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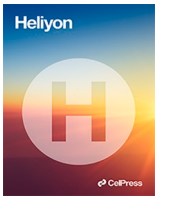

Review article

Research progress on the chemical components and pharmacological effects of *Physalis alkekengi* L. var. *franchetii* (Mast.) Makino

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ABSTRACT

Physalis Calyx seu Fructus is the dry calyx or the calyx with fruit of the Solanaceae plant *Physalis alkekengi* L. var. *franchetii* (Mast.) Makino, with a long history of use in medicine and food. However, despite its many potential therapeutic and culinary applications, *P. alkekengi* is not being exploited for these applications on a large scale. This study analysed various research related to the different chemical components of *P. alkekengi*, including steroids, flavonoids, alkaloids, phenylpropanoids, sucrose esters, piperazines, volatile oils, polysaccharides, amino acids, and trace elements. In addition, research related to the pharmacological activities of *P. alkekengi*, including its anti-inflammatory, anti microbial, antioxidative, hypoglycaemic, analgesic, antitumour, and immunomodulatory effects were investigated. Research articles from 1974 to 2023 were obtained from websites such as Google Scholar, Baidu Scholar, and China National Knowledge Infrastructure, and journal databases such as Scopus and PubMed, with the keywords such as *Physalis alkekengi*, components, effects, and activities. This study aims to provide a comprehensive understanding of the progress of phytochemical and pharmacological research on the phytochemical and pharmacological aspects of *P. alkekengi* and a reference for the better exploitation of *P. alkekengi* in the food and pharmaceutical industries.

Abbreviations: SOD, Superoxide dismutase; CAT, Catalase; GSH-Px, Glutathione peroxidase; COX-2, Cyclooxygenase; 5-LOX, 5-Lipoxygenase; PLA2, Phospholipase A2; PGE2, Prostaglandin E2; LTB4, Leukotriene B4; IL, Interleukin; LPS, Lipopolysaccharide; Akt, also known as; PKB, Protein kinase B; MAPK, Mitogen-activated protein kinase; NF-κB, Nuclear factor kappa-B; iNOS, Inducible nitric oxide synthase; NO, Nitric oxide; TNF-α, Tumor necrosis factor-α; MCP-1, Monocyte chemotactic protein-1; IκB-α, Inhibitor of NF-κB; NAFLD, Nonalcoholic fatty liver disease; MDA, Malondialdehyde; DPPH, 2,2-Diphenyl-1-picrylhydrazyl; OH, Hydroxyl radical; ABTS, 2,2-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); O2-, Superoxide anion; NaNO2, Sodium nitrite; KEAP1, Kelch-like ECH-associated protein 1; NRF2, Nuclear factor-erythroid 2-related factor 2; STZ, Streptozotocin; GLUT4, Glucose transporter 4; PI3K, Phosphatidylinositol-3-kinase; InsR, Insulin receptor; GK, Glucokinase; GLUT2, Glucose transporter 2; PK, Pyruvate kinase; PEPCK, Phosphoenolpyruvate carboxykinase; LTA4H, Leukotriene A-4 hydrolase; IgG, Immunoglobulin G; IgG1, Immunoglobulin G1; IgG2b, Immunoglobulin G2b; STAT3, Signal transducers and activators of transcription 3; ROS, Reactive oxygen species; JAK2, Janus kinase 2; CDK1, Cycle protein-dependent kinase 1; PARP, Poly ADP-ribose polymerase; mTOR, Mammalian target of rapamycin; CDK2, Cyclin-dependent kinase 2; MET, Mesenchymal-epithelial transition protein; OVA, Ovalbumin; IFN-γ, Interferon γ; PKC, Protein kinase C.

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1. Introduction

Physalis Calyx seu Fructus, also known as Jin-Deng-Long, is the dried calyx or calyx with fruit of *Physalis alkekengi* L. var. *franchetii* (Mast.) Makino, which is a perennial herb in the Solanaceae family. It is widely distributed in Europe and Asia, including Korea and Japan, and is also cultivated in North America. In China, it is cultivated mainly in the northeast, northwest, and Inner Mongolia, with more widespread cultivation and wild growth in the northeast [1,2].

Physalis alkekengi has been used in medicine for nearly two thousand years and has been recorded in many herbal books throughout the ages, with a wide range of functions and applications. It was first recorded in *Erya* [3], one of the earliest dictionaries in China, and was annotated by Guo Pu. The earliest publication on traditional Chinese medicine, *Shen Nong Ben Cao Jing* [4] of the Han Dynasty, records that *P. alkekengi* has flat nature and sour flavour, and is used to treat fever and fullness, calm the mind and invigorate the vital energy, facilitate the flow of water, and alleviate pain during childbirth. Li Shizhen of the Ming dynasty recorded in *Compendium of Materia Medica* [5] that its seedlings, leaves, roots, and stems have bitter flavour and cold nature, and are non-toxic, and are used to relieve heat and fullness, calm the mind, improve vitality, and aid diuresis. According to *Shen Nong Ben Cao Jing*, the juice of *P. alkekengi* is effective in treating jaundice. Additionally, *P. alkekengi* has been used to treat sore throat, hoarse voice, cough with phlegm, aspergillosis, and eczema [6].

At present, more than 530 compounds have been isolated from *P. alkekengi*, mainly including steroids, flavonoids, alkaloids, phenylpropanoids, sucrose esters, piperazines, volatile oils, polysaccharides, various amino acids, and trace elements [7–10]. Modern pharmacological studies have shown that *P. alkekengi* has anti-inflammatory, anti microbial, antioxidative, hypoglycaemic, analgesic, anti-tumour, and immune regulating effects and is of great nutritional and medicinal value. However, despite its many potential therapeutic and culinary applications, *P. alkekengi* is not being exploited for these applications on a large scale. In order to further exploit and utilize this natural resource, data relating to the chemical composition and pharmacological research of *P. alkekengi* from 1974 to 2023 were obtained using websites, such as Google Scholar, Baidu Scholar, and China National Knowledge Infrastructure, and

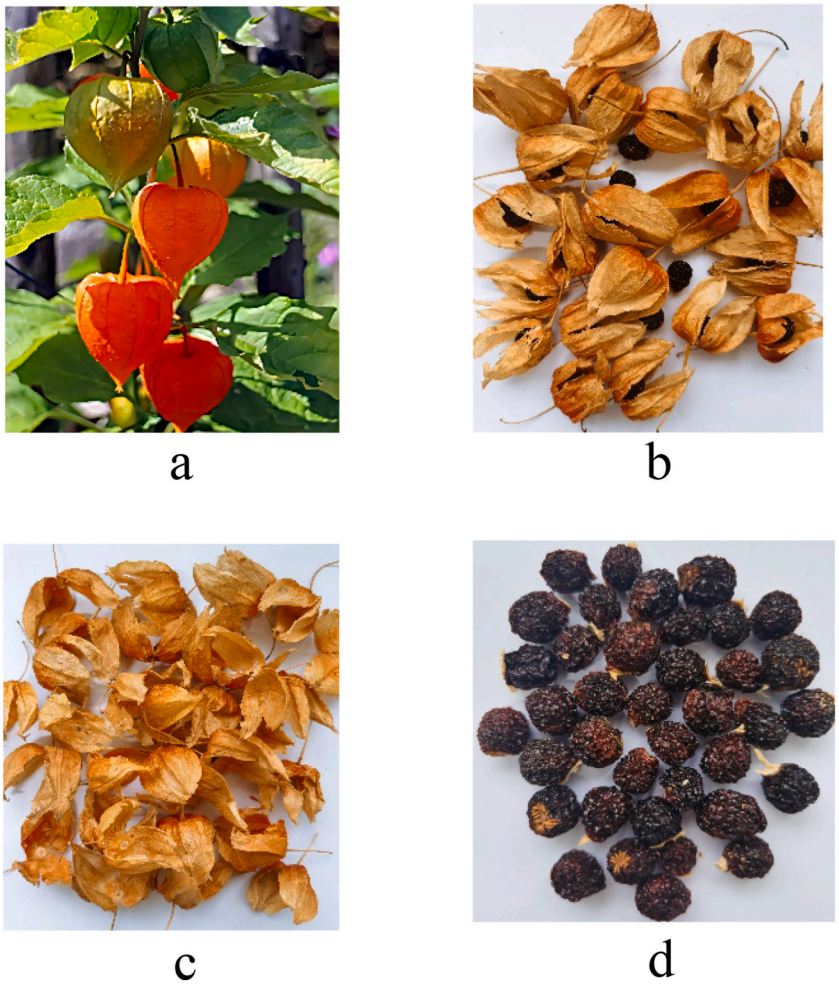

Fig. 1. Images of *P. alkekengi*. (a) The whole plant; (b) Dried calyxes with fruits; (c) Dried calyxes; (d) Dried fruits.

journal databases, such as Scopus and PubMed, with the keywords such as Physalis alkekengi, components, effects, and activities, in an attempt to comprehensively review the chemical composition and pharmacological research progress of *P. alkekengi*.

2. Botanical origin

A botanical map of *P. alkekengi* L. var. *franchetii* (Mast.) Makino and pictures of dried calyxes and fruits are shown in Fig. 1(a–d). The stems are sparsely branched or unbranched, and the nodes are sometimes dilated and often pubescent, especially the younger parts. The leaves vary in shape from long-ovate to broadly ovate and sometimes rhombic-ovate, are between 5 and 15 cm long and 2–8 cm wide, apically acuminate, and have bases that are asymmetrically and narrowly cuneate. Their margins are either complete and undulate or are coarsely toothed, and both surfaces are pilose, with greater density along the nerves. Petioles are between 1 and 3 cm long. Pedicels are between 0.6 and 1.6 cm long, erect when flowering, but curve downwards in maturity, and are densely pilose but not deciduous. Calyxes are broadly campanulate, approximately 0.6 cm in length, densely pilose, with triangular teeth and hirsute margins. It has a white, rotate corolla, between 1.5 and 2 cm in diameter, with broad and short lobes spreading apically, which abruptly narrows into a triangular spike; the exterior is pubescent, and the margin is ciliate. The stamens and style are both shorter than the corolla. The fruiting pedicel is 2–3 cm long and persistently pilose. The fruiting calyx is ovate, 2.5–4 cm long and 2–3.5 cm wide, thinly leathery, and conspicuously reticulate, with 10 longitudinal ribs. It is orange or fiery red in colour, persistently pilose, apically closed, and the base is depressed. The soft, juicy berries are globose, orange-red in colour, and 1–1.5 cm in diameter. Finally, the seeds are reniform, yellowish in colour, and approximately 0.2 cm in length [2,11,12].

3. Chemical components

Among the 530 chemical constituents isolated from *P. alkekengi*, steroids and flavonoids are the main active ingredients. The composition percentages of each compound type in *P. alkekengi* are shown in Fig. 2, and the compound information is summarised in Table 1.

3.1. Steroids

Steroids are the main components of *P. alkekengi*. A total of 164 steroids have been isolated and identified from the calyx, fruit, and above-ground parts of *P. alkekengi*, accounting for 30.65% of the total compound types. These include physalins, neophysalins, sterols, and withanolides, among which physalins are the most abundant. The study of physalins in *P. alkekengi* began in 1969 with the isolation and identification of physalin A by Japanese scholars, and since then several physalins compounds have been identified. Phylasins are a class of steroidal compounds with a bitter taste [8]. The basic structure of physalins consists of a 13,14-seco-16, 24-cycloergostane skeleton. Neophysalins were first discovered by Japanese scholars in 1991 [13]. The difference between neophysalins and physalins is that the C-15 of physalins is directly linked to C-16, and C-14 forms a lactone ring with C-17, whereas the C-14 of neophysalins is directly linked to C-16, and C-15 forms a lactone ring with C-17 [8].

Sterols are mainly found in the fruit, seeds, and calyx of *P. alkekengi* [14]. At present, physanol A and physanol B have been isolated from the fruits of *P. alkekengi*, and a variety of 4α-methyl sterols, mainly gramisterol and obtusifoliol, have been isolated from the unsaponifiables of the seed oil, in addition to a variety of 4-desmethyl sterols [10]. Withanolides are a class of ergostane lactones containing 28 carbon atoms derived from the ergostane backbone and characterised by the formation of δ- or γ-lactones by linking the C-22 to the C-26, or the C-23 to the C-26 in the side chain [15]. Specific information on the steroids in *P. alkekengi* is given in Table 1.

