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黄皮属植物中香豆素成分及其药理活性研究进展

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摘要:本文在前期对黄皮属植物中香豆素成分研究的基础上,结合系统的文献调研,对芸香科黄皮属植物中香豆素成分结构类型、检测、提取分离、结构鉴定及其药理活性的研究进展进行了归纳和总结。

关键词:芸香科;黄皮属;香豆素

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Research Progress on Coumarins from *Clausena* and Their Pharmacological Activities

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Abstract:On basis of preliminary studies and literature research about coumarins from *Clausena* and their pharmacological activities, the structures, detection, isolation, structural elucidation and pharmacological activities of coumarins from *Clausena* (Rutaceae) are reviewed in this paper.

Key words:Rutaceae; *Clausena*; coumarins

黄皮属(*Clausena*)为芸香科(Rutaceae)植物,全世界约有25种,我国约有13种,主要分布于西南及华南各省区,云南有11种^[1]。该属药用植物在我国自古供药用,古代本草及现代中药书籍中多有记载,民间应用更为广泛。该属植物化学成分极为丰富,主要包括呋喃生物碱、香豆素、倍半萜、苯环衍生物、四降三萜和黄酮等。香豆素为本属植物的主要成分,其结构类型多样,包括单萜基取代、异戊烯基取代、呋喃、吡喃、二氧六环、二聚体等。目前,已从黄皮属10余种植物中分离鉴定了141种香豆素成分。

据文献报道,黄皮属香豆素具有广泛的药理活性,主要表现在抗肿瘤、降血糖、抗菌等方面。为了进一步对该属植物中香豆素成分及其药理活性进行研究,本文结合前期对该属植物小叶臭黄皮

(*Clausena excavata*)中香豆素的研究^[2,3],归纳总结了该属植物中香豆素的结构类型、检测、提取分离、结构鉴定及药理活性,以便对该类化合物的深入研究和开发利用作为参考。

1 黄皮属植物的种类及分布

芸香科(Rutaceae)黄皮属(*Clausena*)植物多为乔木或小灌木植物,约25种,分布于印度西北至我国西南至台湾,南至印度尼西亚、大洋洲北部及巴布亚新几内亚、非洲西北部等地。我国约有13种,主要分布于西南及华南各省区,云南有11个种^[1]。

2 黄皮属植物香豆素的结构类型

香豆素是一类具有苯骈α-吡喃酮结构的化合物,可看作顺式邻羟基桂皮酸脱水形成的内酯。香豆素可以分为简单香豆素、呋喃香豆素、吡喃香豆素和取代的α-吡喃酮香豆素等。绝大多数香豆素在C-7位有羟基或烃基取代,具有芳香气味。单萜基取代、呋喃和吡喃香豆素在黄皮属植物中普遍存在,

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且数量及含量相对较高,是黄皮属植物的特征成分。

2.1 单萜基取代香豆素

迄今为止,从黄皮属植物中得到的单萜基取代香豆素绝大多数是在其母核的7位进行取代,个别

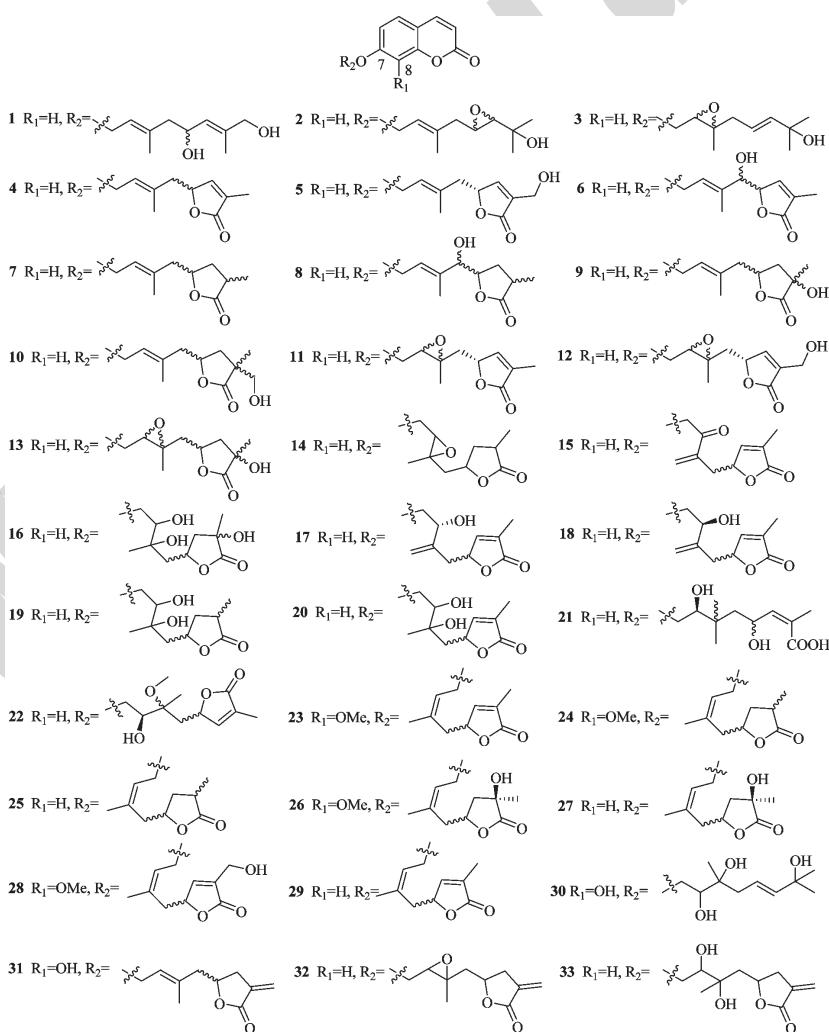
取代在5位。目前已从黄皮属 *Clausenna excavate*、*C. anisata*、*C. suffruticosa*、*C. anisum-olens*、*C. lansium* 等植物中分离得到54种单萜基取代香豆素,其名称、植物来源及文献出处见表1,结构类型见图1。

