

# 马齿苋中黄酮类及生物碱类的研究进展

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## 摘要

马齿苋(*Portulaca oleracea* L.)为马齿苋属分布较广的药食同源植物。马齿苋中含有黄酮、生物碱等多种化学成分, 具有抗肿瘤、神经保护、抗氧化、抑菌、保肝、抗衰老等药理作用, 可用于治疗阿尔茨海默病、帕金森氏病、三阴性乳腺癌、宫颈癌、肝癌、糖尿病、高血脂等疾病。本文对近年来马齿苋中黄酮及生物碱类的化学成分、药理作用、体内代谢过程进行总结, 以期马齿苋在医药和食品方面的利用提供参考。

## 关键词

马齿苋, 黄酮类, 生物碱类, 药理作用, 药物代谢

# Research Progress on Flavonoids and Alkaloids in *Portulaca oleracea* L.

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## Abstract

*Portulaca oleracea* L. is a medicinal and food-homologous plant in the genus *Portulaca*. Purslane contains flavonoids, alkaloids and other chemical components, with anti-tumor, neuroprotective, antioxidant, bacteriostatic, hepatoprotective, anti-aging and other pharmacological effects, can be used to treat Alzheimer's disease, Parkinson's disease, triple-negative breast cancer, cervical cancer, liver cancer, diabetes, hyperlipidemia, and other diseases. This work summarized the chemical composition, pharmacological activities and metabolism of flavonoids and alkaloids in purslane in recent years, in order to provide reference for the utilization of purslane in medicine and

food.

## Keywords

*Portulaca oleracea* L., Flavonoids, Alkaloids, Pharmacology, Drug Metabolism

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## 1. 引言

马齿苋(*Portulaca oleracea* L.)为马齿苋科马齿苋属马齿苋的干燥地上部分,又名长命草、长寿菜、马舌菜等,如图1所示。它是一年生肉质草本的药食同源植物[1],广布于世界各地的温热带地区。在《本草纲目》[2]及《新修本草》[3]中记载,马齿苋具味酸、性寒等特点。民间常作为菜肴,包括凉拌、清炒、包饺子等。近年来,国内外学者对马齿苋的化学成分、药理作用、临床应用进行了深入的研究,结果表明马齿苋具有神经保护[4]、抗菌[5]、抗氧化[6]、抗炎[7][8]、降血糖[9]及降血脂[10][11][12]、抗癌[13]、保肝[14]等丰富的药理作用,可作为保健品[15]和化妆品[16]。马齿苋中含有黄酮、生物碱、多酚、萜类及甾醇、香豆素、多糖等多种化学成分,其中黄酮、生物碱是马齿苋的主要活性成分,研究报道从该植物中已分离鉴定出32个黄酮类化合物及71个生物碱类化合物。本文将对该植物中生物碱及黄酮的化学成分、药理作用、体内代谢等研究进行综述,旨在为马齿苋在医药、食品、化妆品等方面的开发提供参考。



Figure 1. *Portulaca oleracea* L. taken by the author in Luoping Qujing, on April of 2023

图1. 马齿苋(2023年4月),摄于曲靖罗平

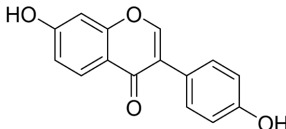
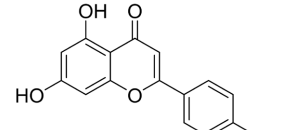
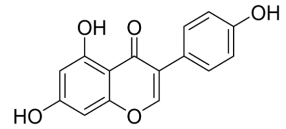
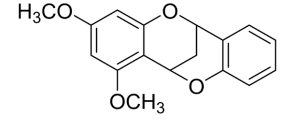
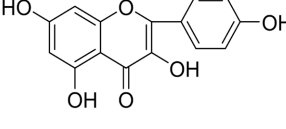
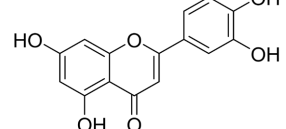
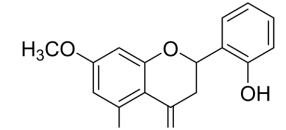
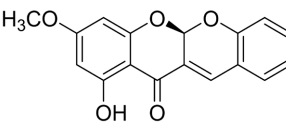
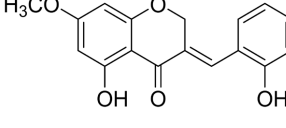
## 2. 化学成分

### 2.1. 黄酮类化学成分

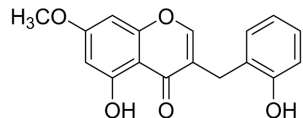
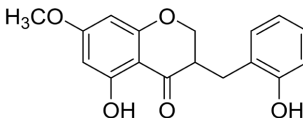
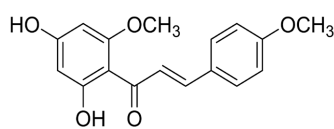
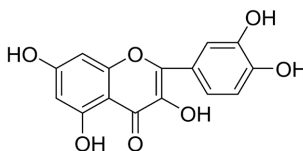
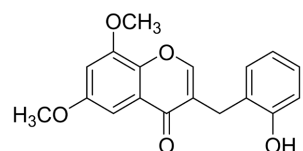
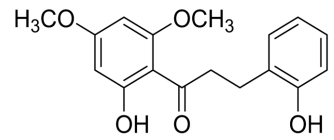
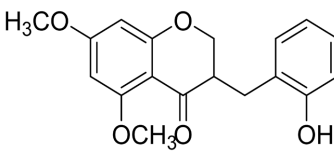
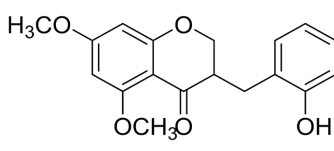
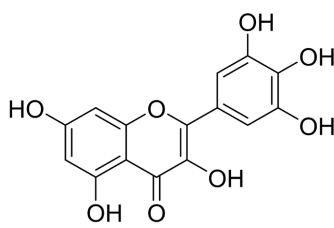
黄酮类化学成分按分子量从小到大排序,如表1所示。