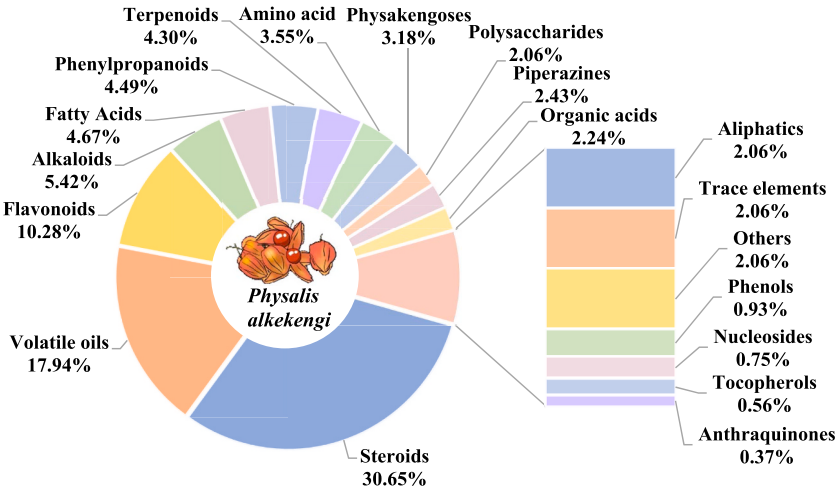

Fig. 2. Proportion of compound types isolated from *P. alkekengi*.

Table 1
Compounds in *Physalis alkekengi*.

NO.	Compound	Molecular Formula	Origin Parts	Reference
Steroids				
1	Physalin A	$C_{28}H_{30}O_{10}$	Stems, Leaves	[7,8,10,15,32]
2	Physalin B	$C_{28}H_{30}O_{9}$	Stems, Leaves	[7,8,10,15,32]
3	Physalin C	$C_{28}H_{30}O_{9}$	Calyxes	[7,8,10,33]
4	Physalin D	$C_{28}H_{32}O_{11}$	Fruits	[7,8,10,34]
5	Physalin D_1	$C_{28}H_{32}O_{11}$	Fruits	[35]
6	Physalin E	$C_{28}H_{32}O_{11}$	Calyxes	[7,10,36]
7	Physalin F	$C_{28}H_{30}O_{10}$	Calyxes	[7,10,26,37]
8	Physalin G	$C_{28}H_{30}O_{10}$	Calyxes	[7,8,10,26]
9	Physalin H	$C_{28}H_{31}ClO_{10}$	Calyxes	[7,10,26]
10	Physalin I	$C_{29}H_{34}O_{11}$	Whole plants	[7,10,38]
11	Physalin J	$C_{28}H_{32}O_{11}$	Stems, Leaves	[7,10,15]
12	Physalin J1	$C_{28}H_{32}O_{11}$	Stems, Leaves	[15]
13	Physalin K	$C_{28}H_{30}O_{11}$	Leaves	[8,10]
14	Physalin L	$C_{28}H_{32}O_{10}$	Whole plants	[7,8,10,39]
15	Physalin M	$C_{28}H_{32}O_{9}$	Whole plants	[7,8,10,39]
16	Physalin N	$C_{28}H_{30}O_{10}$	Fruits, Calyxes	[7,8,10,40]
17	Physalin O	$C_{28}H_{32}O_{10}$	Fruits, Calyxes	[7,8,10,40]
18	Physalin P	$C_{28}H_{30}O_{10}$	Fruits	[41]
19	Physalin Q	$C_{28}H_{30}O_{12}$	Leaves	[7]
20	Physalin QQ	$C_{29}H_{34}O_{10}$	Roots, Stems	[42]
21	Physalin R	$C_{28}H_{30}O_{9}$	Epigeal parts	[7,8,10,32]
22	Physalin S	$C_{28}H_{32}O_{10}$	Epigeal parts	[7,8,10]
23	Physalin T	$C_{28}H_{34}O_{11}$	Calyxes	[7,8,43]
24	Physalin U	$C_{29}H_{34}O_{11}$	Whole plants	[7]
25	Physalin V	$C_{30}H_{34}O_{10}$	Whole plants	[7]
26	Physalin W	$C_{30}H_{36}O_{11}$	Whole plants	[7,8,38]
27	Physalin W′	$C_{28}H_{30}O_{10}$	Aerial parts	[7,8]
28	Physalin X	$C_{28}H_{30}O_{10}$	Roots, Stems	[7,8,42]
29	Physalin X′	$C_{28}H_{30}O_{10}$	Calyxes	[33]
30	Physalin Y	$C_{28}H_{32}O_{10}$	Calyxes	[7,33]
31	Physalin Z	$C_{28}H_{30}O_{10}$	Calyxes	[7,33]
32	Physalin I	$C_{29}H_{34}O_{10}$	Calyxes	[7,33]
33	Physalin II	$C_{29}H_{34}O_{10}$	Calyxes	[7,33]
34	Physalin III	$C_{28}H_{32}O_{12}$	Calyxes	[44]
35	Physalin IV	$C_{28}H_{32}O_{12}$	Calyxes	[44]
36	Physalin V	$C_{28}H_{32}O_{10}$	Calyxes	[45]
37	Physalin VI	$C_{28}H_{32}O_{11}$	Calyxes	[45]
38	Physalin VII	$C_{29}H_{34}O_{11}$	Calyxes	[45]
39	Physalin XIII	$C_{29}H_{32}O_{11}$	Whole plants	[46]
40	Isophysalin I	$C_{29}H_{34}O_{11}$	Calyxes	[45]
41	Isophysalin A	$C_{28}H_{29}O_{10}$	Calyxes	[45]
42	Isophysalin B	$C_{28}H_{30}O_{9}$	Stems, Leaves	[7,8,15,42]
43	Isophysalin G	$C_{28}H_{30}O_{10}$	Calyxes	[7,8,47]
44	Alkekengilin A	$C_{28}H_{28}O_{9}$	Calyxes	[7,8,48]
45	Alkekengilin B	$C_{28}H_{28}O_{9}$	Calyxes	[7,8,48]
46	2,3,25,27-Tetrahydrophysalin A	$C_{28}H_{34}O_{10}$	Calyxes	[33]
47	3-Hydroxyphysalin A	$C_{28}H_{32}O_{11}$	Calyxes	[33]
48	3-Methoxyphysalin A	$C_{29}H_{34}O_{11}$	Calyxes	[33]
49	3-Methoxy-7-hydroxy-6-deoxyphysalin D	$C_{29}H_{36}O_{12}$	Calyxes	[33]
50	3-Methoxy-6,7,9,10-tetradehydrophysalin B	$C_{29}H_{32}O_{10}$	Calyxes	[33]
51	3-*O*-Methylphysalin X	$C_{29}H_{32}O_{10}$	Calyxes	[44]
52	3β-Hydroxy-2-hydrophysalin A	$C_{28}H_{32}O_{11}$	Calyxes	[7,49]
53	3β-ethoxyl-2,3-dihydro-4,7-didehydrophysalin B	$C_{30}H_{34}O_{10}$	Calyxes, Fruits	[50]
54	7α-Hydroxy-5-deoxy-4-dehydrophysalin IX	$C_{28}H_{30}O_{11}$	Fruits, Calyxes	[51]
55	7β-Hydroxyphysalin A	$C_{28}H_{30}O_{10}$	Fruits, Calyxes	[33,40]
56	7β-Hydroxyphysalin L	$C_{28}H_{32}O_{10}$	Calyxes	[26,33,41]
57	7β-Hydroxy-25,27-didehydrophysalin L	$C_{28}H_{30}O_{10}$	Calyxes	[33]
58	7β-Hydroxyphysalin O	$C_{28}H_{32}O_{10}$	Calyxes	[33]
59	7β-Methoxylisophysalin B	$C_{29}H_{32}O_{10}$	Calyxes	[45]
60	7β-Methoxylisophysalin C	$C_{29}H_{32}O_{10}$	Calyxes	[45]
61	7β-Ethoxyl-isophysalin C	$C_{30}H_{34}O_{10}$	Calyxes, Fruits	[50]
62	4,7-Dehydrophysalin B	$C_{28}H_{29}O_{9}$	Calyxes	[45]

(*continued on next page*)

Table 1 (*continued*)

NO.	Compound	Molecular Formula	Origin Parts	Reference
63	4,7-Didehydrophysalin B	$C_{28}H_{28}O_9$	Calyxes, Roots, Stems	[33,36,41,42]
64	4,7-Didehydroneophysalin B	$C_{28}H_{28}O_9$	Calyxes, Fruits	[41]
65	4,7-Didehydro-7-deoxyphysalin A	$C_{28}H_{28}O_9$	Calyxes	[33]
66	4,7-Didehydro-7-deoxyneophysalin A	$C_{28}H_{28}O_9$	Calyxes	[26,33]
67	4,7-Didehydro-7-deoxyneophysalin L	$C_{28}H_{30}O_9$	Calyxes	[7]
68	4-Hydroxy-25,27-dihydroneophysalin A	$C_{28}H_{32}O_{11}$	Calyxes	[33]
69	25,27-Didehydrophysalin L	$C_{28}H_{30}O_{10}$	Calyxes	[26,52]
70	25,27-Dihydro-4,7-didehydro-7-dehydroneophysalin A	$C_{28}H_{30}O_9$	Calyxes	[7,8,10]
71	25,27-Dihydro-4,7-didehydro-7-deoxyphysalin A	$C_{28}H_{30}O_9$	Calyxes	[33]
72	25,27-Dihydro-4,7-didehydro-7-deoxyneophysalin A	$C_{28}H_{30}O_9$	Calyxes	[7,30,36]
73	3α-Methoxy-2,3-dihydro-4,7-didehydrophysalin B	$C_{29}H_{32}O_{10}$	Stems, Leaves	[53]
74	3β-Methoxy-2,3-dihydro-4,7-didehydrophysalin B	$C_{29}H_{32}O_{10}$	Stems, Leaves	[53]
75	5,6α-Epoxy-physalin C	$C_{28}H_{30}O_{10}$	Calyxes	[33]
76	5,6β-Epoxy-physalin C	$C_{28}H_{30}O_{10}$	Calyxes	[33]
77	5-Deoxy-4-dehydrophysalin IX	$C_{28}H_{30}O_{10}$	Fruits, Calyxes	[51]
78	5α-Ethoxy-6β- hydroxy-5,6-dihydrophysalin B	$C_{30}H_{36}O_{11}$	Calyxes, Fruits	[54]
79	5α-hydroxy-7-dehydro-25,27-dihydro-7-deoxyneophysalin A	$C_{28}H_{32}O_{10}$	Calyxes	[49]
80	5α-Hydroxy-25,27-dihydro-4,7-didehydro-7-deoxyneophysalin A	$C_{28}H_{32}O_{10}$	Calyxes	[30,55]
81	5α-Hydroxy-25,27-dihydro-7-dehydro-7-deoxyneophysalin A	$C_{28}H_{32}O_{10}$	Fruits, Calyxes	[56]
82	5α,7α-Dihydroxy-25,27-dihydrophysalin A	$C_{28}H_{34}O_{11}$	Calyxes	[33]
83	5α,7β-Dihydroxy-25,27-dihydrophysalin A	$C_{28}H_{34}O_{11}$	Calyxes	[33]
84	5α,6β-dihydroxy-25,27-dihydro-7-deoxyphysalin A	$C_{28}H_{34}O_{11}$	Calyxes	[49]
85	5α,6β-Dihydroxyphysalin C	$C_{28}H_{32}O_{11}$	Fruits	[29]
86	5α,6β-Dihydroxyphysalin R	$C_{28}H_{32}O_{11}$	Calyxes	[7,49]
87	5β,6β-Dihydroxyphysalin D	$C_{28}H_{32}O_{11}$	Calyxes	[33]
88	6-Hydroxy-4,5-didehydro-7-deoxyphysalin A	$C_{28}H_{30}O_{10}$	Calyxes	[33]
89	6-Hydroxy-25,27-dihydro-4,5-didehydro-7-deoxyphysalin A	$C_{28}H_{32}O_{10}$	Calyxes	[33]
90	16,24-cyclo-13,14-secoergosta-2-ene-18,26-dioic acid-14:17,14:27-diepoxy-11β,13,20,22-tetrahydroxy-5α-methoxy-1,15-dioxo-γ-lactone-δ-lactone	$C_{28}H_{30}O_{12}$	Calyxes	[45]
91	Physagulin A	$C_{30}H_{38}O_7$	Whole plants	[7,10]
92	Physagulin B	$C_{30}H_{39}ClO_7$	Whole plants	[7,10,38]
93	Physagulin D	$C_{34}H_{52}O_{10}$	Whole plants	[7,10]
94	Physagulin J	$C_{30}H_{42}O_8$	Whole plants	[38]
95	Withaphysalin B	$C_{28}H_{36}O_6$	Calyxes	[57]
96	Withaphysalin E	$C_{28}H_{34}O_7$	Calyxes	[7,10]
97	Withaphysalin F	$C_{28}H_{36}O_7$	Calyxes	[7,10]
98	Withaphysalin G	$C_{28}H_{36}O_6$	Calyxes	[7,10]
99	Withaphysalin N	$C_{28}H_{36}O_7$	Calyxes	[57]
100	Withaphysalin U	$C_{30}H_{41}ClO_7$	Calyxes	[57]
101	Withagulatin A	$C_{28}H_{38}O_6$	Roots, Stems	[42]
102	Withanolide A	$C_{28}H_{38}O_6$	Roots, Stems	[7,58]
103	Withangulatin A	$C_{30}H_{38}O_8$	Whole plants	[38]
104	Withaminimin	$C_{30}H_{40}O_8$	Whole plants	[38]
105	Withalkekengin	$C_{30}H_{41}ClO_7$	Whole plants	[38]
106	Physapubescin	$C_{30}H_{42}O_8$	Stems, Leaves	[15]
107	Physapubescin G	$C_{30}H_{42}O_8$	Stems, Leaves	[15]
108	Physapubescin I	$C_{32}H_{44}O_{10}$	Stems, Leaves	[15]
109	Physapubescin K	$C_{31}H_{44}O_8$	Stems, Leaves	[15]
110	Physapubescin M	$C_{27}H_{38}O_7$	Stems, Leaves	[15]
111	Physapubescin N	$C_{28}H_{42}O_8$	Stems, Leaves	[15]
112	Alkekenginin A	$C_{30}H_{42}O_8$	Fruits	[35]
113	Alkekenginin B	$C_{33}H_{54}O_9$	Fruits	[35]
114	Alkekenginin C	$C_{32}H_{46}O_{11}$	Stems, Leaves	[15]
115	Alkekenginin D	$C_{31}H_{46}O_9$	Stems, Leaves	[15]
116	Alkekenginin E	$C_{30}H_{44}O_9$	Stems, Leaves	[15]
117	Alkekenginin F	$C_{31}H_{46}O_9$	Stems, Leaves	[15]
118	26-carbonyl-physapubescin A	$C_{30}H_{48}O_8$	Stems, Leaves	[15]
119	26-ethoxy-physapubescin B	$C_{32}H_{46}O_8$	Stems, Leaves	[15]
120	5-hydroxyl-6-chloro-physapubescin B	$C_{30}H_{43}ClO_8$	Stems, Leaves	[15]
121	Philadelphicalactone A	$C_{28}H_{40}O_7$	Fruits	[59]
122	15-hydroxy-withaphysalin B	$C_{28}H_{36}O_7$	Calyxes	[57]
123	15-hydroxy-withphysalin U	$C_{28}H_{34}O_6$	Calyxes	[57]
124	(17*S*,20*R*,22*R*)-5β,6β-epoxy-18,20-dihydroxy-1-oxowitha-2,24-dienolide	$C_{28}H_{38}O_6$	Calyxes	[57]
125	(17*S*, 20*R*,22*R*)-5β,6β:18,20-diepoxy-15α,18β-dihydroxy-1-oxowitha-24-enolide (18*R* and 18*S*)	$C_{28}H_{38}O_7$	Calyxes	[57]
126	(17*S*,20*R*,22*R*)-5β,6β:18,20-diepoxy-18β-hydroxy-1-oxowitha-24-enolide (18*R* and 18*S*)	$C_{28}H_{38}O_6$	Calyxes	[57]
127	(20*S*.22*R*)-15α-acetoxy-5α-chloro-6β,14β-dihydroxy-1-oxowitha-2,24-dienolide	$C_{30}H_{41}ClO_7$	Whole plants	[60]