表1 黄皮属单萜基取代香豆素的名称、植物来源及文献出处

Table 1 Name, plant origin and literature of monoterpenoid substituted coumarins from *Clausena*

| No. | Name | Source | Part | Ref. |
|-----|------------------|---------------------------|------------------|--------|
| 1 | Excavatin A | <i>Clausenna excavate</i> | leaves | [4] |
| 2 | Excavatin B | <i>C. excavate</i> | leaves | [4] |
| 3 | Excavatin C | <i>C. excavate</i> | leaves | [4] |
| 4 | Excavatin D | <i>C. excavate</i> | leaves | [3,4] |
| 5 | Excavatin E | <i>C. excavate</i> | leaves | [3,4] |
| 6 | Excavatin F | <i>C. excavate</i> | leaves | [4] |
| 7 | Excavatin G | <i>C. excavate</i> | leaves | [3,4] |
| 8 | Excavatin H | <i>C. excavate</i> | leaves | [4] |
| 9 | Excavatin I | <i>C. excavate</i> | leaves | [4] |
| 10 | Excavatin J | <i>C. excavate</i> | leaves | [4] |
| 11 | Excavatin K | <i>C. excavate</i> | leaves | [3,4] |
| 12 | Excavatin L | <i>C. excavate</i> | leaves | [3,4] |
| 13 | Excavatin M | <i>C. excavate</i> | leaves | [4] |
| 14 | Excavacoumarin A | <i>C. excavate</i> | leaves | [3,5] |
| 15 | Excavacoumarin B | <i>C. excavate</i> | leaves | [3,6] |
| 16 | Excavacoumarin C | <i>C. excavate</i> | aerial part | [7] |
| 17 | Excavacoumarin D | <i>C. excavate</i> | aerial part | [7] |
| 18 | Excavacoumarin E | <i>C. excavate</i> | aerial part | [7] |
| 19 | Excavacoumarin F | <i>C. excavate</i> | aerial part | [7] |
| 20 | Excavacoumarin G | <i>C. excavate</i> | aerial part | [7] |
| 21 | Excavacoumarin H | <i>C. excavate</i> | aerial part | [7] |
| 22 | Excavacoumarin I | <i>C. excavate</i> | aerial part | [8] |
| 23 | Clauslactone K | <i>C. excavate</i> | leaves and twigs | [9] |
| 24 | Clauslactone L | <i>C. excavate</i> | leaves and twigs | [9] |
| 25 | Clauslactone M | <i>C. excavate</i> | leaves and twigs | [9] |
| 26 | Clauslactone N | <i>C. excavate</i> | leaves and twigs | [10] |
| 27 | Clauslactone O | <i>C. excavate</i> | leaves and twigs | [10] |
| 28 | Clauslactone P | <i>C. excavate</i> | leaves and twigs | [10] |
| 29 | Clauslactone Q | <i>C. excavate</i> | leaves and twigs | [10] |
| 30 | Clausenaexcavin | <i>C. excavate</i> | fruits | [11] |
| 31 | Clauslactone E | <i>C. excavate</i> | leaves | [3,12] |
| 32 | Clauslactone F | <i>C. excavate</i> | leaves | [12] |
| 33 | Clauslactone G | <i>C. excavate</i> | leaves | [12] |
| 34 | Clauslactone H | <i>C. excavate</i> | leaves | [12] |
| 35 | Clauslactone I | <i>C. excavate</i> | leaves | [12] |
| 36 | Clauslactone J | <i>C. excavate</i> | leaves | [12] |
| 37 | Clauslactone R | <i>C. excavate</i> | leaves and stems | [13] |
| 38 | Clauslactone S | <i>C. excavate</i> | leaves and stems | [13] |
| 39 | Anisocoumarin J | <i>C. excavate</i> | leaves and stems | [13] |
| 40 | Anisocoumarin H | <i>C. anisata</i> | leaves | [3,14] |