Table 1. Flavonoids components

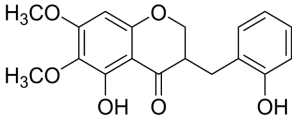
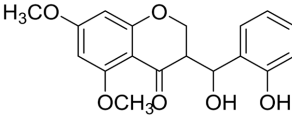
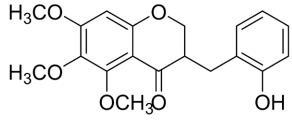
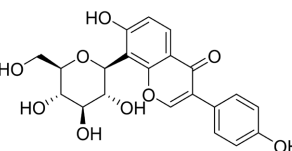
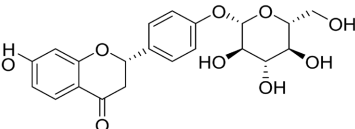
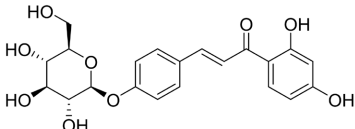
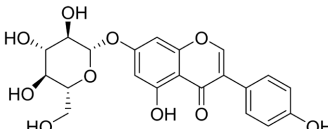
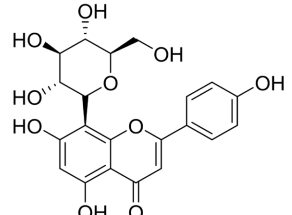
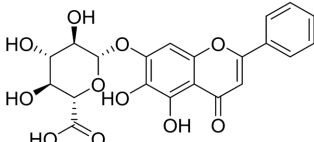
表 1. 黄酮类化学成分

名称	分子式	分子量(Da)	结构式	文献来源
大豆黄酮	$C_{15}H_{10}O_4$	254.2410		[17]
芹菜素	$C_{15}H_{10}O_5$	270.2400		[17]
染料木素	$C_{15}H_{10}O_5$	270.2400		[17]
5,7-二甲氧基-4-O-2-环黄烷	$C_{17}H_{16}O_4$	284.3110		[17]
山奈酚	$C_{15}H_{10}O_6$	286.2390		[17]
木犀草素	$C_{15}H_{10}O_6$	286.2390		[17]
(2s)-5,2-二羟基-7-甲氧基黄烷酮	$C_{16}H_{14}O_5$	286.2830		[17]
oleracone G	$C_{17}H_{12}O_5$	296.2780		[18]
portulacaneone D	$C_{17}H_{14}O_5$	298.2940		[17] [19]

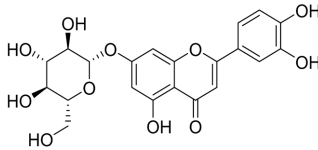
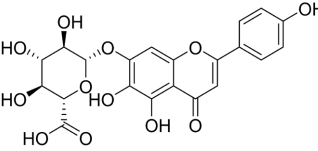
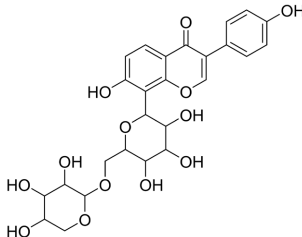
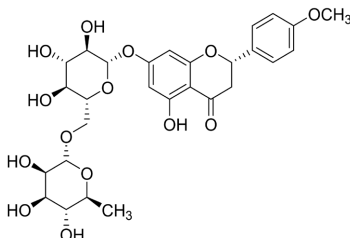
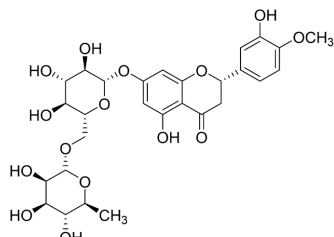
## Continued

oleracone D	$C_{17}H_{14}O_5$	298.2940		[17]
oleracone C	$C_{17}H_{16}O_5$	300.3100		[17]
2,4-二羟基-4,6-二甲氧基查尔酮	$C_{17}H_{16}O_5$	300.3100		[17]
槲皮素	$C_{15}H_{10}O_7$	302.2380		[17]
oleracone J	$C_{18}H_{16}O_5$	312.3210		[20]
oleracone E	$C_{17}H_{18}O_5$	302.3260		[17]
portulacanone A	$C_{18}H_{18}O_5$	314.3370		[17]
oleracone K	$C_{18}H_{18}O_5$	314.3370		[20]
杨梅素	$C_{15}H_{10}O_8$	318.2370		[17]

## Continued

portulacanone C	$C_{18}H_{18}O_6$	330.3360		[17]
portulacanone E	$C_{18}H_{18}O_6$	330.3360		[18]
portulacanone B	$C_{19}H_{20}O_6$	344.3630		[17]
葛根素	$C_{21}H_{20}O_9$	416.3820		[17]
甘草苷	$C_{21}H_{22}O_9$	418.3980		[17]
异甘草苷	$C_{21}H_{22}O_9$	418.3980		[17]
染料木苷	$C_{21}H_{20}O_{10}$	432.3810		[17]
牡荆素	$C_{21}H_{20}O_{10}$	432.3810		[17]
黄芩苷	$C_{21}H_{18}O_{11}$	446.3640		[17]