(*continued on next page*)

Table 1 (*continued*)

NO.	Compound	Molecular Formula	Origin Parts	Reference
128	(22*R*)-5β,6β:14α,17:14β,26-triepoxy-2α-ethoxy-13,20,22-trihydroxy-1,15-dioxo-16α,24-cyclo-13,14-secoergosta-18,27-dioic acid 18 → 20,27 → 22-dilactone	$C_{30}H_{36}O_{11}$	Whole plants	[60]
129	23-hydroxy-jitosapogenin-3-*O*-β-*D*-glucose-(1 → 4)-β-*D*-galacto side	$C_{39}H_{64}O_{15}$	Fruits	[61]
130	26-*O*-β-*D*-glucopyranosyl-3β,20α,26-triol-25(*R*)-Δ5,22-diene-furosta-3-*O*-α-*L*-rhamnopyranosyl (1 → 2)-[α-*L*-rhamnopyranosyl (1 → 4)]-β-*D*-glucopyranosyl	$C_{51}H_{82}O_{22}$	Fruits	[61]
131	2α,3β-dihydroxy-5α-pregn-16-en-20-one-3-*O*-β-*D*-glucopyranos yl-(1 → 4)-β-*D*-galactopyranoside	$C_{33}H_{52}O_{13}$	Fruits	[61]
132	Physanol A	$C_{36}H_{50}O_4$	Fruits, Seeds	[7,8,10,14,62]
133	Physanol B	$C_{36}H_{52}O_4$	Fruits, Seeds	[7,8,10,14,62]
134	Physalindicanol B	$C_{28}H_{46}O_2$	Calyxes, Fruits	[54]
135	Gramisterol	$C_{29}H_{48}O$	Calyxes, Fruits	[7,10,14,54]
136	Obtusifoliol	$C_{30}H_{50}O$	Calyxes, Fruits	[7,10,14]
137	Saringosterol	$C_{29}H_{48}O_2$	Calyxes	[8]
138	β-Sitosterol	$C_{29}H_{50}O$	Fruits, Calyxes	[30]
139	7-Oxo-β-sitosterol	$C_{29}H_{48}O_2$	Whole plants	[46]
140	7β-Hydroxysitosterol	$C_{29}H_{50}O_2$	Whole plants	[46]
141	Sargassuol A	$C_{27}H_{43}O_3$	Whole plants	[46]
142	Stigmasterol	$C_{29}H_{48}O$	Calyxes	[32]
143	14α-Methyl-5α-β(11) cholesterol	$C_{28}H_{48}O$	Calyxes	[7,8]
144	Cholesterol	$C_{27}H_{46}O$	Calyxes	[7,10]
145	24-Methyl-cholesterol	$C_{28}H_{48}O$	Calyxes	[7]
146	24-Ethyl-cholesterol	$C_{29}H_{50}O$	Calyxes	[10]
147	Cycloartanol	$C_{30}H_{52}O$	Seeds	[7,10]
148	Cycloartenol	$C_{30}H_{50}O$	Seeds	[7,10]
149	Lanost-8-en-3β-ol	$C_{30}H_{52}O$	Seeds	[10]
150	Daucosterol	$C_{35}H_{60}O_6$	Calyxes	[58,63]
151	Isofucosterol	$C_{29}H_{48}O$	Roots, Stems	[7,58]
152	3β,24ξ-Dihydroxy-ergosta-5, 25-dienolide	$C_{28}H_{46}O_2$	Whole plants	[38]
153	Ergosta-5,25-diene-3β, 24ξ-diol	$C_{28}H_{46}O_2$	Calyxes, Fruits	[54]
154	(22*E*)-5α,8α-Epidioxyergosta-6,22-dien-3β-ol	$C_{28}H_{44}O_3$	Calyxes, Fruits	[54]
155	(3β)-3-Hydroxy-26,27-dinorcholest-5-en-24-one	$C_{25}H_{40}O_2$	Calyxes, Fruits	[54]
156	26,27-Dinorcholest-4-ene-3,24-dione	$C_{25}H_{38}O_2$	Calyxes, Fruits	[54]
157	(3β, 22*E*)-3-Hydroxy-26,27-dinorcholesta-5,22-dien-24-one	$C_{25}H_{38}O_2$	Calyxes, Fruits	[54]
158	3β-Hydroxy-(22*E*,24*R*)-ergosta-5,8,22-trien-7-one	$C_{28}H_{42}O_2$	Calyxes, Fruits	[54]
159	3β-Hydroxystigmasta-5,22-dien-7-one	$C_{29}H_{46}O_2$	Whole plants	[46]
160	Stigmasta-5,22-dien-3β,7β-diol	$C_{29}H_{48}O_2$	Whole plants	[46]
161	3β-hydroxy-cholest-5-en-7-one	$C_{27}H_{44}O_2$	Whole plants	[46]
162	(24*R*)-5,28-stigmastadiene-3β,24-diol-7-one	$C_{29}H_{47}O_{10}$	Whole plants	[46]
163	(24*S*)-5,28-stigmastadiene-3β,24-diol-7-one	$C_{29}H_{47}O_{10}$	Whole plants	[46]
164	Gitogenin	$C_{27}H_{44}O_4$	Calyxes, Fruits	[54]
	Flavonoids			
165	Physaflavonol	$C_{17}H_{14}O_8$	Calyxes, Aerial parts	[52]
166	Ombuine	$C_{17}H_{14}O_7$	Calyxes	[7,8,14,20]
167	Luteolin	$C_{15}H_{10}O_6$	Calyxes	[26,63]
168	Cynaroside	$C_{21}H_{20}O_{11}$	Calyxes	[26]
169	Catechin	$C_{15}H_{14}O$	Calyxes	[26]
170	*L*-Epicatechin	$C_{15}H_{14}O_6$	Calyxes	[26]
171	Rutin	$C_{27}H_{30}O_{16}$	Calyxes	[26]
172	Quercetin	$C_{15}H_{10}O_7$	Fruits, Calyxes	[26,40,63]
173	Kaempferide	$C_{16}H_{12}O_6$	Fruits, Calyxes	[40]
174	Kaempferol	$C_{15}H_{10}O_6$	Calyxes	[7,30]
175	Myricetin	$C_{15}H_{10}O_8$	Calyxes	[7,30]
176	Diosmetin	$C_{16}H_{12}O_6$	Calyxes	[26]
177	Apigenin	$C_{15}H_{10}O_5$	Calyxes	[7,26]
178	Chrysoeriol	$C_{16}H_{12}O_6$	Calyxes, Fruits	[7,8,54]
179	Eriodictyol	$C_{15}H_{10}O_5$	Calyxes, Fruits	[54]
180	Phytolaccin	$C_{17}H_{14}O_7$	Roots, Stems	[42]
181	Rhamnazin	$C_{17}H_{14}O_7$	Calyxes, Fruits	[54]
182	Wogonin	$C_{16}H_{12}O_5$	Fruits, Calyxes	[56]
183	Nobiletin	$C_{21}H_{22}O_8$	Fruits, Calyxes	[56]
184	Liquiritigenin	$C_{15}H_{12}O_4$	Fruits, Calyxes	[56]
185	Luteolin-4′-*O*-glucoside	$C_{21}H_{20}O_{11}$	Calyxes, Fruits	[64]
186	Luteolin-7-*O*-glucoside	$C_{21}H_{20}O_{11}$	Calyxes, Fruits	[64]
187	Luteolin-7-β-*D*-glucoside	$C_{21}H_{20}O_{11}$	Calyxes	[10]

(*continued on next page*)

Table 1 (*continued*)