| No. | Name | Source | Part | Ref. |
|-----|--|------------------------|------------------|--------|
| 41 | Anisocoumarin I | <i>C. anisata</i> | Leaves | [14] |
| 42 | Capnolactone | <i>C. anisata</i> | leaves | [14] |
| 43 | 7-[(2'E,6'E)-7- Carboxy-5'(ζ)-hydroxy-3'-methyocta- 2',6'-dienyloxy]-coumarin | <i>C. suffruticosa</i> | leaves | [15] |
| 44 | Hekumarone | <i>C. anisum-olens</i> | leaves and twigs | [16] |
| 45 | Anisumarin | <i>C. anisum-olens</i> | leaves and twigs | [17] |
| 46 | Aurapten | <i>C. anisum-olens</i> | leaves and twigs | [17] |
| 47 | 7[(E)-7'-Hydroxy-3',7'-dimethyocta- 2',5'-dienyloxy]-coumarin | <i>C. anisum-olens</i> | leaves and twigs | [3,17] |
| 48 | Excavarin A | <i>C. excavate</i> | leaves | [3,18] |
| 49 | Anisucumarin A | <i>C. anisum-olens</i> | leaves and twigs | [19] |
| 50 | Anisucumarin B | <i>C. anisum-olens</i> | leaves and twigs | [19] |
| 51 | Hekumarin A | <i>C. anisum-olens</i> | leaves and twigs | [20] |
| 52 | Hekumarin B | <i>C. anisum-olens</i> | leaves and twigs | [20] |
| 53 | Clausenalansim B | <i>C. lansium</i> | twigs | [21] |
| 54 | 5-Geranyloxy-7-hydroxycoumarin | <i>C. excavate</i> | Leaves and stems | [13] |



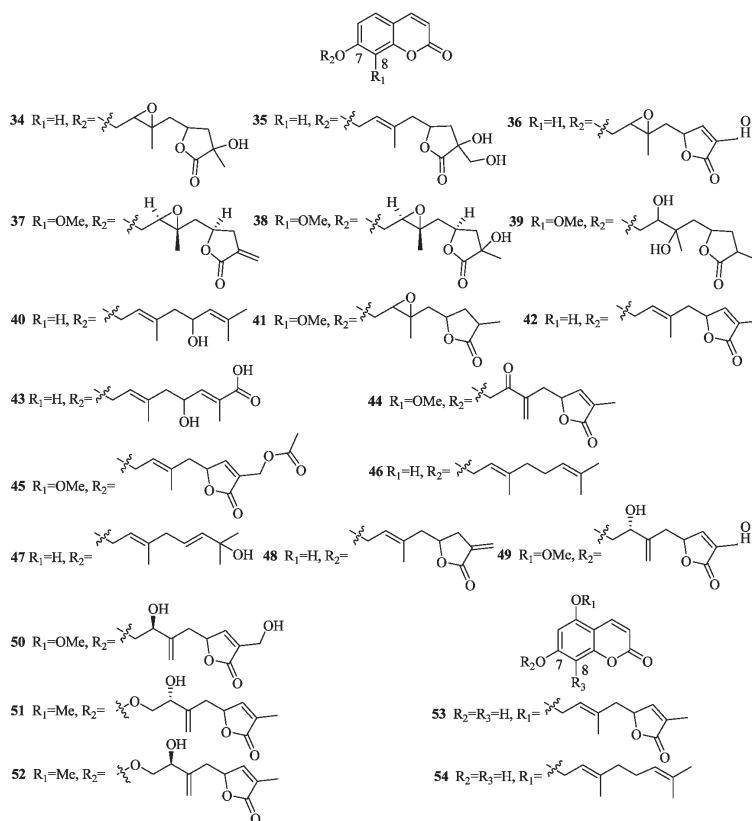


图 1 单萜基取代香豆素结构类型

Fig. 1 Chemical structures of monoterpene substituted coumarins

2.2 异戊烯基取代香豆素

异戊烯基取代香豆素是黄皮属植物中仅次于单萜基取代的简单香豆素,目前已从该属 *C. excavata*、

C. anisata、*C. lansium*、*C. indica* 等植物中分离得到 17 种异戊烯基取代的香豆素,其名称、植物来源及文献出处见表 2,结构类型见图 2。

表 2 黄皮属异戊烯基取代香豆素的名称、植物来源及文献出处

Table 2 Name, plant origin, and literature of iso-substituted coumarins from *Clausena*