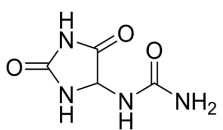
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木犀素-7-O-葡萄糖苷	$C_{21}H_{22}O_{10}$	448.3800		[17]
野黄芩苷	$C_{21}H_{18}O_{12}$	462.3630		[17]
葛根素-6-O-木糖苷	$C_{26}H_{28}O_{13}$	548.4970		[17]
金合欢素-7-O-beta-D-芸香糖苷	$C_{28}H_{34}O_{14}$	594.5660		[17]
橙皮苷	$C_{28}H_{34}O_{15}$	610.5650		[17]

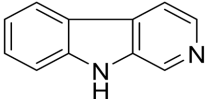
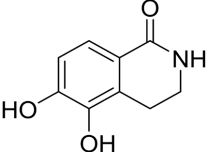
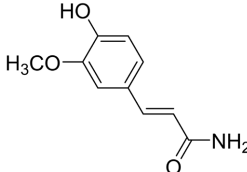
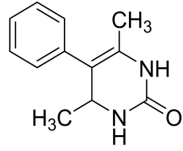
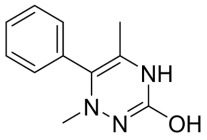
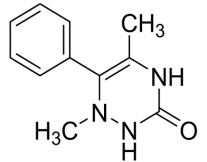
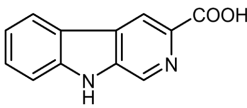
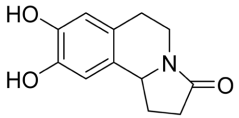
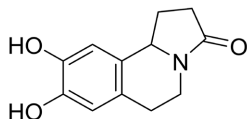
## 2.2. 生物碱类化学成分

生物碱类化学成分按分子量从小到大排序，如表 2 所示。

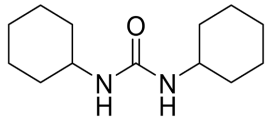
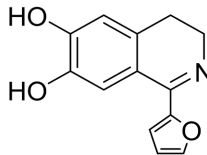
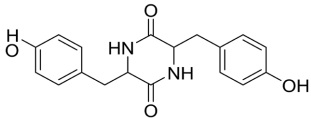
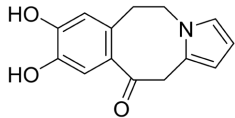
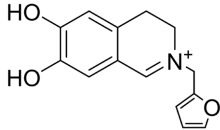
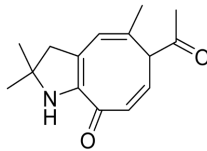
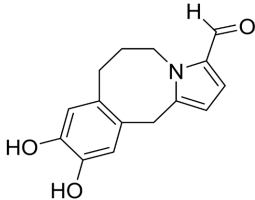
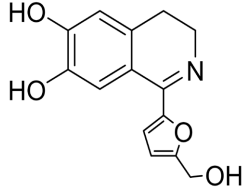
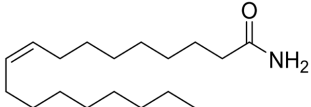
**Table 2.** Alkaloids components  
**表 2.** 生物碱类化学成分

名称	分子式	分子量(Da)	结构式	文献来源
尿囊素	$C_4H_6N_4O_3$	158.1170		[17]

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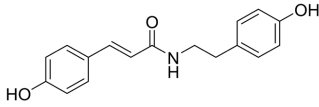
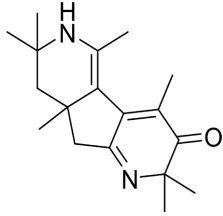
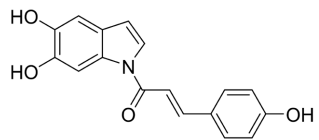
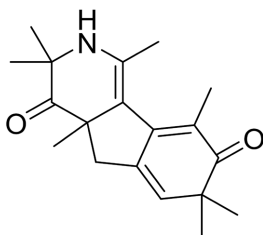
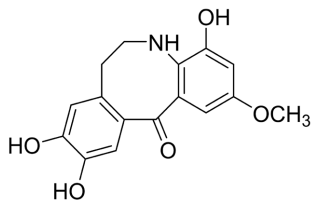
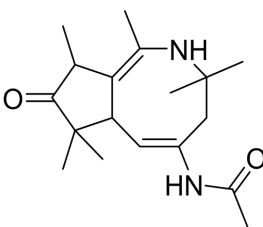
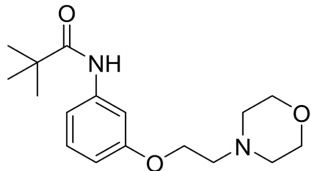
$\beta$ -咔啉	$C_{11}H_8N_2$	168.1990		[21]
oleraciamide G	$C_9H_9NO_3$	179.1750		[17]
阿魏酸酰胺	$C_{10}H_{11}NO_3$	193.2020		[21]
triazinone	$C_{12}H_{14}N_2O$	202.2570		[21]
1,5-二甲基-6-苯基-1,6,3,4-四氢-1,2,4-二氢-2(1H)-三嗪	$C_{11}H_{13}N_3O$	203.2450		[17]
1,5-二甲基-6-苯基-1,2-二氢-1,2,4-三嗪-3(2H)-酮	$C_{11}H_{13}N_3O$	203.2450		[17]
$\beta$ -咔啉-3-羧酸	$C_{12}H_8N_2O_2$	212.2080		[21]
马齿苋酰胺 E	$C_{12}H_{13}NO_3$	219.2400		[17]
金莲花碱	$C_{12}H_{13}NO_3$	219.2400		[17]

