential chemotaxonomic biomakers to differentiate *U. pumila* from other species of the Ulmaceae family. Although salicylic acid (**29**) and daucosterol (**31**) have been found in numerous plant species, they were found only in *Ulmus*, *Hemiptelea* and *Holoptelea* among the family Ulmaceae (Table 1), which may indicate chemical correlation between the genera mentioned above.

Our paper has investigated the diversity of the phytochemical composition of *U. pumila* leaves. Chemotaxonomic studies have shown that the genus *Ulmus* may be closely related to the genera *Hemiptelea*, *Zelkova*, and *Holoptelea*. Overall, this phytochemical investigation enhanced our knowledge of the chemical diversity of *U. pumila*.

CRediT authorship contribution statement

Deri Hu: Writing – original draft, Investigation. **Zhenyu Liu:** Writing – original draft, Investigation. **Yue Yu:** Writing – original draft, Investigation. **Chenghao Wu:** Investigation. **Jinze Liu:** Investigation. **Dongzhou Kang:** Investigation. **Junzhe Min:** Writing – review & editing, Conceptualization. **Mingshan Zheng:** Writing – review & editing, Conceptualization.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bse.2024.104907.

References

Anju, Sharma, S., Dhanetia, H.R., 2020. Green synthesis of copper nanoparticles using *Holoptelea integrifolia* fruit extract. Rasayan J. Chem. 13 (4), 2664–2671.

Bu, P.B., Li, Y.R., Jiang, M., et al., 2013. Glycosides from the bark of *Machilus robusta*. J. Asian Nat. Prod. Res. 15 (5), 482–491.

Chang, B.S., Kwon, Y.S., Kim, C.M., 2004. The chemical structures and their antioxidant activity of the components isolated from the heartwood of *Hemiptelea davidii*. Saengyak Hakhoe Chi 35 (1), 80–87.

Chen, Z.Q., Li, X.T., Huang, Y.Q., et al., 2022. High-resolution NMR spectroscopy for measuring complex samples based on chemical-shift-difference selection. Phys. Chem. Chem. Phys. 25 (2), 999–1005.

Cheng, S.Y., Li, N., Yu, Y., et al., 2020. A new flavonoid from the bark of *Ulmus pumila* L. Biochem. Systemat. Ecol. 88, 103956.

Cho, E.J., Yokozawa, T., Rhyu, D.Y., et al., 2003. The inhibitory effects of 12 medicinal plants and their component compounds on lipid peroxidation. Am. J. Chin. Med. 31 (6), 907–917.

Choi, S.E., Park, G.H., Yoo, M.J., et al., 2019. Preparation Method of Composition with Antibacterial Activity against Skin Flora and Athlete's Foot. KR2019053629.

Chumbalov, T.K., Nurgalieva, G.M., Abdykalykova, R.A., 1972. Flavonol glycosides from the leaves of *Ulmus pinnato-ramosa*. Chem. Nat. Compd. 8 (2), 241-241.

Dai, T.D., Tam, N.T., Thien, D.D., et al., 2018. A new furanocoumarin glycoside from the roots of *Ficus hirta*. Lett. Org. Chem. 15 (12), 1007–1011.

Drzewiecka, K., Gsecka, M., Rutkowski, P., et al., 2018. Arsenic forms and their combinations induce differences in phenolic accumulation in *Ulmus laevis* Pall. J. Plant Physiol. 220, 34–42.

D'Angiolo, M., De Leo, M., Camangi, F., et al., 2022. Chemical constituents of *Ulmus minor* subsp. minor fruits used in the Italian phytoalimurgic tradition and their anti-inflammatory activity evaluation #. Planta. Méd. 88 (9/10), 762–773.

Flora of China Editorial Committee, 2003. Flora of China, vol. 5. Science Press and Missouri Botanical Garden Press, Beijing, pp. 1–10.