| No. | Name | Source | Part | Ref. |
|-----|----------------------------|--------------------|----------------------|------|
| 55 | Anisocoumarin E | <i>C. anisata</i> | leaves | [14] |
| 56 | Anisocoumarin F | <i>C. anisata</i> | leaves | [14] |
| 57 | Anisocoumarin G | <i>C. anisata</i> | leaves | [14] |
| 58 | Triphasiol | <i>C. anisata</i> | leaves | [14] |
| 59 | Isoponcimarín | <i>C. anisata</i> | leaves | [14] |
| 60 | Isomeranzin | <i>C. anisata</i> | fruits | [30] |
| 61 | Auraptenol | <i>C. anisata</i> | fruits | [30] |
| 62 | Osthol | <i>C. excavata</i> | root barks | [22] |
| 63 | Gravelliferone | <i>C. lansium</i> | root barks | [34] |
| 64 | Angustifolin | <i>C. lansium</i> | root barks | [34] |
| 65 | Graveliferone methyl ether | <i>C. anisata</i> | Stem barks and roots | [25] |
| 66 | Swietenocoumarin I | <i>C. anisata</i> | Stem barks and roots | [25] |
| 67 | Aniisocoumarin A | <i>C. anisata</i> | Stem barks and roots | [25] |
| 68 | Cedrellopsin | <i>C. excavata</i> | root barks | [22] |
| 69 | 6,8-Diprenylumbelliferone | <i>C. indica</i> | leaves | [23] |
| 70 | Coumarrayin | <i>C. anisata</i> | root barks | [24] |
| 71 | Anisocoumarin B | <i>C. anisata</i> | stem barks and roots | [25] |

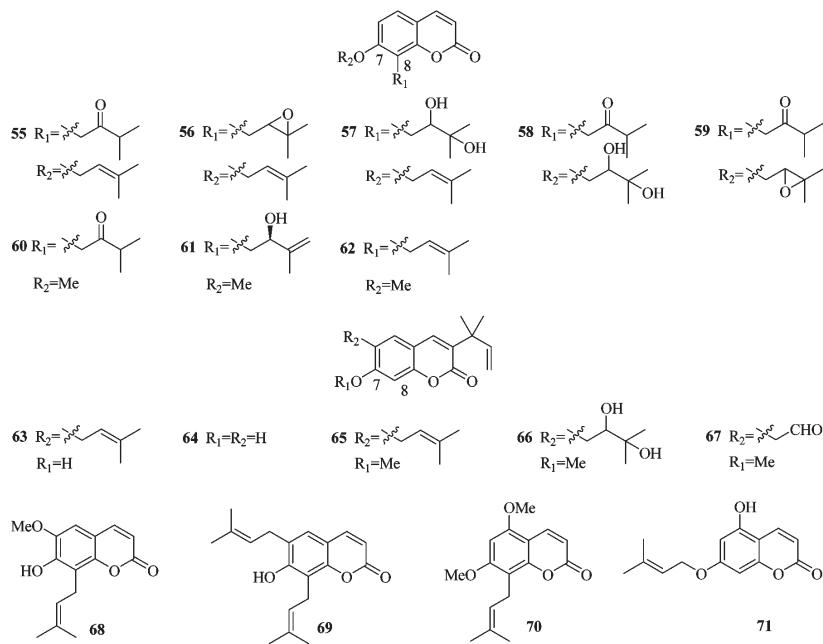


图 2 异戊烯基取代香豆素结构类型

Fig. 2 Chemical structures of iso-substitutedcoumarins

2.3 其他取代基取代的香豆素

黄皮属植物中的简单取代香豆素除了单萜基取代和异戊烯基取代以外,还从 *C. excavate*、*C. lansi-*

um、*C. vestita* 等植物中分离鉴定了 5 种其它取代基取代的香豆素,它们的名称、植物来源及文献出处见表 3,结构类型见图 3。

表 3 黄皮属植物中其他取代基取代的香豆素的名称、植物来源及文献出处

Table 3 Name, plant origin, and literature of other substitutedcoumarins from *Clausena*

| No. | Name | Source | Part | Ref. |
|-----|------------------|--------------------|--------------|---------|
| 72 | Umbelliferone | <i>C. excavate</i> | leaves | [4] |
| 73 | Isoscopoletin | <i>C. lansium</i> | twigs | [21] |
| 74 | Scopoletin | <i>C. excavate</i> | fruits | [11,25] |
| 75 | Clauslactone U | <i>C. vestita</i> | whole plants | [26] |
| 76 | 3-Benzylcoumarin | <i>C. lansium</i> | Stem barks | [27] |