NO.	Compound	Molecular Formula	Origin Parts	Reference
188	Luteolin-4-*O*-β-*D*-glucoside	$C_{21}H_{20}O_{11}$	Calyxes, Fruits	[40]
189	Luteolin-7-*O*-α-*D*-glucoside	$C_{21}H_{20}O_{11}$	Calyxes	[36]
190	Luteolin-7-*O*-β-*D*-glucoside	$C_{21}H_{20}O_{11}$	Roots, Stems	[7,58,65,66]
191	Luteolin-7-*O*-α-D-glucopyranoside	$C_{21}H_{20}O_{11}$	Calyxes	[14]
192	Luteolin-7-*O*-β-D-glucopyranoside	$C_{21}H_{20}O_{11}$	Calyxes	[30]
193	Luteolin-4′-*O*-β-D-glucopyranoside	$C_{21}H_{20}O_{11}$	Calyxes	[30,66]
194	Luteolin-7,4′-di-*O*-β-D-glucopyranoside	$C_{27}H_{30}O_{16}$	Calyxes	[7,8,14,20]
195	Luteolin-7,3′-di-*O*-β-D-glucopyranoside	$C_{27}H_{30}O_{16}$	Calyxes	[66]
196	Quercetin-3-*O*-β-D-glucopyranoside	$C_{21}H_{20}O_{12}$	Calyxes	[66]
197	Quercetin-3,7-di-*O*-β-D-glucopyranoside	$C_{27}H_{30}O_{17}$	Calyxes	[66]
198	3′,4′-*O*-demethyl quercetin	$C_{17}H_{14}O_7$	Calyxes	[37]
199	3′,4′-Dimethoxymyricetin	$C_{17}H_{14}O_8$	Calyxes	[8,67]
200	5,7-Dimethoxycoumarin	$C_{11}H_{10}O_4$	Calyxes	[26]
201	5,4′,5′-Trihydroxy-7,3′-dimethoxyflavonol	$C_{17}H_{14}O_8$	Fruits, Calyxes	[7,8]
202	5,6,7-Trimethoxy-flavone	$C_{18}H_{16}O_5$	Calyxes	[7]
203	Isoquercitrin	$C_{21}H_{20}O_{12}$	Fruits, Calyxes	[7,26,30,40]
204	Kaemperide-3-*O*-glucoside	$C_{22}H_{22}O_{11}$	Fruits, Calyxes	[40]
205	4′-Methoxy kaempferol	$C_{16}H_{12}O_6$	Calyxes	[36]
206	Kaempferol-4′-methoxy-7-*O*-β-D-glucopyranoside	$C_{22}H_{20}O_{11}$	Calyxes	[7,30]
207	Kaempferol-4′-methoxy-3-*O*-β-D-glucopyranoside	$C_{22}H_{20}O_{11}$	Calyxes	[7,30]
208	Kaempferol-3-*O*-β-D-Glucose	$C_{21}H_{10}O_{11}$	Calyxes	[37]
209	Dihydrokaempferol-7-*O*-glucoside	$C_{21}H_{22}O_{11}$	Calyxes, Fruits	[40]
210	3,7-di-*O*-α-*L*-rhamnopyransoyl kaempferol	$C_{27}H_{22}O_{14}$?	Calyxes	[37]
211	Apigenin-7-glucoside	$C_{21}H_{20}O_{10}$	Calyxes	[26]
212	Apigenin-7-*O*-β-*D*-glucoside	$C_{21}H_{20}O_{10}$	Calyxes	[68]
213	Apigenin-7-*O*-β-D-glucopyranoside	$C_{21}H_{20}O_{10}$	Calyxes	[14]
214	Chrysoeriol-7-*O*-β-glucopyranoside	$C_{22}H_{22}O_{11}$	Calyxes, Fruits	[41]
215	Chrysoeriol-7-*O*-β-*D*-glucoside	$C_{22}H_{22}O_{11}$	Calyxes	[68]
216	Diosmetin-*O*-β-D-glucopyranoside	$C_{22}H_{22}O_{11}$	Calyxes	[16]
217	Diosmetin-7-*O*-β-*D*-glucoside	$C_{22}H_{22}O_{11}$	Calyxes	[68]
218	Malvidin-3-*O*-glucoside	$C_{23}H_{24}O_{12}$	Calyxes, Fruits	[40]
219	Rhamnazin-3-*O*-glucopyranoside	$C_{23}H_{26}O_{12}$	Calyxes, Fruits	[64]
Alkaloids				
220	3α-Tigloyloxytropane	$C_{13}H_{21}NO_2$	Roots	[7,8,10,14]
221	Tigloidine	$C_{13}H_{21}NO_2$	Roots	[8,14]
222	Tropine	$C_8H_{15}NO$	Roots	[7,8,10,14]
223	Hygrine	$C_8H_{15}NO$	Roots	[7,8]
224	Cuscohygrine	$C_{13}H_{24}N_2O$	Roots	[7,8,14]
225	Pseudotropine	$C_8H_{15}NO$	Roots	[7,8,10]
226	3α-Tigloyloxy tropane *N*-oxide	$C_{13}H_{21}NO_3$	Roots	[7,8,10]
227	Phygrine	$C_6H_{28}N_2O_2$	Roots	[8,14,69]
228	Calystegin A_3	$C_7H_{13}NO_3$	Roots	[8,70]
229	Calystegin A_5	$C_7H_{13}NO_3$	Roots	[8,70]
230	Calystegin B_1	$C_7H_{13}NO_4$	Roots	[8,70]
231	Calystegin B_2	$C_7H_{13}NO_4$	Roots	[8,70]
232	Calystegin B_3	$C_7H_{13}NO_4$	Roots	[8,70]
233	Calystegin C_1	$C_7H_{13}NO_5$	Roots	[8,70]
234	1β-Amino-2α,3β,5β-trihydroxycycloheptane	$C_7H_{16}NO_3$	Roots	[8,14,70]
235	Anaferine	$C_{13}H_{24}N_2O$	Roots	[8]
236	Anahygrine	$C_{13}H_{24}N_2O$	Roots	[8]
237	*Trans*-*N*-feruloyl-3-*O*-methyldopamine	$C_{19}H_{21}NO_5$	Calyxes, Fruits	[41]
238	5-Hydroxy-2-pyridinemethanol	$C_6H_7NO_2$	Calyxes, Fruits	[41]
239	Feruloyltyramine	$C_{18}H_{19}NO_4$	Calyxes, Fruits	[64]
240	*N*-trans-feruloyltyramine	$C_{18}H_{19}NO_4$	Calyxes	[31]
241	*N*-*p*-coumaroyltyramine	$C_{17}H_{17}NO_3$	Calyxes	[31]
242	Neoechinulin A	$C_{19}H_{21}N_3O_2$	Calyxes, Fruits	[64]
243	3-(4-hydroxy-3-methoxyphenyl)-*N*-(4-methylphenyl)-2-propenamide	$C_{17}H_{17}NO_3$	Calyxes, Fruits	[64]
244	Aurantiamide	$C_{25}H_{26}N_2O_3$	Calyxes, Fruits	[54]
245	Isoechinulin A	$C_{24}H_{29}N_3O_3$	Calyxes, Fruits	[54]
246	*N*-benzoyl-*L*-phenylalaninol	$C_{16}H_{17}NO_2$	Calyxes, Fruits	[54]
247	Aurantiamide acetate	$C_{27}H_{28}N_2O_4$	Calyxes, Fruits	[54]
248	Ginsenine	$C_{13}H_{14}N_2O_2$	Fruits	[61]
Phenylpropanoids				
249	Ferulic acid	$C_{10}H_{10}O_4$	Calyxes	[16,26]
250	*Trans*-ferulic acid	$C_{10}H_{10}O_4$	Whole plants	[39]
251	Chlorogenic acid	$C_{16}H_{18}O_9$	Fruits, Calyxes	[16,31,41]

(*continued on next page*)

Table 1 (*continued*)

NO.	Compound	Molecular Formula	Origin Parts	Reference
252	Syringalide B	$C_{24}H_{28}O_{10}$	Fruits, Calyxes	[16,41,68]
253	Syringaresinol	$C_{22}H_{26}O_8$	Fruits, Calyxes	[41]
254	3-Caffeoylquinic acid methyl ester	$C_{18}H_{22}O_9$	Fruits, Calyxes	[16,31,41]
255	(+)-Medioresinol-*O*-β-*D*-di-glucopyranoside	$C_{33}H_{44}O_{17}$	Fruits, Calyxes	[16,68]
256	(+) -Syringaresinol-*O*-β-*D*-di-glucopyranoside	$C_{34}H_{46}O_{18}$	Fruits, Calyxes	[16,41,68]
257	(+)-Pinoresinol-*O*-β-*D*-di-glucopyranoside	$C_{32}H_{42}O_{16}$	Fruits, Calyxes	[16,41,68]
258	Scopoletin-7-*O*-β-*D*-di-glucopyranoside	$C_{22}H_{28}O_{14}$	Fruits, Calyxes	[68]
259	Syringaresinol-4′-*O*-β-*D*-glucopyranoside	$C_{28}H_{36}O_{13}$	Calyxes	[31]
260	*p*-Coumaric acid	$C_9H_8O_3$	Calyxes	[26,36,41]
261	6,6′,7,7′-Tetrahydroxy-5,5′-dicoumarol	$C_{18}H_{10}O_8$	Calyxes	[36]
262	Caffeic acid	$C_9H_8O_4$	Fruits, Calyxes	[30,40,41]
263	Esculetin	$C_9H_6O_4$	Calyxes	[26,30]
264	8-Hydroxy-7-methoxycoumarin	$C_{10}H_8O_4$	Fruits, Calyxes	[41]
265	3,4-Dimethoxy-5-hydroxy-cinnamyi alcohol-9-*O*-β-*D*-glucopyranoside	$C_{17}H_{24}O_9$	Fruits, Calyxes	[41]
266	Sachaliside 1	$C_{15}H_{20}O_7$	Fruits, Calyxes	[41]
267	3-caffeoyl quinic acid	$C_{16}H_{18}O_9$	Fruits, Calyxes	[40]
268	4,5,3′,4′-Tetrahydroxy-2,7′-cycloligna-7,7′-dien-9,9′-olide	$C_{18}H_{12}O_6$	Calyxes	[30]
269	Syringaresinol-4,4′-*O*-di-β-*D*-glucoside	$C_{34}H_{46}O_{18}$	Calyxes	[30]
270	Cinnamic acid	$C_9H_8O_2$	Fruits	[71]
271	*p*-Hydroxy-cinnamic acid	$C_9H_8O_3$	Fruits	[71]
272	Schizandrin	$C_{24}H_{32}O_7$	Fruits, Calyxes	[56]
Terpenoids				
273	Physalisitin A	$C_{15}H_{24}O_3$	Calyxes	[16]
274	Physalisitin B	$C_{15}H_{24}O_2$	Calyxes	[16]
275	Physalisitin C	$C_{15}H_{22}O_2$	Calyxes	[16]
276	Citroside A	$C_{19}H_{30}O_8$	Fruits, Calyxes	[16,41]
277	(6*S*,9*R*)-Roseoside	$C_{19}H_{30}O_8$	Fruits, Calyxes	[16,41]
278	(6*S*,9*S*)-Roseoside	$C_{19}H_{30}O_8$	Fruits, Calyxes	[16,41]
279	(6*R*,9*S*)-3-Oxo-α-ionol-β-*D*-glucopyranoside	$C_{19}H_{30}O_7$	Fruits, Calyxes	[16,41]
280	Oleanolic acid	$C_{30}H_{48}O_3$	Calyxes	[37,58]
281	Physanoside A	$C_{25}H_{40}O_{12}$	Leaves, Stems	[16,72]
282	Physanoside B	$C_{25}H_{40}O_{12}$	Leaves, Stems	[16,72]
283	Neryl-1-*O*-β-*D*-glucopyranosyl-(1 → 2)-*O*- [α-*L*-arabinopy-ranosyl-(1 → 6)] -*O*-β-*D*-glucopyranoside	$C_{27}H_{46}O_{15}$	Calyxes	[16,31]
284	Ursolic acid	$C_{30}H_{48}O$	Calyxes	[16]
285	Blumenol A	$C_{13}H_{20}O_3$	Fruits, Calyxes	[56,64]
286	Dehydrovomifoliol	$C_{13}H_{18}O_3$	Fruits, Calyxes, Roots, Stems	[41,42]
287	3β-Hydroxy-5,6-epoxy-7-megastigmen-9-one	$C_{13}H_{20}O_3$	Fruits, Calyxes	[41]
288	Rel-(3*E*)-4-[(1*R*,2*R*,4*S*)-1,2,4-trihydroxy-2,6,6-trimethylcyclohexyl]-3-buten-2-one	$C_{13}H_{22}O_4$	Fruits, Calyxes	[41]
289	4aβ-Decahydro-8aα-methyl-4-methylene-6β-(1-methylethenyl)-1α,3α-naphthalenediol	$C_{15}H_{24}O_2$	Calyxes, Fruits	[54]
290	Capsidiol	$C_{15}H_{24}O_2$	Calyxes, Fruits	[54]
291	(+)-Anhydro-β-rotunol	$C_{15}H_{20}O_2$	Calyxes, Fruits	[54]
292	Pubinernoid A	$C_{11}H_{16}O_3$	Fruits, Calyxes	[41,54]
293	4-(3,4-dihydroxy-4-methylpentyl)-3-(hydroxymethyl)-2,4-dimethylcyclohexa-2,5-dien-1-one	$C_{15}H_{24}O_4$	Roots, Stems	[42]
294	7-(3-hydroxyprop-1-en-2-yl)-1,4a-dimethyl-5,6,7,8-tetrahydronaphthalen-2(4aH)-one	$C_{15}H_{20}O_2$	Roots, Stems	[42]
295	3-*O*-α-*L*-Arabinopyranose-Hedera sapogenin-28-*O*-(4-*O*-acetyl)-α-*L*-rhamnopyranose-(1 → 4)-β-*D*-glucopyranose-(1 → 6)-β-*D*-glucopyranosyl	$C_{49}H_{78}O_{19}$	Fruits	[61]
Physakengoses				
296	Physakengose A	$C_{29}H_{50}O_{13}$	Aerial parts	[18]
297	Physakengose B	$C_{33}H_{56}O_{14}$	Aerial parts	[18]
298	Physakengose C	$C_{31}H_{52}O_{14}$	Aerial parts	[18]
299	Physakengose D	$C_{29}H_{50}O_{13}$	Aerial parts	[18]
300	Physakengose E	$C_{34}H_{58}O_{14}$	Aerial parts	[18]
301	Physakengose F	$C_{34}H_{56}O_{14}$	Aerial parts	[18]
302	Physakengose G	$C_{36}H_{60}O_{15}$	Aerial parts	[18]
303	Physakengose H	$C_{36}H_{58}O_{15}$	Aerial parts	[18]
304	Physakengose I	$C_{36}H_{62}O_{14}$	Aerial parts	[18]
305	Physakengose J	$C_{36}H_{60}O_{14}$	Aerial parts	[18]
306	Physakengose K	$C_{38}H_{64}O_{15}$	Aerial parts	[17]
307	Physakengose L	$C_{35}H_{58}O_{15}$	Aerial parts	[17]
308	Physakengose M	$C_{35}H_{58}O_{15}$	Aerial parts	[17]
309	Physakengose N	$C_{35}H_{58}O_{14}$	Aerial parts	[17]
310	Physakengose O	$C_{34}H_{58}O_{14}$	Aerial parts	[17]
311	Physakengose P	$C_{22}H_{34}O_{13}$	Aerial parts	[17]
312	Physakengose Q	$C_{22}H_{36}O_{13}$	Aerial parts	[17]
Piperazines				
313	(3*S*,6*R*)-3-isopropyl-6-(2-methyl propyl)-2,5-piperazine diketone	$C_{11}H_{20}N_2O_2$	Calyxes	[19]