Ghosh, C., Chung, H.Y., Nandre, R.M., et al., 2012. An active extract of *Ulmus pumila* inhibits adipogenesis through regulation of cell cycle progression in 3T3-L1 cells. Food Chem. Toxicol. 50, 2009–2015.

Gu, Z.Y., Feng, C.Y., Li, S.S., et al., 2019. Identification of flavonoids and chlorogenic acids in elm fruits from the genus *Ulmus* and their antioxidant activity. J. Separ. Sci. 42 (18), 2888–2899.

Ham, Y., Kim, T.J., 2020. Inhibitory effect of phenolic acids in *Rubus coreanus* on glucosyltransferase of streptococcus mutans. Curr. Microbiol. 77 (11), 3695–3703.

Hu, Y.K., Bai, X.L., Shi, G.Y., et al., 2023. Polyphenolic glycosides with unusual four-membered ring possessing anti-Parkinson's disease potential from black wolfberry. Phytochemistry 213, 113775.

Huang, Z.H., Liu, Y., Shi, B.L., et al., 2016. Activity changes of defense enzymes and jasmonic acid content during the galls formation in leaves of *Ulmus pumila*. J. Agric. Univ. Hebei. 39 (3), 42–48.

Iwashina, T., Rahayu, S., Nakane, T., et al., 2022. Flavonoids and phenylethanoids from the flowers and leaves of *Aeschynanthus* species and cultivars (Gesneriaceae). Phytochemistry 203, 113367.

Kaweetripob, W., Thongnest, S., Boonsombat, J., et al., 2023. Phukettosides A-E, mono- and bis-iridoid glycosides, from the leaves of *Morinda umbellata* L. Phytochemistry 216, 113890.

Kim, M.M., Seok, J.G., Kim, S.N., et al., 2000. Pharmaceutical Composition for Treatment of Periodontal Diseases and Anti-inflammation. KR20000041190A.

Kwon, Y.M., Lee, J.H., Lee, M.W., 2002. Phenolic compounds from barks of *Ulmus macrocarpa* and its antioxidative activities. Korean J. Pharmacogn. 33 (4), 404–410.

Lee, J.H., Lee, Y.K., Choi, Y.R., et al., 2018. The characterization, selenylation and anti-inflammatory activity of pectic polysaccharides extracted from *Ulmus pumila* L. Int. J. Biol. Macromol. 111, 311–318.

Lee, S.H., Lim, J.M., Lee, S.W., et al., 2023. Effect of fermentation on antioxidant, antimicrobial, anti-inflammatory, and anti-helicobacter pylori adhesion activity of *Ulmus davidiana* var. *japonica* root bark. Food. Sci. Biotechnol. 32 (9), 1257–1268.

Li, Z., Bao, H., 2022. Comparative analysis of metabolic compositions and trace elements of Inonotus hispidus mushroom grown on five different tree species. ACS Omega 7 (11), 9343–9358.

Lopes, A.G., Borges, R.M., Kuhn, S., et al., 2022. Combining high-speed countercurrent chromatography three-phase solvent system with electrospray ionization-mass spectrometry and nuclear magnetic resonance to profile the unconventional food plant *Syzygium malaccense*. J. Chromatogr., A 1677, 463211.

Lortzing, V., Valsamakis, G., Jantzen, F., et al., 2024. Plant defensive responses to insect eggs are inducible by general egg-associated elicitors. Sci. Rep. 14 (1), 1076.

Ma, Q.G., Wei, R.R., Shang, D.L., et al., 2019. Hepatoprotective and neuroprotective flavanes from the fruits of *Ulmus pumila* L. (Ulmaceae). Pak. J. Pharm. Sci. 32 (5), 2059–2064.

Martin-Benito, D., Garcia-Vallejo, M.C., Pajares, J.A., et al., 2005. Triterpenes in elms in Spain. Can. J. For. Res. 35, 199–205.