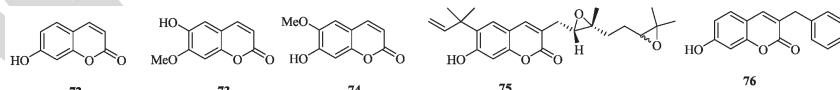


图 3 其他取代基取代的香豆素结构类型

Fig. 3 Chemical structures of other substitutedcoumarins

2.4 呋喃香豆素

呋喃香豆素在黄皮属植物中普遍存在,已从 *C. lansium*、*C. anisata*、*C. lansium*、*C. indica*、*C. dunniana* 等植物中分离得到 29 种,其名称、植物来源及文献出处见表 4,结构类型见图 4。

2.5 吡喃香豆素

吡喃香豆素是黄皮属植物中另一大类普遍存在的香豆素,其结构类型较为丰富,已从 *C. excavate*、*C. indica*、*C. anisata*、*C. pentaphylla*、*C. heptaphylla* 等植物中共分离鉴定 24 种,其名称、植物来源及文献出处见表 5,结构类型见图 5。

表 4 黄皮属植物中呋喃香豆素的名称、植物来源及文献出处

Table 4 Name, plant origin, and literature of furan coumarins from *Clausena*

| No. | Name | Source | Part | Ref. |
|-----|---|--------------------|----------------------|------|
| 77 | Wampetin | <i>C. lansium</i> | leaves | [28] |
| 78 | Indicolactone | <i>C. lansium</i> | root barks | [28] |
| 79 | Indicolactonediol | <i>C. lansium</i> | twigs | [21] |
| 80 | Lansiumarn A | <i>C. lansium</i> | branches | [29] |
| 81 | (E)-8-(6-Hydroperoxy-3,7-dimethylocta-2,7-dienyloxy) psoralen | <i>C. lansium</i> | branches | [29] |
| 82 | Lansiumarin C | <i>C. lansium</i> | branches | [29] |
| 83 | Lansiumarin B | <i>C. lansium</i> | branches | [29] |
| 84 | (E,E)-8-(7-Hydroperoxy-3,7-dimethylocta-2,5-dienyloxy) psoralen | <i>C. lansium</i> | branches | [29] |
| 85 | 8-Geranoxypsoralen | <i>C. lansium</i> | branches | [29] |
| 86 | Clausenalansimin A | <i>C. lansium</i> | twigs | [21] |
| 87 | Imperatorin | <i>C. lansium</i> | stems | [21] |
| 88 | Heraclenin | <i>C. lansium</i> | twigs | [21] |
| 89 | Heraclenol | <i>C. lansium</i> | twigs | [21] |
| 90 | Isogosferol | <i>C. lansium</i> | fruits | [30] |
| 91 | Xanthotoxol | <i>C. lansium</i> | twigs | [21] |
| 92 | Xanthotoxin | <i>C. lansium</i> | fruits | [31] |
| 93 | Anisolactone | <i>C. lansium</i> | leaves | [31] |
| 94 | 2'',3''-Epoxyanisolactone | <i>C. lansium</i> | leaves | [31] |
| 95 | Isoimperatorin | <i>C. anisata</i> | fruits | [30] |
| 96 | Phellopterin | <i>C. lansium</i> | stems | [32] |
| 97 | 5-Hydroxy-8-(3'-methyl-2'-butenyl) furocoumarin | <i>C. lansium</i> | stems | [33] |
| 98 | Bergapten | <i>C. anisata</i> | fruits | [30] |
| 99 | Bergaptol | <i>C. anisata</i> | aerial part | [34] |
| 100 | Chalepensin | <i>C. lansium</i> | root barks | [35] |
| 101 | Clausindine | <i>C. indica</i> | roots | [35] |
| 102 | Chalepin | <i>C. lansium</i> | root barks | [34] |
| 103 | Anisocoumarin C | <i>C. anisata</i> | stem barks and roots | [14] |
| 104 | Anisocoumarin D | <i>C. anisata</i> | stem barks and roots | [14] |
| 105 | Marmesin | <i>C. dunniana</i> | aerial part | [36] |