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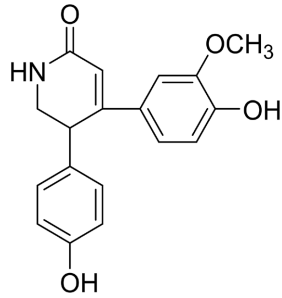
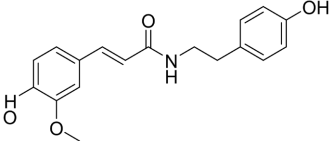
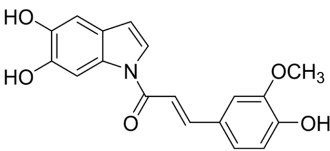
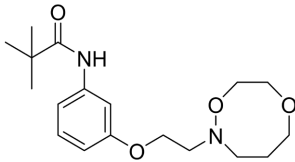
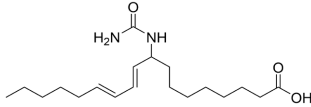
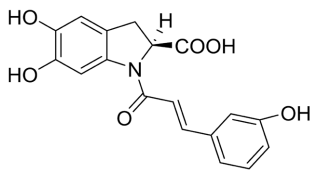
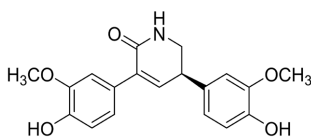
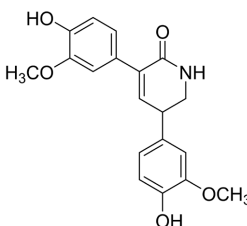
<i>N-N</i> 二环己基脒	$C_{13}H_{24}N_2O$	224.3480		[17]
isoquinoline A	$C_{13}H_{11}NO_3$	229.2350		[21]
环( <i>L</i> -酪氨酸- <i>L</i> -酪氨酸)	$C_{18}H_{18}N_2O_4$	236.3520		[17]
portulacatone B	$C_{14}H_{13}NO_3$	243.2620		[17]
isoquinoline C	$C_{14}H_{14}NO_3^+$	244.2695		[21]
oleracone	$C_{15}H_{19}NO_2$	245.3220		[17]
ortulacatal	$C_{15}H_{15}NO_3$	257.2890		[17]
isoquinoline B	$C_{14}H_{13}NO_4$	259.2610		[21]
油酰胺	$C_{18}H_{35}NO$	281.4840		[17]



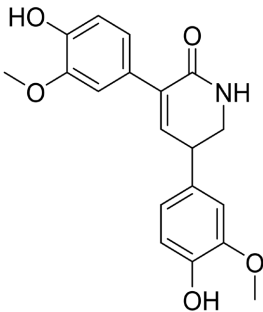
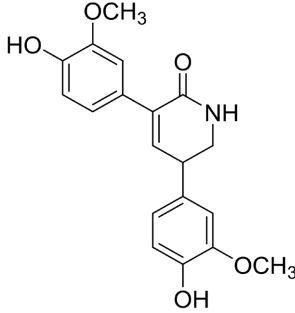
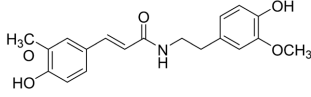
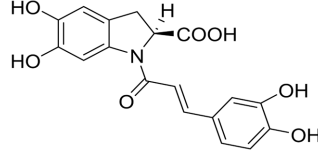
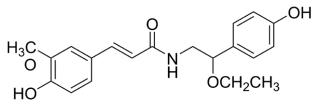
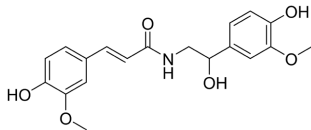
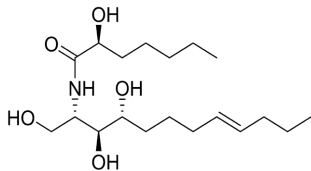
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<i>N</i> -反式对香豆酰基酪胺	$C_{17}H_{17}NO_3$	283.3270		[17]
oleracimine	$C_{18}H_{26}N_2O$	286.4190		[17]
oleraindole A	$C_{17}H_{13}NO_4$	295.2940		[21]
oleracimine A	$C_{19}H_{25}NO_2$	299.4140		[17]
oleracone L	$C_{16}H_{15}NO_5$	301.2980		[17]
oleracone A	$C_{18}H_{28}N_2O_2$	304.4340		[17]
oleraciamide A	$C_{17}H_{26}N_2O_3$	306.4060		[17]

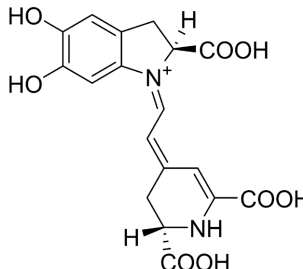
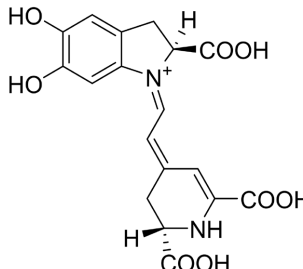
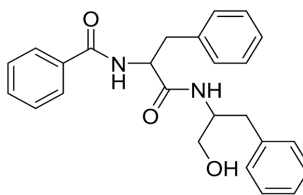
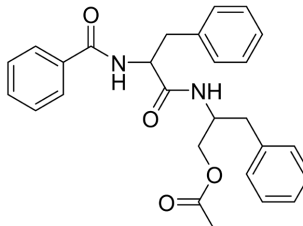
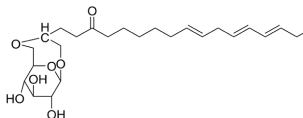
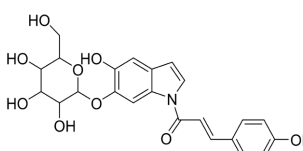
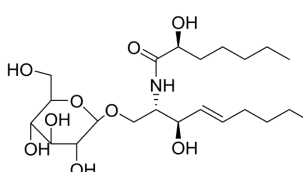
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oleraciamide D	$C_{18}H_{17}NO_4$	311.3370		[17]
<i>N</i> -反式阿魏酰基酪胺	$C_{18}H_{19}NO_4$	313.3530		[17]
oleraindole B	$C_{18}H_{15}NO_5$	325.3200		[21]
oleraciamide B	$C_{18}H_{28}N_2O_4$	336.4320		[17]
oleraurea	$C_{19}H_{34}N_2O_3$	338.4920		[17]
马齿苋酰胺 U	$C_{18}H_{15}NO_6$	341.3190		[21]
dihydropyridinone	$C_{19}H_{19}NO_5$	341.3630		[21]
pyridinone	$C_{19}H_{19}NO_5$	341.3630		[21]