Melek, F.R., El Zalabani, S.M., Ghaly, N.S., et al., 2021. Phytoconstituents with cytotoxic activity from *Ulmus pumila* L. J. Appl. Pharmaceut. Sci. 11 (5), 127–134.

Moon, Y.H., Rim, G.R., 1995. Studies on the constituents of *Ulmus parvifolia*. Saengyak Hakhoe Chi 26 (1), 1–7.

Nadella, D., Paarakh, P.M., Vedamurthy, A.B., 2012. Isolation of phytoconstituents from the stem bark of *Holoptelea integrifolia* (Roxb.). Planch. J. Pharm. Res. 5 (1), 532–533.

Nagatani, Y., Warashina, T., Noro, T., 2001. Studies on the constituents from the aerial part of *Baccharis dracunculifolia* DC. Chem. Pharm. Bull. 49 (11), 1388–1394.

Niklas, K.J., Giannasi, D.E., 1977. Flavonoids and other chemical constituents of fossil *Miocene Zelkova* (Ulmaceae). Science 196 (4292), 877–878.

Park, J.Y., Kim, M.S., Shin, J., et al., 2022. Microencapsulation of de-glycosylated mulberry (*Morus alba* L.) fruit extract through double-layered multiple emulsions of pectic polysaccharide extracted from *Ulmus davidiana* and soy protein isolate. J. Food Process. Preserv. 46 (10), e16833.

Saleem, A., Walshe-Roussel, B., Harris, C., et al., 2009. Characterisation of phenolics in Flor-Essence®—a compound herbal product and its contributing herbs. Phytochem. Anal. 20 (5), 395–401.

Schilbert, H.M., Busche, M., Saez, V., et al., 2024. Generation and characterisation of an *Arabidopsis thaliana* f3h/fls1/ans triple mutant that accumulates eriodictyol derivatives. BMC Plant Biol. 24 (1), 99.

Schott, J., Jantzen, F., Hilker, M., et al., 2023. Elm tree defences against a specialist herbivore are moderately primed by an infestation in the previous season. Tree Physiol. 43 (7), 1218–1232.

Sherman, S.L., Giannasi, D.E., 1988. Foliar flavonoids of *Ulmus* in eastern North America. Biochem. Systemat. Ecol. 16 (1), 51–56.

Shi, Y.H., Zhu, S., Tamura, T., et al., 2016. Chemical constituents with anti-allergic activity from the root of *Edulis Superba*, a horticultural cultivar of *Paeonia lactiflora*. J. Nat. Med. 70 (2), 234–240.

Sun, C.L., Tang, X.L., Zhou, J.F., et al., 2015. Chemical components of flavonoids from leaves of *Zelkova serrata*. Chinese. Pharmaceutical. Journal 50 (20), 1803–1805.

Tian, J.L., Yu, S.H., Wang, L., et al., 2024. New polyacetylenes from *Bidens procera*. Nat. Prod. Res. 38 (7), 1148–1156.

Varfalvyova, A., Kalyniukova, A., Tomaskova, I., et al., 2023. Sugar-based natural deep eutectic solvent ultrasound-assisted extraction for the determination of polyphenolic compounds from various botanical sources. Microchem. J. 194, 109249.

Vu, N.K., Ha, M.T., Ha, Y.J., et al., 2022. Structures and antiosteoclastogenic activity of compounds isolated from edible lotus (*Nelumbo nucifera* Gaertn.) leaves and stems. Fitoterapia 162, 105294.

Wang, D., Xia, M.Y., Cui, Z., et al., 2004. Cytotoxic effects of mansonone E and F isolated from *Ulmus pumila*. Biol. Pharm. Bull. 27 (7), 1025–1030.

Wang, D., Xia, M.Y., Cui, Z., 2006. New triterpenoids isolated from the root bark of *Ulmus pumila* L. Chem. Pharm. Bull. 54 (6), 775–778.