(*continued on next page*)

Table 1 (*continued*)

NO.	Compound	Molecular Formula	Origin Parts	Reference
314	(3*S*, 6*S*)-3-isobutyl-6-isopropyl-2,5-piperazine diketone	$C_{11}H_{20}N_2O_2$	Calyxes	[19]
315	(3*S*,6*S*)-3,6-di-(2-methyl propyl)-2,5-piperazine diketone	$C_{12}H_{22}N_2O_2$	Calyxes	[19]
316	(3*S*,6*S*)-3,6-di-isopropyl-2,5-piperazine diketone	$C_{10}H_{18}N_2O_2$	Calyxes	[19]
317	(3*S*,6*R*)-3-(2-methyl propyl)- 6-benzyl-2,5-piperazine diketone	$C_{15}H_{20}N_2O_2$	Calyxes	[19]
318	(3*S*,6*S*)-3-isobutyl-6-benzyl-2,5-piperazine diketone	$C_{15}H_{20}N_2O_2$	Calyxes	[19]
319	(3*S*,6*S*)-3-isopropyl-6-(*p*-hydroxy benzyl)-2,5-piperazine diketone	$C_{14}H_{18}N_2O_3$	Calyxes	[19]
320	(3*S*,6*R*)-3-isopropyl-6-(*p*-hydroxy benzyl)-2,5-piperazine diketone	$C_{14}H_{18}N_2O_3$	Calyxes	[19]
321	(3*S*,6*R*)-3-(2-methyl propyl)-6-(*p*-hydroxy benzyl)-2,5-piperazine diketone	$C_{15}H_{20}N_2O_3$	Calyxes	[19]
322	(3*S*,6*S*)-3-isobutyl-6-(*p*-hydroxy benzyl)-2,5-piperazine diketone	$C_{15}H_{20}N_2O_3$	Calyxes	[19]
323	(3*S*,6*S*)-3-isopropyl-6-benzyl-2,5-piperazine diketone	$C_{14}H_{18}N_2O_2$	Calyxes	[19]
324	(3*S*,6*R*)-3-isobutyl-6-(2-methyl propyl)-2,5-piperazine diketone	$C_{12}H_{22}N_2O_2$	Calyxes	[19]
325	(3*S*,6*S*)-3-benzyl-6-(*p*-hydroxy benzyl)-2, 5-piperazine diketone	$C_{18}H_{18}N_2O_3$	Calyxes	[19]
Volatile oils				
326	3,4-Dihydroxyphenethyl alcohol	$C_8H_{10}O_3$	Calyxes	[37]
327	Octanoic acid	$C_8H_{16}O_2$	Calyxes with fruit stalk	[20,21]
328	3,7-dimethyl- (*E*)-2,6-Octadien-1-ol	$C_{10}H_{18}O$	Calyxes	[20]
329	2,4-decadienal	$C_{10}H_{16}O$	Calyxes	[20]
330	6,10-dimethyl-(*Z*)-5,9-undecadien-2-one	$C_{13}H_{22}O$	Calyxes	[20]
331	4-(2,6,6-trimehyl-cyclohexen-1-yl)-(*E*)-3-buten-2-one	$C_{13}H_{20}O$	Calyxes	[20]
332	6,11-dimethyl-2,6,10-dodecatrien-1-ol	$C_{14}H_{24}O$	Calyxes	[20]
333	Tetradecanoic acid	$C_{14}H_{28}O_2$	Calyxes	[20]
334	2,3,5,8-tetramethyl-decane	$C_{14}H_{30}$	Calyxes	[20]
335	6,10,14-trimethyl-2-pentadecanone	$C_{18}H_{36}O$	Calyxes	[20]
336	6,10,14- trimethyl-5,9,13-petadecatrien-2-one	$C_{18}H_{30}O$	Calyxes	[20]
337	1-chloro-octadecane	$C_{18}H_{37}Cl$	Calyxes	[20]
338	14-methyl-pentadecanoic acid-methyl ester	$C_{17}H_{34}O_2$	Calyxes	[20]
339	1,(*E*)-11,(*Z*)-13-octadecatriene	$C_{18}H_{32}$	Calyxes	[20]
340	(*Z*)-9-octadecenal	$C_{18}H_{34}O$	Calyxes	[20]
341	n Decanoic acid	$C_{10}H_{20}O_2$	Calyxes with fruit stalk	[21]
342	(*E*)-6,10-Dimethyl-5,9-undecadien-2-one	$C_{13}H_{22}O$	Calyxes with fruit stalk	[21]
343	(*E*)-4-(2,6,6-Trimethyl-1-cyclohexane-1alkenyl)-3-butene-2-one	$C_{13}H_{20}O$	Calyxes with fruit stalk	[21]
344	3,3,7,7-Tetramethyl-5-(2-methyl-1-allyl)-tricyclic[4.1.0.0.2.4]-heptane	$C_{15}H_{24}$	Calyxes with fruit stalk	[21]
345	3,7,11- Trimethyl-1,6,10-dodecatrien-3-ol	$C_{15}H_{26}O$	Calyxes with fruit stalk	[21]
346	α-Bisabolol	$C_{15}H_{26}O$	Calyxes with fruit stalk	[21]
347	(−)-Spatula eucalyptol	$C_{15}H_{24}O$	Calyxes with fruit stalk	[21]
348	Isoaromadendrene oxide	$C_{15}H_{24}O$	Calyxes with fruit stalk	[21]
349	Decalin-1,1,4,7-tetramethyl-1H-cyclopropyl[e] azulene-4-ol	$C_{15}H_{26}O$	Calyxes with fruit stalk	[21]
350	Cubenol	$C_{15}H_{26}O$	Calyxes with fruit stalk	[21]
351	Cadinol	$C_{15}H_{26}O$	Calyxes with fruit stalk	[21]
352	Epiglobulol	$C_{15}H_{26}O$	Calyxes with fruit stalk	[21]
353	Oleyl alcohol	$C_{18}H_{34}O_2$	Calyxes with fruit stalk	[21]
354	2-Nonadecanone	$C_{19}H_{38}O$	Calyxes with fruit stalk	[21]
355	1,5-Dimethyl-3-hydroxy-8-(1-methylene-2-hydroxyethyl)-di-cyclo[4.4.0]decane-5-ene	$C_{15}H_{24}O_2$	Calyxes with fruit stalk	[21]
356	Trans-Longipino carvenol	$C_{15}H_{24}O$	Calyxes with fruit stalk	[21]
357	Myristic acid	$C_{14}H_{28}O_2$	Calyxes with fruit stalk	[21]
358	Solavetivone	$C_{15}H_{22}O$	Calyxes with fruit stalk	[21]
359	Pentadecanoic acid	$C_{15}H_{30}O_2$	Calyxes with fruit stalk	[21]

(*continued on next page*)

Table 1 (*continued*)

NO.	Compound	Molecular Formula	Origin Parts	Reference
360	Hexahydrofarnesylacetone	$C_{18}H_{36}O$	Calyxes with fruit stalk	[21]
361	Farnesylacetone	$C_{18}H_{30}O$	Calyxes with fruit stalk	[21]
362	(*Z*)-7-Methyl hexadecenoate	$C_{17}H_{32}O_2$	Calyxes with fruit stalk	[21]
363	Butyl octyl phthalate	$C_{20}H_{30}O_4$	Calyxes with fruit stalk	[21]
364	n-Palmitic Acid	$C_{16}H_{32}O_2$	Calyxes, Fruits	[21,23,54]
365	9,12-Octadecadienoic acid methyl ester	$C_{19}H_{34}O_2$	Calyxes with fruit stalk	[21]
366	5- Dodecyl-2(3H)-furan	$C_{16}H_{30}O_2$	Calyxes with fruit stalk	[21]
367	9,12-Linoleic acid	$C_{18}H_{32}O_2$	Calyxes with fruit stalk	[21]
368	Heptacosane	$C_{27}H_{56}$	Calyxes with fruit stalk	[21]
369	Octacosane	$C_{28}H_{68}$	Calyxes with fruit stalk	[21]
370	Methyl palmitate	$C_{17}H_{34}O_2$	Roots, Stems	[23]
371	Ethyl palmitate	$C_{16}H_{32}O_2$	Roots, Stems	[23]
372	(*Z*)9-Octadecenamide	$C_{13}H_{35}NO$	Roots, Stems	[23]
373	6,9-Methyl octadecadienoate	$C_{19}H_{34}O_2$	Roots, Stems	[23]
374	8,9-Didehydro-9-formylisolongifolene	$C_{15}H_{18}O_2$	Roots, Stems	[23]
375	Solavetivone	$C_{15}H_{22}O$	Roots, Stems	[23]
376	(*E*)11-Hexadecenoic acid	$C_{16}H_{30}O_2$	Roots, Stems	[23]
377	5-Dodecyl-2-furanone	$C_{16}H_{30}O_2$	Roots, Stems	[23]
378	Aromadendrene-2-oxide	$C_{15}H_{24}O$	Roots, Stems	[23]
379	1-Cyclohexyl heptene	$C_{13}H_{24}$	Roots, Stems	[23]
380	(*E*)4-(2,6,6-trimethyl-2-cyclohexenyl)-3-butene-2ketone	$C_{13}H_{20}O$	Roots, Stems	[23]
381	1-Pentadecene	$C_{15}H_{30}$	Roots, Stems	[23]
382	Pentadecane	$C_{15}H_{32}$	Roots, Stems	[23]
383	Hexadecane	$C_{16}H_{34}$	Roots, Stems	[23]
384	Heptadecane	$C_{17}H_{36}$	Roots, Stems	[23]
385	Octadecane	$C_{18}H_{38}$	Roots, Stems	[23]
386	Nonadecane	$C_{19}H_{40}$	Roots, Stems	[23]
387	Pentacosane	$C_{25}H_{52}$	Roots, Stems	[23]
388	Tetratetracontane	$C_{44}H_{90}$	Roots, Stems	[23]
389	(*E*)2,4-Diphenyl-4-methyl amylene	$C_{18}H_{20}$	Roots, Stems	[23]
390	(*Z*,*Z*,*Z*)9,12,15-Octadecatrienoicacid, methyl ester	$C_{19}H_{32}O_2$	Roots, Stems	[23]
391	α-Pinene	$C_{10}H_{16}$	Fruits	[28]
392	Camphene	$C_{10}H_{16}$	Fruits	[28]
393	Sabinene	$C_{10}H_{16}$	Fruits	[28]
394	β-Pinene	$C_{10}H_{16}$	Fruits	[28]
395	Myrcene	$C_{10}H_{16}$	Fruits	[28]
396	*p*-Cymene	$C_{10}H_{14}$	Fruits	[28]
397	Limonene	$C_{10}H_{16}$	Fruits	[28]
398	γ-Terpinene	$C_{10}H_{16}$	Fruits	[28]
399	Camphenilone	$C_9H_{14}O$	Fruits	[28]
400	β-Linalool	$C_{10}H_{18}O$	Fruits	[28]
401	Nonanal	$C_9H_{18}O$	Fruits	[28]
402	Camphor	$C_{10}H_{16}O$	Fruits	[28]
403	1-Terpinen-4-ol	$C_{10}H_{18}O$	Fruits	[28]
404	α-Terpineol	$C_{10}H_{18}O$	Fruits	[28]
405	Nerol	$C_{10}H_{18}O$	Fruits	[28]
406	n-Tridecane	$C_{13}H_{28}$	Fruits	[28]
407	Isoamyl benzyl ether	$C_{12}H_{18}O$	Fruits	[28]
408	Neryl acetate	$C_{12}H_{20}O_2$	Fruits	[28]
409	Sibirene	$C_{15}H_{24}$	Fruits	[28]
410	β-Caryophyllene	$C_{15}H_{24}$	Fruits	[28]
411	Germacrene D	$C_{15}H_{24}$	Fruits	[28]
412	β-Selinene	$C_{15}H_{24}$	Fruits	[28]
413	α-Zingiberene	$C_{15}H_{24}$	Fruits	[28]
414	Bicyclogermacrene	$C_{15}H_{24}$	Fruits	[28]
415	δ-Cadinene	$C_{15}H_{24}$	Fruits	[28]
416	α-Cadinene	$C_{15}H_{24}$	Fruits	[28]
417	1-*epi*-Cubenol	$C_{15}H_{26}O$	Fruits	[28]
418	(2*E*,6*E*)-Methyl farnesoate	$C_{16}H_{26}O_2$	Fruits	[28]

(*continued on next page*)

Table 1 (*continued*)