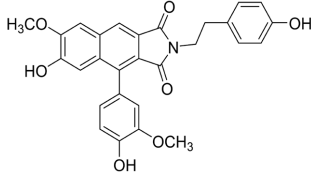
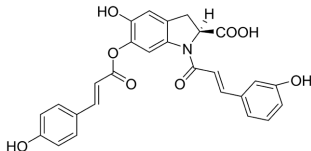
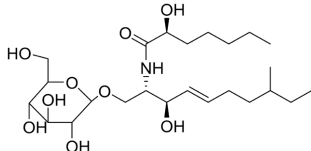
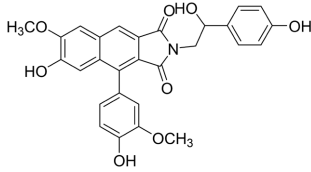
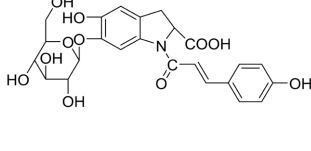
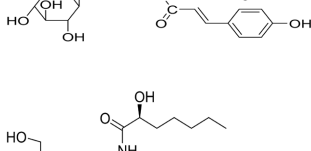
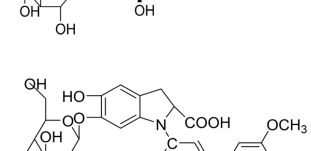
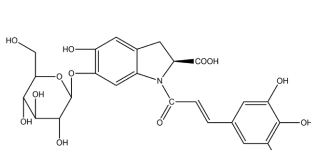

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3,5-二(3-甲氧基, 4-羟苯基)-5,6-二氢, 2(1H)-吡啶酮	$C_{19}H_{19}NO_5$	341.3630		[17]
(3 <i>R</i> )-3,5-二(3-甲氧基-4-羟苯基)-2,3-二氢-2(1H)-吡啶酮	$C_{19}H_{19}NO_5$	341.3630		[17]
<i>N</i> -反式阿魏酰基-3-甲氧基酪胺	$C_{19}H_{21}NO_5$	343.3790		[17]
马齿苋酰胺 W	$C_{18}H_{15}NO_7$	357.3180		[21]
7-乙氧基 - 反式 - 阿魏酰基苯胺	$C_{20}H_{23}NO_5$	357.4060		[17]
<i>N</i> -阿魏酰基去甲肾上腺素	$C_{19}H_{21}NO_6$	359.3780		[17]
portulaceramide A	$C_{19}H_{37}NO_5$	359.5070		[21]

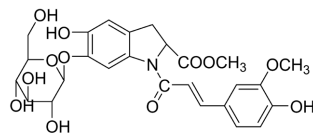
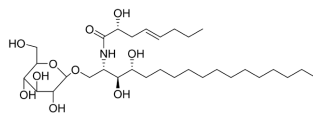
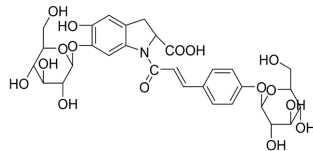
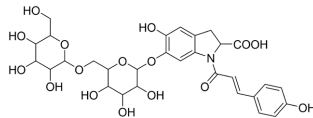
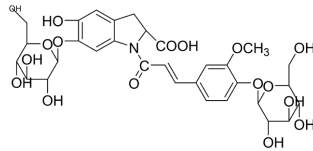
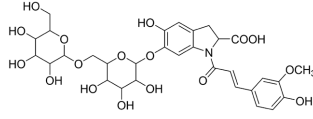
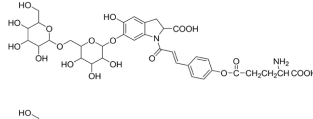
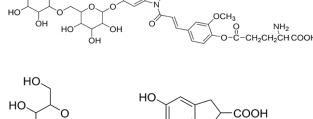
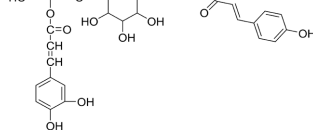
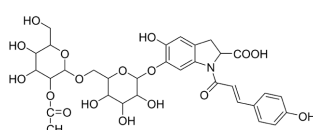
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甜菜红素	$C_{18}H_{17}N_2O_8^+$	389.3395		[17]
马齿苋碱 II	$C_{18}H_{17}N_2O_8^+$	389.3395		[21]
橙黄胡椒酰胺乙酸酯	$C_{25}H_{26}N_2O_3$	402.4940		[17]
枸杞酰胺	$C_{27}H_{28}N_2O_4$	444.5310		[17]
oleraciamide C	$C_{26}H_{40}O_7$	452.5880		[17]
oleraindole D	$C_{23}H_{23}NO_9$	457.4350		[17]
马齿苋脑苷 C	$C_{22}H_{41}NO_9$	463.5680		[21]