Wang, D., Xia, M.Y., Jiang, N., et al., 2012. Chemical constituents of root bark of *Ulmus pumila* (III). J. Shenyang Pharm. Univ. 29 (3), 190–192.

Wang, J., Wang, D.Q., Huang, M.Q., et al., 2023. Identification of nonvolatile chemical constituents in Chinese Huangjiu using widely targeted metabolomics. Food Res. Int. 172, 113226.

Wang, Y., Jiang, W., Li, C.L., et al., 2024. Integrated transcriptomic and metabolomic analyses elucidate the mechanism of flavonoid biosynthesis in the regulation of mulberry seed germination under salt stress. BMC Plant Biol. 24 (1), 132.

Wang, Z.N., Sun, B., Yang, R., et al., 2023. Flavonoids and other phenolics from *Camellia nitidissima* chi flowers. Nat. Prod. Res. 37 (2), 180–187.

Won, J.Y., Son, S.Y., Lee, S., et al., 2018. Strategy for screening of antioxidant compounds from two Ulmaceae species based on liquid chromatography-mass spectrometry. Molecules 23 (7), 1830/1–1830/15.

Xu, X.Q., Huang, X.H., Chen, J., et al., 2017. A new flavonoid glycoside from *Viburnum macrocephalum* f. keteleeri. Chem. Nat. Compd. 53 (6), 1035–1037.

Yang, C.J., Shen, J.Y., Shang, J.W., et al., 2024. Physiological response and differential gene expression analysis of *Hemiptelea davidii* (Ulmaceae) seedlings under PEG stress. Pakistan J. Bot. 56 (2), 491–505.

Yang, H.H., Son, J.K., Jung, B., et al., 2011. Epifriedelanol from the root bark of *Ulmus davidiana* inhibits cellular senescence in human primary cells. Planta Med. 77 (5), 441–449.

Yang, J.X., Qi, Y.Y., Li, H.Y., et al., 2021. Determination of quinic acids in *Helichrysum arenarium* (L.) moench by ultrafiltration affinity and ultra-high-performance liquid chromatography coupled with quadrupole-time-of-flight mass spectrometry (UF-UPLC-Q-TOF-MS). Anal. Lett. 54 (5), 772–789.

Yu, Y., Elshafei, A., Zheng, X.D., et al., 2021. Chemical constituents of *Chimaphila japonica* miq. Biochem. Systemat. Ecol. 95, 104219.

Yu, Y., Hu, D.R., Liu, J.Z., et al., 2024. Constituents of *Chimaphila japonica* and their diuretic activity. Molecules 29 (5), 1092.

Yu, Y., Liu, D., Elshafei, A., et al., 2023. Chemical constituents from *Chimaphila japonica* Miq. and their chemotaxonomic significance. Biochem. Systemat. Ecol. 109, 104664.

Zhang, H.H., Jin, L., Zhang, J.B., et al., 2022. Chemical constituents from the bulbs of *Lilium davidii* var. *unicolor* and anti-insomnia effect. Fitoterapia 161, 105252.

Zheng, M.S., Cui, D.R., Yu, Y., et al., 2024. Compounds Extracted from *Ulmus Pumil* Bark and Preparation Method and Application in Anti Sepsis Induced Acute Liver Injury. CN118047822.

Zheng, M.S., Lee, Y.K., Li, Y., et al., 2010a. Inhibition of dna topoisomerases I and II and cytotoxicity of compounds from *Ulmus davidiana* var. *japonica*. Arch Pharm. Res. (Seoul) 33 (9), 1307–1315.

Zheng, M.S., Yang, J.H., Li, Y., et al., 2010b. Anti-inflammatory activity of constituents isolated from *Ulmus davidiana* var. *japonica*. Biomol. Ther. 18 (3), 321–328.

Zhou, Z., Shao, H., Han, X., et al., 2017. The extraction efficiency enhancement of polyphenols from *Ulmus pumila* L. barks by trienzyme-assisted extraction. Ind. Crop. Prod. 97, 401–408.