NO.	Compound	Molecular Formula	Origin Parts	Reference
419	(2*Z*,6*E*)-Farnesyl acetate	$C_{17}H_{28}O_2$	Fruits	[28]
420	(5*Z*,9*E*)-Farnesyl acetone	$C_{18}H_{30}O$	Fruits	[28]
421	Phytol	$C_{20}H_{40}O$	Fruits	[28]
Polysaccharides				
422	Mannose	$C_6H_{12}O_6$	Roots, Stems	[23]
423	GlcUA	$C_6H_{10}O_7$	Roots, Stems	[23]
424	Galactose	$C_6H_{12}O_6$	Roots, Stems	[23]
425	Xylose	$C_5H_{10}O_5$	Roots, Stems	[23]
426	Arabinose	$C_5H_{10}O_5$	Roots, Stems	[23]
427	Rhamnose	$C_6H_{12}O_5$	Roots, Stems	[23]
428	α-D-glucose	$C_6H_{12}O_6$	Calyxes	[65]
429	GalA	$C_6H_{10}O_7$	Fruits	[73]
430	Fucose	$C_6H_{12}O_5$	Roots	[22]
431	Sucrose	$C_{12}H_{22}O_{11}$	Fruits	[61]
432	Maltose	$C_{12}H_{22}O_{11}$	Fruits	[61]
Amino acids				
433	Arginine	$C_6H_{14}N_4O_2$	Calyxes	[26]
434	L-Phenylalanine	$C_9H_{11}NO_2$	Calyxes	[26]
435	Glutamic acid	$C_5H_9NO_4$	Calyxes	[26]
436	Valine	$C_5H_{11}NO_2$	Calyxes	[26]
437	L-Proline	$C_5H_9NO_2$	Calyxes	[71]
438	*M*-Phenylalanine	$C_9H_{11}NO_2$	Calyxes	[71]
439	L-Leucine	$C_6H_{13}NO_2$	Fruits	[71]
440	*L*-Tryptophan	$C_{11}H_{19}N_2O_2$	Fruits	[71]
441	Aspartic acid	$C_4H_7NO_4$	Seeds	[28]
442	Serine	$C_3H_7NO_3$	Seeds	[28]
443	Glycine	$C_2H_5NO_2$	Seeds	[28]
444	Histidine	$C_6H_9N_3O_2$	Seeds	[28]
445	Threonine	$C_4H_9NO_3$	Seeds	[28]
446	Alanine	$C_3H_7NO_2$	Seeds	[28]
447	Cysteine	$C_3H_7NO_2S$	Seeds	[28]
448	Tyrosine	$C_9H_{11}NO_3$	Seeds	[28]
449	Methionine	$C_5H_{11}NO_2S$	Seeds	[28]
450	Lysine	$C_6H_{14}N_2O_2$	Seeds	[28]
451	Isoleucine	$C_6H_{13}NO_2$	Seeds	[28]
Fatty Acids				
452	Capric	$C_{20}H_{40}O_2$	Seeds, Peels	[28]
453	Undecylic	$C_{11}H_{22}O_2$	Seeds, Peels	[28]
454	Lauric	$C_{12}H_{24}O_2$	Seeds, Peels	[28]
455	Tridecylic	$C_{13}H_{26}O_2$	Seeds, Peels	[28]
456	Myristoleic	$C_{14}H_{26}O_2$	Seeds, Peels	[28]
457	Palmitoleic	$C_{16}H_{30}O_2$	Seeds, Peels	[28]
458	Margaric	$C_{17}H_{34}O_2$	Seeds, Peels	[28]
459	Heptadecenoic	$C_{17}H_{32}O_2$	Seeds, Peels	[28]
460	Stearic	$C_{18}H_{36}O_2$	Seeds, Peels	[28]
461	Oleic	$C_{18}H_{34}O_2$	Seeds, Peels	[28]
462	Linoleic	$C_{18}H_{32}O_2$	Seeds, Peels	[28]
463	Linolenic	$C_{18}H_{30}O_2$	Seeds, Peels	[28]
464	Eicosadienoic	$C_{20}H_{36}O_2$	Seeds, Peels	[28]
465	Eicosatrienoic	$C_{20}H_{34}O_2$	Seeds, Peels	[28]
466	Eicosatetraenoic	$C_{20}H_{32}O_2$	Seeds, Peels	[28]
467	Eicosapentaenoic	$C_{20}H_{30}O_2$	Seeds, Peels	[28]
468	n-Hexacosanoic acid	$C_{26}H_{52}O_2$	Fruits, Calyxes	[41]
469	Hendecanoic acid	$C_{11}H_{22}O_2$	Calyxes, Fruits	[54]
470	Tetra-cosanic acid	$C_{24}H_{48}O_2$	Calyxes	[37]
471	(*Z*)-9,10,11-trihydroxy-12-octadecenoic acid	$C_{18}H_{34}O_5$	Calyxes	[37,58]
472	Tricosanoic Acid	$C_{23}H_{46}O_2$	Aerial parts	[52]
473	Glyceryl monostearate	$C_{21}H_{42}O_4$	Roots, Stems	[58]
474	Glyceryl ester of Behenic Acid	$C_{25}H_{50}O_4$	Calyxes	[52]
475	Succinct acid	$C_4H_6O_4$	Fruits	[29]
476	(8,11)-Dienoic acid	$C_{16}H_{28}O_2$	Fruits	[29]
Organic acids				
477	Nicotinic acid	$C_6H_5NO_2$	Fruits	[71]
478	Vanillic acid	$C_8H_8O_4$	Fruits, Calyxes	[41]
479	Citric acid	$C_6H_8O_7$	Calyxes	[26,30,40]
480	Succinic acid	$C_4H_6O_4$	Fruits, Calyxes	[40]
481	Cumaric acid	$C_9H_8O_3$	Fruits, Calyxes	[40]
482	Quinic acid	$C_7H_{12}O_6$	Calyxes	[26]

(*continued on next page*)

Table 1 (*continued*)

NO.	Compound	Molecular Formula	Origin Parts	Reference
483	Gallic acid	$C_7H_6O_5$	Calyxes	[26]
484	Gentisic Acid	$C_7H_6O_4$	Calyxes	[26]
485	3-Indoleacrylic acid	$C_{11}H_9NO_2$	Calyxes	[26]
486	5-Methyl-3-pyridinecarboxylicacid	$C_7H_7NO_2$	Fruits	[34]
487	5-Hydroxymethylfuroic acid	$C_6H_6O_4$	Fruits	[34,64,74]
488	2-((2-Ethylhexyloxy)carbonyl)benzoic acid	$C_{16}H_{22}O_4$	Fruits	[29]
Aliphatics				
489	N-tetracosane	$C_{24}H_{50}$	Calyxes, Fruits	[64]
490	Dibutyl phthalate	$C_{16}H_{22}O_4$	Calyxes, Fruits	[64]
491	Bis(2-ethylhexyl)phthalate	$C_6H_6O_4$	Calyxes, Fruits	[64]
492	1-*O*-(9*Z*,12*Z*-octadecadienoyl)glycerol	$C_{21}H_{38}O_4$	Calyxes, Fruits	[54]
493	Methyl(10*E*,12*Z*)-9-hydroxy-octadecadienoate	$C_{19}H_{34}O_3$	Calyxes, Fruits	[54]
494	1,5-Dimethyl citrate	$C_8H_{12}O_7$	Fruits	[34,74]
495	5-Hydroxymethylfurfural	$C_6H_6O_3$	Fruits, Calyxes	[56]
496	5-(hydroxymethyl)-2-(dimethoxymethyl)furan	$C_8H_{12}O_4$	Fruits, Calyxes	[56]
497	1-Citric acid ethyl ester	$C_8H_{12}O_7$	Fruits	[29]
498	1-Citric acid methyl ester	$C_7H_{10}O_7$	Fruits	[29]
499	9,12-Ethyl octadeca-9,12-dienoate	$C_{20}H_{36}O_2$	Fruits	[29]
Nucleosides				
500	Adenine	$C_5H_5N_5$	Calyxes	[31]
501	Adenosine	$C_{10}H_{13}N_5O_4$	Calyxes	[31]
502	Guanosine	$C_{10}H_{13}N_5O_5$	Calyxes	[26]
503	Uridine	$C_9H_{12}N_2O_6$	Calyxes	[26]
Anthraquinones				
504	Emodin	$C_{15}H_{10}O_5$	Calyxes	[26]
505	Aurantio-obtusin-6-*O*-β-*D*-glucoside	$C_{23}H_{24}O_{12}$	Calyxes	[26]
Phenols				
506	Ethyl caffeate	$C_{11}H_{12}O_4$	Calyxes	[30]
507	Ethyl ferulate	$C_{12}H_{14}O_4$	Calyxes	[30]
508	Syringic acid	$C_9H_{10}O_5$	Calyxes, Fruits	[30,71]
509	Hydroxytyrosol	$C_8H_{10}O_3$	Fruits	[71]
510	Hydroquinone	$C_6H_6O_2$	Calyxes	[52]
Tocopherols				
511	α-Tocopherol	$C_{29}H_{50}O_2$	Seeds, Peels	[28]
512	β-Tocopherol	$C_{28}H_{48}O_2$	Seeds, Peels	[28]
513	γ-Tocopherol	$C_{28}H_{48}O_2$	Seeds, Peels	[28]
Trace elements				
514	Potassium (K)	K	Seeds	[28]
515	Sodium (Na)	Na	Seeds	[28]
516	Calcium (Ca)	Ca	Seeds	[28]
517	Magnesium (Mg)	Mg	Seeds	[28]
518	Iron (Fe)	Fe	Seeds	[28]
519	Manganese (Mn)	Mn	Seeds	[28]
520	Copper (Cu)	Cu	Seeds	[28]
521	Zinc (Zn)	Zn	Seeds	[28]
522	Lead (Pb)	Pb	Seeds	[28]
523	Cadmium (Cd)	Cd	Seeds	[28]
524	Chromium (Cr)	Cr	Seeds	[28]
Others				
525	7-Epiloliolide	$C_{11}H_{16}O_3$	Fruits, Calyxes	[41]
526	Tetillapyrone	$C_{11}H_{14}O_6$	Fruits, Calyxes	[41]
527	3,5-dimethoxy-4-hydroxybenzaldehyde	$C_9H_{10}O_4$	Roots, Stems	[42]
528	1-*O*-β-*D*-glucopyra-*n*-osyl-2-*N*-(2′-hydroxypalmitoyl)octadeca sphi-nga-4,8-dienine	$C_{40}H_{75}NO_9$	Fruits	[29]
529	Dihydrofuran-2,5-dione	$C_4H_4O_3$	Fruits	[29]
530	Cyclo-(*L*-leucyl-*L*-isoleucyl)	$C_{12}H_{22}N_2O_2$	Fruits	[29]
531	Cyclo(tyrosine-amidocaproic) -bipeptid	$C_{15}H_{20}N_2O_3$	Calyxes	[74]
532	Cuneataside E	$C_{24}H_{40}O_{11}$	Calyxes	[52]
533	1-*O*-[3-*O*-2-methyl-5-(2,3,4-trimethyl)phenyl-2,3-pentanediol]-β-*D*-xylopyranosyl-(1 → 6)-β-*D*-galactopyranoside	$C_{26}H_{42}O_{11}$	Fruits, Calyxes	[56]
534	(*Z*)-Hex-3-en-1-ol *O*-β-*D*-xylcopyranosyl-(1–6)-β-*D*-glucopyran-osyl-(1–2)-β-*D*-glucopyranoside	$C_{23}H_{40}O_{15}$	Calyxes	[75]
535	(*E*)-Hex-3-en-1-ol *O*-β-*D*-xylcopyranosyl-(1–6)-β-*D*-glucopyran-osyl-(1–2)-β-*D*-glucopyranoside	$C_{23}H_{40}O_{15}$	Calyxes	[75]

3.2. Flavonoids

Flavonoids are a class of compounds characterised by the parent nucleus of 2-phenylchromogenic ketones. Fifty-five flavonoids have been isolated from *P. alkekengi*, accounting for 10.28% of the total compound types, which is one of the important active ingredients in *P. alkekengi*. Flavonoids in *P. alkekengi* are mostly isolated from the fruit, calyx, and calyx-fruit combination [7], mainly

including flavonoids and flavonoid glycosides. Specific information on the flavonoids in *P. alkekengi* is given in Table 1.

3.3. Alkaloids

Alkaloids are a class of naturally-occurring nitrogen-containing organic compounds. Twenty-nine alkaloids have been isolated from *P. alkekengi*, accounting for 5.42% of the total compound types. Alkaloids in *P. alkekengi* are predominantly concentrated in the roots and lower portions of the primary stem [7]. These mainly include tigloidine, tropine, hygrine, cuscohygrine, pseudotropine, and phygrine. Specific information on the alkaloid constituents in *P. alkekengi* is given in Table 1.