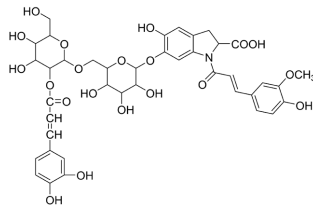
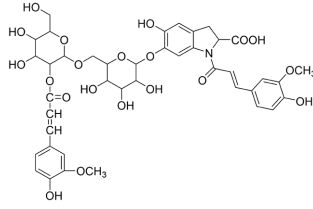
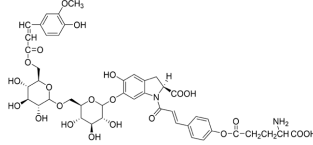
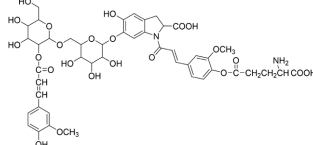
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oleraisoindole A	$C_{28}H_{23}NO_7$	485.4920		[17]
马齿苋酰胺 T	$C_{27}H_{21}NO_8$	487.4640		[21]
马齿苋脑苷 D	$C_{24}H_{45}NO_9$	491.6220		[21]
oleraisoindole	$C_{28}H_{23}NO_8$	501.4910		[17]
马齿苋酰胺 A	$C_{24}H_{25}NO_{11}$	503.4600		[17]
马齿苋酰胺 G	$C_{25}H_{27}NO_{11}$	517.4870		[17]
马齿苋脑苷 B	$C_{26}H_{49}NO_9$	519.6760		[21]
马齿苋酰胺 B	$C_{25}H_{27}NO_{12}$	533.4860		[17]
马齿苋酰胺 V	$C_{24}H_{25}NO_{13}$	535.4580		[21]

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马齿苋酰胺 F	$C_{26}H_{29}NO_{12}$	547.5130		[17]
马齿苋脑苷 A	$C_{31}H_{59}NO_{10}$	605.8100		[21]
马齿苋酰胺 C	$C_{30}H_{35}NO_{16}$	665.6010		[17]
马齿苋酰胺 H	$C_{30}H_{35}NO_{16}$	665.6010		[17]
马齿苋酰胺 D	$C_{31}H_{37}NO_{17}$	695.6270		[17]
马齿苋酰胺 I	$C_{31}H_{37}NO_{17}$	695.6270		[17]
马齿苋酰胺 P	$C_{36}H_{42}N_2O_{19}$	794.7160		[17]
马齿苋酰胺 Q	$C_{36}H_{43}N_2O_{20}$	824.7420		[17]
马齿苋酰胺 K	$C_{39}H_{41}NO_{19}$	827.7450		[17]
马齿苋酰胺 N	$C_{40}H_{43}NO_{19}$	841.7720		[17]

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马齿苋酰胺 L	$C_{40}H_{43}NO_{20}$	857.7710		[17]
马齿苋酰胺 O	$C_{41}H_{45}NO_{20}$	871.7980		[17]
马齿苋酰胺 S	$C_{46}H_{50}N_2O_{22}$	970.8870		[21]
马齿苋酰胺 R	$C_{46}H_{52}N_2O_{23}$	1000.9130		[17]

### 3. 药理作用

#### 3.1. 黄酮类药理作用

##### 3.1.1. 抗肿瘤作用

黄酮类化合物具有良好的抗肿瘤作用。其抗肿瘤机制可分为 3 种：1) 抑制恶性细胞增值；2) 诱导细胞凋亡；3) 抑制恶性细胞迁移及侵袭。马齿苋中含有丰富的杨梅素和槲皮素。Song 等人[22]的研究结果表明杨梅素不仅可激活 Hippo 信号通路，靶向于 LATS1/2-YAP 信号因子，抑制肝癌细胞的增殖；还能结合白血病 K562 细胞中的 hIMPDPH 因子干扰嘌呤核苷酸的合成，从而抑制其增殖，发挥治疗白血病的作用；杨梅素还可作用于 MAPK 信号通路，激活 EPK1/2、JNK 基因、并使 P38 磷酸化，抑制 Akt 磷酸化及其下游 P70S6K、P90RSK 的调控因子，从而抑制恶性细胞的增殖，用于治疗人胎盘绒毛膜癌、三阴性乳腺癌。此外，杨梅素[22]还能阻断人胶质母细胞瘤上游的表皮生长因子受体 EGFR/P13K/Akt 和下游 RAS-EPK 通路，诱导细胞凋亡，用于胶质母细胞瘤的治疗；杨梅素[22]也可以显著降低 MDA-MB-231 细胞中 MMP-2/9 和 ST6GALNAC5 蛋白的表达，从而有效的抑制癌细胞的迁移、侵袭和粘附。Song 等人[23]的研究结果也表明槲皮素可通过 NF- $\kappa$ B/TLR/NLRP3 通路抑制肝脏炎症，减缓 PI3K/Nrf2 介导的氧化应激，抑制与肝病发展相关的凋亡因子的表达。

##### 3.1.2. 治疗阿尔茨海默病

阿尔茨海默病又名老年痴呆(Alzheimer's disease, AD), 是以进行性认知功能障碍为主要特征的神经退行性病变，主要表现为记忆及认知的受损。其中  $\beta$ -样淀粉蛋白的沉积、 $\tau$  的过度磷酸化的累积、神经炎