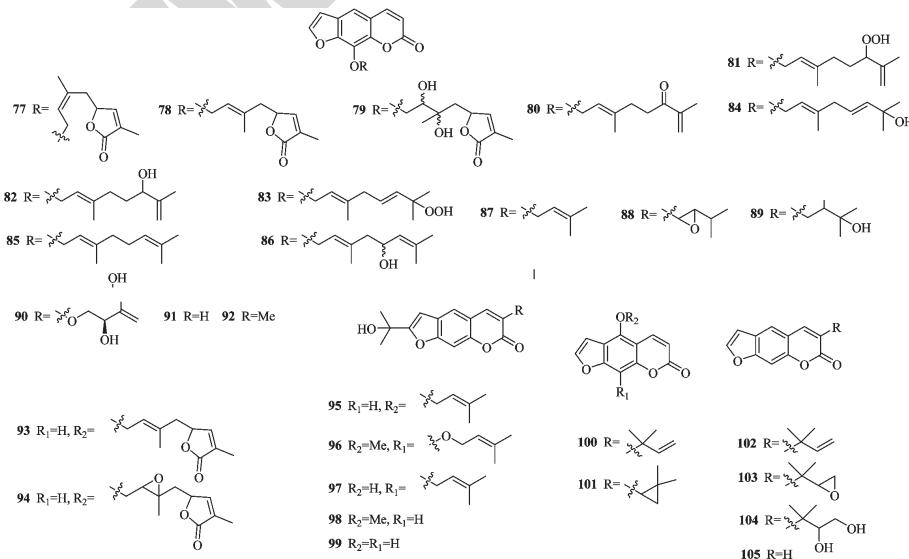


图 4 呋喃香豆素结构类型

Fig. 4 Chemical structure of furan coumarins

表 5 黄皮属植物中吡喃香豆素的名称、植物来源及文献出处

Table 5 Name, plant origin, and literature of pyrancoumarins from *Clausena*

| No. | Name | Source | Part | Ref. |
|-----|--|-----------------------|-------------|--------|
| 106 | Clausenidin | <i>C. excavate</i> | root barks | [22] |
| 107 | Claucavatin A | <i>C. excavate</i> | root barks | [22] |
| 108 | O-Methylated clausenidin | <i>C. excavate</i> | rhizomes | [37] |
| 109 | Clausenin | <i>C. indica</i> | leaves | [2,23] |
| 110 | Kinocoumarin | <i>C. excavate</i> | root barks | [22] |
| 111 | Clausarin | <i>C. excavate</i> | root barks | [2,22] |
| 112 | Clausenidin | <i>C. excavate</i> | root barks | [2,22] |
| 113 | Xanthoxyletin | <i>C. excavate</i> | root barks | [22] |
| 114 | Xanthyletin | <i>C. excavate</i> | root barks | [2,22] |
| 115 | Dentatin | <i>C. excavate</i> | root barks | [2,37] |
| 116 | 3-(1,1-Dimethylallyl)-xanthyletin | <i>C. anisata</i> | root barks | [24] |
| 117 | Clausmarin B | <i>C. excavate</i> | root barks | [22] |
| 118 | Clausmarin A | <i>C. pentaphylla</i> | aerial part | [38] |
| 119 | Clausmarin B | <i>C. pentaphylla</i> | aerial part | [38] |
| 120 | Clausmarin C | <i>C. pentaphylla</i> | aerial part | [38] |
| 121 | Lunamarin A | <i>C. heptaphylla</i> | leaves | [38] |
| 122 | Lunamarin B | <i>C. heptaphylla</i> | leaves | [39] |
| 123 | Lunamarin C | <i>C. heptaphylla</i> | leaves | [40] |
| 124 | Seselin | <i>C. excavate</i> | fruits | [11] |
| 125 | Clauexcavatin A | <i>C. excavate</i> | roots | [2] |
| 126 | Clauexcavatin B | <i>C. excavate</i> | roots | [2] |
| 127 | Citrusarin A | <i>C. excavate</i> | roots | [2] |
| 128 | 2H,8H-Benzo[1,2-b;3,4-b']dipyran-8-one | <i>C. excavate</i> | roots | [2] |
| 129 | Nordentatin | <i>C. excavate</i> | roots | [2] |