3.4. Phenylpropanoids

Phenylpropanoids have a benzo-alpha-pyrone structure as their parent nucleus. Twenty-four phenylpropanoids have been isolated from the calyxes of *P. alkekengi*, accounting for 4.49% of the total compound types. These mainly include a variety of phenylpropionic acids such as ferulic acid, chlorogenic acid, and caffeic acid [16]. Specific information on the phenylpropanoids in *P. alkekengi* is given in Table 1.

3.5. Physakengoses

Physakengoses are primarily composed of sucrose and long-chain fatty acid esters [16]. Zhang et al. [17,18] isolated 17 new physakengoses from *P. alkekengi*, including physakengoses A-Q. Specific information on the physakengoses in *P. alkekengi* is given in Table 1.

3.6. Piperazines

Piperazines are a class of compounds featuring the piperazine structure. Shu et al. [19] isolated thirteen piperazines from *P. alkekengi*, marking the first ever discovery of these compounds in *Physalis* L. Specific information on the piperazines in *P. alkekengi* is given in Table 1.

3.7. Volatile oils

Volatile oils refer to a cluster of fragrant substances that exhibit volatility. Ninety-six volatile oils have been isolated from *P. alkekengi*, accounting for 17.94% of the total compound types. These mainly include fatty acids and sesquiterpenoids [8], among which fatty acids such as octanoic, decanoic, pentadecanoic, n-palmitic, and myristic acids are the main components. In addition, the volatile components are mainly in the calyx, with less in the fruit [20,21]. Specific information on the volatile oils in *P. alkekengi* is given in Table 1.

3.8. Polysaccharides

Polysaccharides play an important role in various life processes and possess multiple health benefits. The polysaccharides are mainly extracted from the fruit and calyx parts of *P. alkekengi* [22], among which 8.9% polysaccharides content in the fruits [7], such as mannose, glucose, galactose, xylose, arabinose, rhamnose, fucose, sucrose, and maltose [23]. Specific information on the polysaccharide analogues in *P. alkekengi* is given in Table 1.

3.9. Amino acids

Amino acids are a class of organic compounds containing basic amino and acidic carboxyl groups. *Physalis alkekengi* contains a variety of amino acids, with nineteen amino acids having been isolated and identified, accounting for 3.55% of the total compound types. The fruits of *P. alkekengi* contain 18 essential amino acids, accounting for 30.66% of the total amino acids [24], among which arginine, glutamic acid, and aspartic acid are the mainly components [25]. In addition, the calyxes contain 16 amino acids, mainly including phenylalanine, glutamic acid, proline, valine, and tryptophan [26], of which the essential amino acids account for 29.13% of the total amino acids [27]. Specific information on the amino acids in *P. alkekengi* is given in Table 1.

3.10. Other chemical components

In addition, *P. alkekengi* also contains trace elements such as potassium, sodium, calcium, magnesium, iron, manganese, copper, zinc, lead, cadmium, and chromium [28]. It also contains aliphatics such as n-tetracosane, dibutyl phthalate, 1-citric acid ethyl ester, 1-citric acid methyl ester, ethyl linoleate, and 5-hydroxymethyl furfural [29], organic acids such as citric, succinic, cumaric, quinic, gallic, and gentisic acids [26], terpenoids such as citroside A, (6*S*,9*R*)-roseoside, (6*S*,9*S*)-roseoside, and ursolic acid [16], phenols such as ethyl caffeate, ethyl ferulate, and syringic acid [30], tocopherols α, β, and γ [28], anthraquinones such as emodin and aurantio-obtusin-6-o-β-*d*-glucoside [26], nucleosides such as adenosine, guanosine, and uridine [31], and many other compounds.

4. Pharmacological effects

Modern pharmacological studies have shown that *P. alkekengi* has various pharmacological effects such as anti-inflammatory, anti microbial, antioxidative, hypoglycaemic, analgesic, immunomodulatory, and anti-tumour activities. A schematic diagram of the main pharmacological mechanism of effects of *P. alkekengi* is shown in Fig. 3.

4.1. Anti-inflammatory effects

The inflammatory response is a defensive reaction of the body to cellular damage and is the basis for the pathogenesis of multiple diseases. The crude extract of *P. alkekengi* by water extraction and alcohol precipitation could significantly inhibit xylene-induced acute oedema and exudative inflammation and reduce the number of inflammatory cells in rats with acute pharyngitis [76]. The aqueous extract of *P. alkekengi* alleviated symptoms of dextran sulphate sodium-induced ulcerative colitis in mice. It can reduce the secretion of the inflammatory factors interleukin (IL)-6 and IL-1β by increasing the antioxidant activity of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GSH-Px) and significantly inhibit their mRNA expression in mouse colonic tissues, thus alleviating colitis [77]. The aqueous extract of the calyx of *P. alkekengi* may exert anti-inflammatory effects by inhibiting cyclooxygenase-2 (COX-2) and 5-lipoxygenase (5-LOX) expression and activities and inhibiting phospholipase A_2 (PLA_2), thereby doubly inhibiting the arachidonic acid metabolic pathway and reducing the production of prostaglandin E_2 (PGE_2) and leukotriene B_4 (LTB_4) [78]. The alcohol extracts of the fruits of *P. alkekengi* were found to inhibit the secretion of the hyperglycaemia-induced

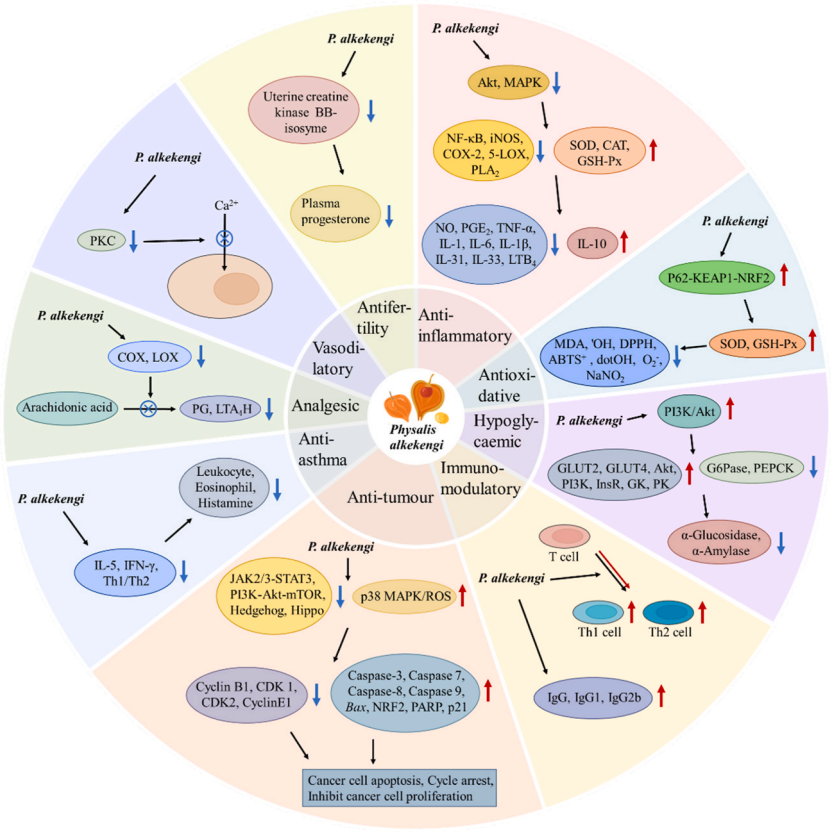

Fig. 3. Main pharmacological mechanism of effects of *P. alkekengi*.
Abbreviations: SOD, Superoxide dismutase; CAT, Catalase; GSH-Px, Glutathione peroxidase; COX-2, Cyclooxygenase; 5-LOX, 5-Lipoxygenase; PLA2, Phospholipase A2; PGE2, Prostaglandin E2; LTB4, Leukotriene B4; IL, Interleukin; Akt, also known as PKB, Protein kinase B; MAPK, Mitogen-activated protein kinase; NF-κB, Nuclear factor kappa-B; iNOS, Inducible nitric oxide synthase; NO, Nitric oxide; TNF-α, Tumour necrosis factor-α; MDA, Malondialdehyde; DPPH, 2,2-Diphenyl-1-picrylhydrazyl; 'OH, Hydroxyl radical; ABTS, 2,2-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); O2-, Superoxide anion; NaNO2, Sodium nitrite; KEAP1, Kelch-like ECH-associated protein 1; NRF2, Nuclear factor-erythroid 2-related factor 2; GLUT4, Glucose transporter 4; PI3K, Phosphatidylinositol-3-kinase; InsR, Insulin receptor; GK, Glucokinase; GLUT2, Glucose transporter 2; PK, Pyruvate kinase; PEPCK, Phosphoenolpyruvate carboxykinase; LTA4H, Leukotriene A-4 hydrolase; IgG, Immunoglobulin G; IgG1, Immunoglobulin G1; IgG2b, Immunoglobulin G2b; STAT3, Signal transducers and activators of transcription 3; ROS, Reactive oxygen species; JAK2, Janus kinase 2; CDK1, Cycle protein-dependent kinase 1; PARP, Poly ADP-ribose polymerase; mTOR, Mammalian target of rapamycin; CDK2, Cyclin-dependent kinase 2; IFN-γ, Interferon γ; PKC, Protein kinase C.

pro-inflammatory factors IL-31 and IL-33, while upregulating the anti-inflammatory factor IL-10, thereby suppressing inflammation [79]. In addition, the ethanol, petroleum ether, and ethyl acetate extracts of *P. alkekengi* can alleviate lipopolysaccharide (LPS)-induced inflammatory responses, mainly by blocking protein kinase B (Akt, also known as PKB) and p38 mitogen-activated protein kinase (MAPK) signalling pathways, inhibiting nuclear factor kappa-B (NF-κB) transcription and inducible nitric oxide synthase (iNOS) and COX-2 expression, and reducing the production of nitric oxide (NO), PGE_2, tumour necrosis factor-α (TNF-α), IL-1, IL-6, and reactive oxygen species [54,64,80].

The total steroidal saponins from the calyx of *P. alkekengi* can dose-dependently inhibit the production of the inflammatory factors NO, IL-6, IL-1β, and monocyte chemotactic protein-1 (MCP-1), thereby suppressing the expression of COX-2 to alleviate the inflammatory response, and have a significant inhibitory effect on LPS-induced inflammatory response in RAW264.7 macrophages [81]. Wang et al. [82] showed that physalin A reduced the overproduction of PGE_2, TNF-α, and NO, inhibited the expression of COX-2 and iNOS, significantly inhibited nuclear translocation of NF-κB p65 and phosphorylation of inhibitor of NF-κB (IκB-α), and exerted anti-inflammatory effects by blocking LPS-induced activation of the NF-κB signalling pathway in RAW 264.7 cells.

Yao et al. [83] found galuteolin in *P. alkekengi* reduced the secretion of TNF-α, IL-6, and NO as well as gene copy number of TNF-α, IL-6, and iNOS in LPS-induced RAW264.7 cells, resulting in effective anti-inflammatory effects. Chen et al. [84] found that the combination of physalin A, luteolin, and cynaroside had significant synergistic inhibitory effects on LPS-induced NO and TNF-α release from macrophages, and the combination significantly reduced LPS-induced expression of iNOS protein. In addition, Zhang et al. [85] found a dose-dependent inhibition of COX-2 enzymes by sesquiterpenoids in *P. alkekengi*, and Xu [15] showed that withanolides also have strong anti-inflammatory activity. In conclusion, numerous studies have shown that all extracted parts of *P. alkekengi* show significant anti-inflammatory activity and can be widely studied and applied as anti-inflammatory agents. Among the active components, steroids and flavonoids are most studied for their anti-inflammatory effects. The possible main components are physalins and luteolin, which mainly exert anti-inflammatory effects by inhibiting the expression of COX-2, iNOS, and NF-κB p65, reducing various pro-inflammatory factors, and thereby increasing antioxidant capacity.

4.2. Anti microbial effects

Pathogenic microorganisms can cause infections and many diseases when they invade the body. The ethanol extract of the calyx of *P. alkekengi* has an inhibitory effect on alpha and beta Streptococcus, *Staphylococcus aureus*, *Bacillus subtilis*, and *Bacillus cereus*, with the strongest inhibitory effect on beta Streptococcus and *Bacillus cereus* [65,86]. In addition, the ethanol extract and the polysaccharide of *P. alkekengi* promote the growth of probiotics such as *Bacteroides*, *Clostridium*, and *Lactobacillus*, inhibit the growth of pathogenic bacteria such as *Escherichia coli*, and improve the balance of intestinal microecology [49,87,88]. It has been determined that the methanol and dichloromethane extracts and physalin D of *P. alkekengi* had antibacterial effects against gram-positive bacterial species, gram-negative bacterial species, and *Candida* species by broth microdilution and disk diffusion methods, with the best antibacterial effect against gram-positive bacteria [89]. And the ethyl acetate-extracted parts of *P. alkekengi* also showed antibacterial activity against *Helicobacter pylori* [90].