斑块及神经纤维的缠结是 AD 的主要病理表现[24]。目前, 治疗 AD 的药物主要分为五类: 1) 乙酰胆碱酯酶抑制剂, 如多奈哌齐、加兰他明; 2) *n*-甲基-*d*-天冬氨酸受体调节剂, 如美金刚胺; 3) A $\beta$  靶向免疫剂, 如 Gantenerumab 单抗, 能降低  $\beta$ -样淀粉蛋白的沉积; 4)  $\tau$  的靶向治疗药物: 亚甲基蓝; 5) BACE1 抑制剂: 限制新斑块的形成, 但不能抑制已生成斑块的生长, 若联合 A $\beta$  靶向免疫的单抗能发挥协同作用。目前, 开发抗阿尔茨海默病的药物一直在 II、III 期临床试验阶段失败所停滞。因此, 开发一个有效治疗 AD 的药物极为重要。脑中铁离子过载会加重神经元的损伤, 导致氧化应激, 诱发阿尔茨海默病。研究结果显示杨梅素[22]是理想的铁离子的螯合剂, 可抑制转铁蛋白受体 1 的表达, 增加抗氧化酶的活性, 使脑中铁离子含量维持稳态, 从而减轻小鼠认知功能障碍。加之, 杨梅素还能抑制乙酰胆碱酯酶, 能有效降低 AD 小鼠的神经和记忆损伤。王潞等人[25]也证实了杨梅素可显著增加 AD 模型大鼠的海马 CA3 锥体神经元的数目, 改善学习记忆障碍。李海涛等人[26]证实了山奈酚、芹菜素、木犀草素、杨梅素、槲皮素具有较强的抗氧化作用, 能预防老年痴呆及心血管疾病。Zhao 和 Salehi 等人[27] [28] [29]检测到芹菜素对淀粉样前体蛋白(APP/PS1)双转基因 AD 小鼠的神经保护作用。Li 等人[30]研究表明染料木素可通过 A $\beta$  调节代谢、A $\beta$  诱导氧化应激、A $\beta$  诱导线粒体功能障碍、A $\beta$  诱导细胞凋亡、 $\tau$  蛋白调节代谢等五方面来抑制 A $\beta$  的产生及其诱导的神经毒性的形成并改善  $\tau$  蛋白的过度磷酸化及认知功能障碍。此外, Duan 等人[20]研究发现 oleracone J 和 oleracone K 的酚羟基分别与 TYR-377、TYR-124 形成氢键发挥抗乙酰胆碱酯酶的作用, 其抗乙酰胆碱酯酶的 IC<sub>50</sub> 值分别为 59.08  $\mu$ mol/L 及 67.89  $\mu$ mol/L。

### 3.1.3. 治疗帕金森氏病

帕金森氏病是由中脑黑质多巴胺能神经元变性引起的神经退行性疾病, 导致记忆衰退和运动协调丧失, 主要表现为静坐不能、肌强直、锥体外系反应[31]等, 严重影响患者的生活质量。杨梅素对鱼藤酮诱导的帕金森果蝇模型具有抑制作用, 能延长果蝇寿命, 具有一定的神经保护作用[25]。

### 3.1.4. 抗氧化作用

黄酮类化合物具有强大的抗氧化作用, oleracone j、oleraconek 和 oleraconeg 均具清除 1,1-二苯-2-吡啶-肼(DPPH)自由基的能力, 与抗氧化剂丁基羟基茴香醚的 IC<sub>50</sub> 为 57.41  $\mu$ mol/L 相比, 以上三个化合物的 IC<sub>50</sub> 值分别为 18.34  $\mu$ mol/L、23.92  $\mu$ mol/L、27.57  $\mu$ mol/L, 表明 oleraconej [20]、oleraconek [20]及 oleraconeg [32]具有良好的抗氧化能力。Wang 等人[33]发现山奈酚是羟基自由基的清除剂, IC<sub>50</sub> 值为 0.5  $\mu$ mol/L。此外, Parhiz 等人[34]的研究证实了橙皮苷不仅能清除自由基, 还可通过 ERK/Nrf2 信号通路增强抗氧化细胞的防御功能。

### 3.1.5. 抑菌作用

黄酮类化合物是广谱的抑菌药物。刘治廷等人[17]的研究结果表明, 槲皮素、芹菜素、黄芩苷等黄酮类化合物可破坏细胞膜的结构和影响微生物的能量代谢, 发挥抑菌的作用。

### 3.1.6. 保肝作用

马齿苋总黄酮可预防肝癌及肝硬化。乔靖怡等人[35]的研究表明马齿苋总黄酮能降低由四氯化碳诱导的大鼠肝损伤指数, 降低肝组织中 MDA、NO、TNF- $\alpha$  和 IL-6 含量, 以及血清中 ALT、AST、ALP 和 TBIL 水平, 同时增强 SOD、GSH-PX 活性。

## 3.2. 生物碱类药理作用

### 3.2.1. 抗肿瘤作用

王天宇等人[36]发现马齿苋脑苷 a 能诱导人宫颈癌 HeLa 细胞的凋亡并抑制其迁移与侵袭, 是潜在的



抗宫颈癌药物。oleraciamided [37]与 *n*-反式阿魏酰酪胺的结构相似, 当浓度为 50  $\mu\text{mol/L}$  时能显著抑制人神经母细胞瘤的增殖。