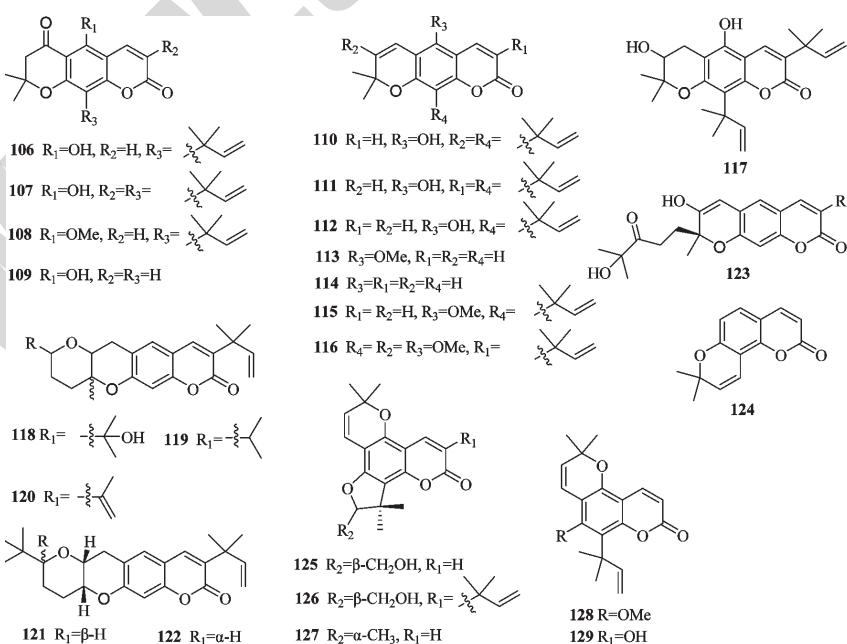


图 5 吡喃香豆素结构类型

Fig. 5 Chemical structure of pyrancoumarins

2.6 二氧六环香豆素

二氧六环香豆素在黄皮属植物中较为罕见,主要是香豆素母核的7、8位形成二氧六环,目前仅

从*C. excavata*植物中得到6种该类型香豆素,其名称、植物来源及文献出处见表6,结构类型见图6。

表6 黄皮属植物中二氧六环香豆素的名称、植物来源及文献出处

Table 6 Name, plant origin, and literature of dioxanecoumarins from *Clausena*

| No. | Name | Source | Part | Ref. |
|-----|-------------------|--------------------|------------------|------|
| 130 | Clauslactone A | <i>C. excavata</i> | leaves | [12] |
| 131 | Clauslactone B | <i>C. excavata</i> | leaves | [12] |
| 132 | Clauslactone C | <i>C. excavata</i> | leaves | [12] |
| 133 | Clauslactone D | <i>C. excavata</i> | leaves | [12] |
| 134 | Clauslactone T | <i>C. excavata</i> | leaves and stems | [13] |
| 135 | Murrayacoumarin C | <i>C. excavata</i> | leaves and stems | [13] |

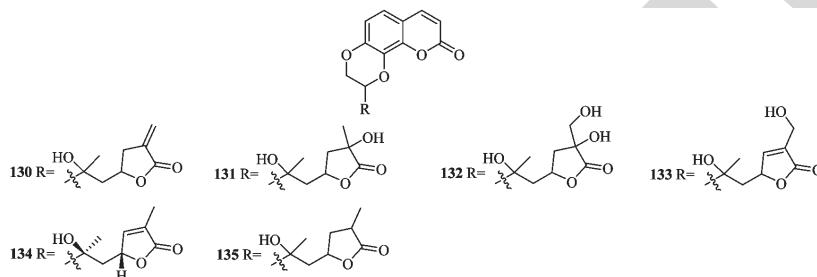


图6 二氧六环香豆素结构类型

Fig. 6 Chemical structures of dioxanecoumarins

2.7 二聚体香豆素

二聚体香豆素在黄皮属植物中也较为罕见,目前共从*C. excavata*和*C. lenis*两种植物中得到6种

该类成分。其名称、植物来源及文献出处见表7,结构类型见图7。

表7 黄皮属植物中二聚体香豆素的名称、植物来源及文献出处

Table 7 Name, plant origin, and literature of dipolymercoumarins from *Clausena*

| No. | Name | Source | Part | Ref. |
|-----|----------------|--------------------|---------------------------|------|
| 136 | Carbazomarin A | <i>C. excavata</i> | stem barks and root barks | [41] |
| 137 | Cladimarin A | <i>C. excavata</i> | branches | [42] |
| 138 | Cladimarin B | <i>C. excavata</i> | branches | [42] |
| 139 | Diseselin A | <i>C. lenis</i> | Aerial parts | [43] |
| 140 | Diseselin B | <i>C. lenis</i> | Aerial parts | [44] |
| 141 | Binorponcitrin | <i>C. excavata</i> | roots | [45] |

3 7位单萜基取代香豆素的检测、提取分离和结构解析

香豆素为黄皮属植物的主要成分,其结构类型较为丰富,其中7位单萜基取代香豆素在该属植物中普遍存在,并且含量较高。因此,有必要对该类成

分的检测、提取分离及结构鉴定加以归纳总结,为今后对该类成分的深入研究提供参考。

3.1 7位单萜基取代香豆素的检测

7位单萜取代基香豆素在紫外灯365 nm下有很强的蓝色荧光,5% H₂SO₄-无水乙醇加热显粉红色或灰色。

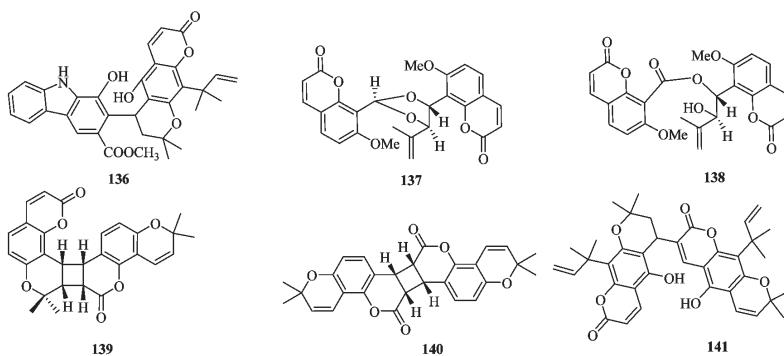


图 7 二聚体香豆素结构类型

Fig. 7 Chemical structure of dipolymercoumarins

3.2 7位单萜基取代香豆素的提取分离

香豆素的提取多以甲醇或丙酮浸渍提取开始,本研究组以甲醇热回流提取,总提取物经乙酸乙酯萃取后通过硅胶柱层析(石油醚-丙酮系统),再经反相柱层析 RP-18(甲醇-水系统),最后经 HPLC(检测波长为 205、254、365 nm)(甲醇-水系统)分离得到 7 位单萜基取代香豆素类化合物。