### 3.2.2. 治疗阿尔茨海默病

生物碱发挥抗乙酰胆碱酯酶活性及其结构的多样性使其成为 AD 的候选药物。其中, oleraisoindolea [38]、oleraciamideg [39]、oleraindoled [39]、oleraindolea-e [18]、及 oleraciamidee [18]具有显著的抗乙酰胆碱酯酶作用。甜菜红素能提升认知障碍小鼠大脑中超氧化物歧化酶、过氧化氢酶、谷胱甘肽还原酶和谷胱甘肽过氧化物酶的水平, 降低丙二醛的水平, 其效果优于维生素 C [4]。马齿苋酰胺 e 不仅能通过抗氧化, 抑制神经细胞的凋亡, 还可改善由 *d*-半乳糖和亚硝酸钠联合给药后诱导的 AD 小鼠模型空间记忆能力[40] [41]。*n*-反式-阿魏酰-3-甲氧基酪氨[42]能抑制磷酸化的  $\tau$  蛋白而发挥治疗阿尔茨海默病。

### 3.2.3. 抗炎作用

*n*-反式-阿魏酰-3-甲氧基酪氨能显著抑制由脂多糖诱导的促炎因子的产生[43]。此外, *n*-反式-对香豆酪胺[8]、oleraisoindole、马齿苋酰胺 e、isoquinolinea、isoquinolineb、isoquinolinec、oleracone、oleracimine 均具有较强的抗炎活性[21]。

### 3.3. 其他药理作用

马齿苋总黄酮可以减轻 *d*-半乳糖及女性生殖系统引起的衰老[36], 其中木犀草素可对糖脂代谢综合征发挥益处[44]。此外, 马齿苋乙醇提取物对甲基汞诱导的神经毒性具有保护作用[45], 且水提取物中甜菜红色素是发挥神经保护的活性成分。

## 4. 体内代谢

马齿苋中黄酮类及生物碱类化合物种类丰富。黄酮类化合物多以糖苷的形式存在, 口服生物利用度较低。黄酮类活性成分是含有多羟基的化合物, 主要在小肠上进行吸收, 经小肠  $\beta$ -葡萄糖苷酶或乳糖酶根皮苷水解酶发生水解, 进而穿过肠壁进入肠上皮细胞, 再经门静脉进入肝脏, 在肝脏细胞色素 P450 酶的作用下发生 I 相代谢[46], II 相代谢主要在尿苷 5'-二磷酸葡萄糖醛酸基转移酶、磺基转移酶、儿茶酚-*O*-甲基转移酶的作用下进行葡萄糖醛酸化、硫酸化、甲基化等, 生成相应的 II 相代谢产物[47]。生物碱类化合物多数含有氮原子, 进入体内吸收迅速, 分布至全身各个组织, 在肝脏中进行代谢。此外, 多数黄酮类及生物碱类化合物能穿透血脑屏障, 发挥治疗中枢神经系统疾病的作用。通过 SwissADME 网站 (<http://swissadme.ch/index.php>)共预测了黄酮类化合物 32 个, 生物碱类化合物 71 个, 其中能穿透血脑屏障(Blood Brain Barrier, BBB)的黄酮类化合物有 12 个, 生物碱类化合物有 19 个, 结果分别如表 3 所示:

Table 3. BBB components

表 3. 穿透血脑屏障的药物

类别	穿过血脑屏障化合物
黄酮	portulacanone D、portulacanone A、oleracone G、oleracone E、oleracone J 2,4-二羟基-4,6-二甲氧基查尔酮、大豆黄酮、5,7-二甲氧基-4- <i>O</i> -2-环黄烷 oleracone C、oleracone K、portulacanone B、(2 <i>s</i> )-5,2-二羟基-7-甲氧基黄烷酮
生物碱	oleracimine A、Isoquinoline A、oleracimine、oleraciamide A、portulacatone B Isoquinoline C、oleracone A、ortulacatal、oleracone、triazinone、oleraciamide B $\beta$ -咪啉-3-羧酸、1,5-二甲基-6-苯基-1,2-二氢-1,2,4-三嗪-3(2H)-酮 油酰胺、 $\beta$ -咪啉、橙黄胡椒酰胺乙酸酯、 <i>N</i> -反式对香豆酰基酪胺 <i>N-N</i> 二环己基脲、1,5-二甲基-6-苯基-1,6,3,4-四氢-1,2,4-2(1H)-三嗪

黄酮类化合物药理活性广泛。目前, 马齿苋的体内代谢研究未见报道, 但马齿苋中分离出的黄酮类化合物的体内代谢研究不胜枚举。从马齿苋中分离出 32 个黄酮类化合物, 其中山奈酚[48] [49]、芹菜素[50]、木犀草素[44] [51]、槲皮素[52]、杨梅素[53]、野黄芩苷[54]、黄芩苷[55]、葛根素[56]、大豆黄酮[57]、甘草苷[58]、牡荆素[59]、橙皮苷[60]、oleraconec [61]、木犀草素-7-*O*-葡萄糖苷[62]等 13 个黄酮类化合物开展了体内代谢研究。

马齿苋中生物碱类化合物的代谢主要是马齿苋酰胺 e [40]、soyalkaloida [63]、oleracone [64]、olerciamide A [65]、oleracimine、aurantiamide acetate [66]。

## 5. 小结与展望

马齿苋的化学成分明确, 药理作用丰富, 广泛应用于各种疾病的预防及治疗、食品添加剂、化妆品抗炎保湿抗氧化剂、牲畜的饲料等。马齿苋中黄酮类及生物碱类化合物着重应用于抗肿瘤、神经保护、抗炎、抗氧化等领域, 具有广阔的应用前景, 尤其在抗肿瘤及神经保护方面。目前, 马齿苋在体内的药物代谢及药物动力学研究鲜有报道, 因此需进一步对其深入研究, 为后期的马齿苋资源开发利用提供科学依据。此外, 有文献报道马齿苋具有一定的肾毒性[67], 因此, 在后期实验中应着重关注马齿苋中哪些化合物在肾脏聚集及是否具有其他的毒性, 为后期的临床研究奠定基础。

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