3.3 7位单萜基取代香豆素的结构解析

¹H NMR 谱中,在低场区有特征的 3、4 位质子信号峰($\delta_H \sim 6.2, \sim 7.8, J \sim 9.6$ Hz)。5、6、8 位质子形成特征的 ABX 偶合系统,三个质子信号峰在 $\delta_H 6.80 \sim 7.60$,偶合常数约为 8.5、2.4 Hz。在¹³C NMR 谱中,低场区(170 ~ 180 ppm)有一个季碳信号峰,通常为单萜基上五元内酯环的羰基碳信号峰,在 100 ~ 165 ppm 显示 9 个香豆素母核特征信号峰,有时在该区域多出 2 个或 4 个峰,通常为单萜基链上双键的信号峰。高场区 0 ~ 80 ppm 常出现 9 个、7 个或 5 个信号峰,通常为不含双键的单萜、含一个双键的单萜或含两个双键的单萜基团峰。

4 黄皮属植物香豆素的药理活性

黄皮属植物在我国民间常用于治疗上感、疟疾、腹痛及胃炎等症状,其粗提物具有广泛的药理活性。香豆素是该属植物的主要成分,也是其生物活性的主要物质基础。

4.1 抗肿瘤活性

据研究报道,从黄皮(*Clausena lansium*)中分离得到的香豆素(Xanthotoxol)对人宫颈癌细胞株 HeLa (IC_{50} 值为 0.013 $\mu\text{g}/\text{mL}$)、肝细胞株 HepG-2 (IC_{50} 值

为 0.34 $\mu\text{g}/\text{mL}$)和肺腺癌细胞株 A-549 (IC_{50} 值为 28.2 $\mu\text{g}/\text{mL}$)具有很强的抑制活性^[46]。彭文文等^[3]研究发现,单萜基香豆素(Excavarin A)对 HeLa 和 A549 均有细胞毒活性(IC_{50} 值分别为 11.26 和 13.55 mg/L),单萜基香豆素(Excavatin G)对 BGC-823 有细胞毒活性(IC_{50} 值为 16.65 mg/L)。Appendino G 等^[47]研究发现,欧前胡素(imperatorin)具有细胞毒活性(IC_{50} 值为 25 $\mu\text{g}/\text{mL}$),且仅对生长细胞有凋亡作用,其作用于细胞周期中的 G1/S 转化期。

4.2 降血糖作用

Shen ZF 等^[48]研究了从黄皮叶中分离得到的香豆素(Indicolactone)能降低正常小鼠和四氧嘧啶高血糖小鼠的血糖,也能对抗肾上腺素的升血糖作用,但对血乳酸的浓度无影响,因此,认为黄皮香豆素的降血糖作用既不同于双胍类,也不同于磺酰脲类药物。Zhang R 等^[49]研究发现呋喃香豆素(indicolactone, 2',3'-epoxyanisolactone 和 anisolactone)均具有一定的降血糖活性。

4.3 抑菌作用

Tada Y 等^[50]发现,欧前胡素(imperatorin)对甲氧西林敏感金黄色葡萄球菌、甲氧西林耐药金黄色葡萄球菌、大肠杆菌和铜绿假单胞菌的最小抑制浓度分别为:250、250、250、60.5 $\mu\text{g}/\text{mL}$ 。

5 结语

香豆素类化合物因其具有分子量小、结构类型较为丰富、易于合成、药理作用广泛和毒性小等特点,并且近年来研究表明,香豆素具有广泛的抗肿瘤活性,结构简单易于修饰,是优良的先导化合物,因

此该类型化合物在抗肿瘤药物研发方面展现出良好的应用前景,已成为抗肿瘤药物研发的重要方向之一。

目前,许多结构特异的天然及结构修饰的香豆素,已经被证实在体内和体外具有确切的抗肿瘤活性。香豆素类化合物本身还具有一般抗肿瘤药物不具有的化学预防和保护作用,且在体内具有低毒性,因此该类化合物在开发抗肿瘤药物方面具有优良的应用前景。但是由于香豆素类化合物活性广泛,抗肿瘤作用机制不明确,构效关系的研究还不够全面和深入,因此在发现具有抗肿瘤活性天然香豆素的基础上,进一步进行结构修饰,研究该类化合物的抗肿瘤机制和构效关系成为今后研究的方向。

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