Meng et al. [91] found that the total saponin content of *P. alkekengi* had an inhibitory effect on four common food spoilage bacteria, including *E. coli*, *Salmonella typhimurine*, *Shigella fowlerii*, and *Listeria monocytogenes*. Yang et al. [92] found that physalin B and physalin E have good antibacterial effects on alpha and beta-haemolytic streptococcus, *S. pneumoniae*, *S. aureus*, and *Moraxella catarrhalis*, and the minimum inhibitory concentration of physalin B was lower than the minimum inhibitory concentration of physalin E and has stronger bacteriostatic activity. Chlorogenic acid has also been found to have significant antimicrobial activity against *S. aureus*, *S. pneumoniae*, *B. subtilis*, *E. coli*, *Shigella dysenteriae*, and *S. typhimurium* [93]. Furthermore, physakengoses B, E-H and K-Q, new compounds discovered in *P. alkekengi* by Zhang et al. [17,18], have strong bacteriostatic activity against *S. aureus*, *B. subtilis*, *Pseudomonas aeruginosa*, and *E. coli*.

Meira et al. [94] showed that physalins B, D, F, and G have anti-*Trypanosoma cruzi* activity, of which physalins B and F are the most effective compounds for trypanosomes and epithelial cell forms. Treatment with physalins can reduce its invasion and development, which may be related to the inhibition of *T. cruzi* protease activity, leading to alterations in its Golgi apparatus. Guimarães et al. [95] found that physalins B and F can reduce the percentage of *Leishmania* infection macrophages and the number of intracellular parasites *in vitro* at macrophages at non-cytotoxic concentrations, with potent antileishmanic activity. Using physalin D to treat mice infected with *Plasmodium burgdorferi* can reduce parasitaemia and delay death, demonstrating its antimalarial activity against *P. falciparum* [96]. Among the five fractions (P1, P2, P3, P4, and P5) obtained by Yao [83], P2, P3, and P4 had inhibitory effects on the growth of *Mycoplasma* toxin, among which P2 and P3 had strong inhibitory effects. In conclusion, many experiments have shown that the multiple extracts of *P. alkekengi* have significant anti microbial effects, and the main active ingredients are physalins, physakengoses, and chlorogenic acid. *Physalis alkekengi* extracts have inhibitory effect on a variety of pathogenic bacteria and parasites and have a regulatory effect by inhibiting harmful bacteria while promoting beneficial bacteria. However, despite their potential, the specific mechanism of action of these extracts is rarely studied, and further research is needed.

4.3. Antioxidative effects

Oxidative stress damage is a common stress injury that predisposes an organism to ageing and various chronic diseases if excess oxygen free radicals are present. The aqueous extracts of the calyx of *P. alkekengi* can enhance the resistance of nematodes to oxidative stress by up-regulating the expression levels of the antioxidant genes *gst-4*, *gst-7*, *sod-3*, and *hsp16.2* in nematodes, thereby delaying aging. In addition, the aqueous extract from *P. alkekengi* was proven to have significant antioxidative effects [97]. Furthermore, the

aqueous extract of *P. alkekengi* can also prevent nonalcoholic fatty liver disease (NAFLD) in mice by reducing the malondialdehyde (MDA) content in the liver tissue of NAFLD model mice [98]. Pei et al. [99] found that n-hexane-acetone extracted from *P. alkekengi* can reduce the MDA content and increase the SOD and GSH-Px enzyme activities in aging rats induced by D-galactose, which can effectively enhance the antioxidant capacity of rats. It has been shown that both the leaf and fruit extracts of *P. alkekengi* showed inhibition of xanthine oxidase, which mainly contains total phenols, flavonoids, and carotenoids [100]. Additionally, Wu et al. [71] examined the scavenging ability of 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals and found that the antioxidant activity of the petroleum ether part of *P. alkekengi* fruit was superior to that of the calyx.

P. alkekengi polysaccharides have a strong scavenging ability against 2, 2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) ($ABTS^+$), hydroxyl radical ('OH), superoxide anion (O_2^-), and DPPH, and have significant antioxidant activity [101–103]. Li et al. [104] found that the calyx, stems, and leaves of *P. alkekengi* have stronger antioxidant activity by fluorescence recovery after photobleaching method, in which the total flavonoids of stems and calyx had stronger scavenging ability of against DPPH, and the total flavonoids of stems and fruits had stronger scavenging activity of against $ABTS^+$. It has been shown that the total flavonoids from the calyx of *P. alkekengi* have the ability to scavenge oxygen radicals such as $ABTS^+$, 'OH, O_2^-, DPPH, and sodium nitrite ($NaNO_2$), and the scavenging ability is enhanced with increasing mass [105]. Zhang et al. [106] showed that physalin B could ameliorate oxidative stress by activating the P62–kelch-like ECH-associated protein 1 (KEAP1)–nuclear factor-erythroid 2-related factor 2 (NRF2) antioxidant pathway to improve NAFLD. Huang et al. [107] used supercritical carbon dioxide extraction to recover carotenoids from the calyx of *P. alkekengi* and confirmed their antioxidant capacity using free radical scavenging activity tests. In conclusion, numerous studies have shown that *P. alkekengi* extracts have significant antioxidative effects, with the main active ingredients being polysaccharides and flavonoids. The mechanism of action is related to enhancing antioxidant gene expression, increasing antioxidant enzyme activity, enhancing resistance to oxidative stress, scavenging oxygen free radicals, thereby reducing oxidative stress damage. Therefore, the use of *P. alkekengi* extract as a natural antioxidant in health and care products and cosmetics has broad prospects for development and application.

4.4. Hypoglycaemic effects

Diabetes is a metabolic disease characterised by hyperglycaemia, and chronic damage to tissues and organs is easily caused by long-term hyperglycaemia. Both the aqueous and ethanol extracts of the calyx of *P. alkekengi* lowered blood glucose levels and increased glucose tolerance in streptozotocin (STZ)-induced diabetic rats, with the ethanol extract of the calyx of *P. alkekengi* having a more significant hypoglycaemic effect [108]. Zhang et al. [109] found that ethyl acetate extracted from *P. alkekengi* can improve glucolipid metabolism in high-fat diet combined with STZ-induced diabetic rats by stimulating glucose uptake and utilization. Hu et al. [110] found that ethyl acetate extracts of the above-ground parts and fruits of *P. alkekengi* could reduce cytochrome P450-2E1 expression, inhibit α-glucosidase, reduce oxidative stress, and enhance glucose transporter 4 (GLUT4) expression and insulin sensitivity, which showed antidiabetic activity both *in vitro* and *in vivo*.

Li et al. [111] elucidated the hypoglycaemic mechanism of *P. alkekengi* polysaccharides by establishing a mouse model of tetraoxonin-induced diabetes. The study demonstrated that *P. alkekengi* polysaccharides can repair and protect the pancreas and pancreatic islet cells to stimulate insulin secretion and lower blood glucose levels. They can also regulate liver glucose metabolism by increasing the synthesis of hepatic glycogen and the content of glucokinase and improve the disorder of glucose metabolism in diabetic mice, thus lowering blood glucose concentration. The molecular mechanism of action involves activation of the phosphatidylinositol-3-kinase (PI3K)/Akt insulin signalling pathway and upregulation of GLUT4, Akt, PI3K, and insulin receptor (InsR) mRNA, which are key molecules of the insulin signalling pathway. This further enhances the effect of insulin signalling, improving the sensitivity of the body to insulin, stimulating glucose transport, promoting the utilization and metabolism of sugar in peripheral tissues and target organs, thus lowering blood glucose. In addition, the steroidal saponins in the calyx of *P. alkekengi* can also reduce blood glucose concentrations and alleviate hyperglycaemic symptoms in tetraoxypyrimidine-induced diabetic mice [112]. Li et al. [113] found that the total steroidal saponins of *P. alkekengi* inhibited α-amylase in a dose-related manner and speculated that competitive reversible inhibition was involved. In addition, physalins in sterols inhibit both α-glucosidase and α-amylase, with more significant inhibition of α-amylase [114]. Wang [115] showed that the polyphenols in the fruits of *P. alkekengi* can also lower blood glucose by promoting the expression of glucokinase (GK), glucose transporter 4 (GLUT2), and pyruvate kinase (PK), inhibiting the expression of glucose-6-phosphatase (G6Pase) and phosphoenolpyruvate carboxykinase (PEPCK), and stimulating key enzymes of glucose metabolism to regulate glucose metabolism in the livers of II-diabetic mice. Mezhlumyan et al. [116] showed that protein fractions in *P. alkekengi* also had high hypoglycaemic activity. In conclusion, a variety of compounds in *P. alkekengi* have hypoglycaemic effects, and their main active ingredients are polysaccharides, sterols, and polyphenols. The glucose-lowering mechanism of *P. alkekengi* extract is mainly related to the activation of the insulin signalling pathway, thereby enhancing insulin level and sensitivity, and hepatic glucose metabolising enzyme activity, and inhibiting glycoside and starch hydrolases, thus lowering blood glucose level. In recent years, the hypoglycaemic effect of *P. alkekengi* has been gradually emphasised, among which the hypoglycaemic effect of the calyx polysaccharides has been studied in greater detail. The significant hypoglycaemic activity of these polysaccharides demonstrated their potential for the development of a natural hypoglycaemic agent for application in pharmaceuticals and health products. Furthermore, the hypoglycaemic effect of the polyphenolic components of the fruit also provides scope for the development and application of *P. alkekengi*.

4.5. Analgesic effects

Pain is a subjective feeling of discomfort caused by damage to tissues in the body. Gong et al. [117] used various pain measurement methods to measure the pain response of mice after gavage with aqueous extract of *P. alkekengi*, indicating that the extract has an analgesic effect. In addition, studies have also shown that aqueous extracts and ethyl acetate sites from the calyx of *P. alkekengi* can also inhibit inflammation-induced pain [78,80]. After measuring the analgesic effect of physalin A using hot plate and torsion methods, Zhao et al. [118] used molecular docking techniques and found that physalin A might exert the analgesic effect by regulating leukotriene A-4 hydrolase (LTA_4H) enzyme activity in the arachidonic acid metabolic pathway. Therefore, physalins have been proposed as the active ingredient that generates this effect. Few studies on the analgesic effects of *P. alkekengi* have been conducted to date. However, the analgesic activity of natural medicine is characterised by few side effects, so *P. alkekengi* shows great clinical potential and warrants further research.

4.6. Immunomodulatory effects

Immunomodulation is a physiological function of the body that relies on the immune system to recognise and eliminate antigenic foreign substances and maintain its own physiological dynamic balance and relative stability. It has been shown that the soluble polysaccharides and calyx saponins of *P. alkekengi* significantly increased the antibody titres of anti-OVA-specific antibodies immunoglobulin G (IgG), immunoglobulin G1 (IgG1), and immunoglobulin G2b (IgG2b) in mouse anti-serum, significantly induced and promoted Th1 and Th2 cell-mediated humoral immune responses, thereby enhancing the cellular and humoral immune responses [119,120]. In addition, *P. alkekengi* fruit polysaccharides could bind to toll-like receptor 4, a surface receptor on mouse bone marrow dendritic cells to affect the immune function of bone marrow dendritic cells and promote initial T cell differentiation to Th1 and Th2 [121]. Yang et al. [122] co-immunised mice with water-soluble polysaccharides of *P. alkekengi* as a nucleic acid vaccine adjuvant, which significantly enhanced their immune response and laid the foundation for the development of *P. alkekengi* polysaccharides in vaccine adjuvants. In conclusion, the immunomodulatory effects of *P. alkekengi* are mainly attributable to its polysaccharides and saponins, and the mechanism of action may be related to promoting T cell differentiation and stimulating Th1 and Th2 immune responses.

4.7. Anti-tumour effects

Cancer is a serious threat to human life and health and causes millions of deaths worldwide every year. Most malignant tumours are treated clinically by surgical resection combined with radiotherapy, but both methods can cause serious irreversible damage to the body. Therefore, there is an urgent need for the research of natural drugs with anti-tumour activity and broad application prospects. It has been shown that the alcohol extract of *P. alkekengi* can effectively inhibit the proliferation and promote apoptosis of colon cancer cells [123]. The trichloromethane extract of *P. alkekengi* showed antiproliferative effects on HeLa, MCF-7, and A431 cell lines, with the fraction containing physalin D being the most active [124].

Steroids are the main active ingredients in the anti-tumour activity of *P. alkekengi*. Li et al. [35] found that steroids in *P. alkekengi* exhibited strong cytotoxicity against HeLa human cervical cancer, SMMC-7721 human hepatocellular carcinoma, and HL-60 human hepatocellular carcinoma tumour cell lines, with physalin B exhibiting the strongest cytotoxicity. Fu et al. [125] showed that physalins in sterols could enhance apoptosis in multiple myeloma cells by inhibiting signal transducers and activators of transcription 3 (STAT3) signalling pathway-induced expression of downstream target genes. He et al. [126] found that physalin A could selectively induce apoptosis in human fibrosarcoma HT1080 cells by activating the death receptor-related exogenous apoptotic pathway and upregulating the expression of caspase-3 and caspase-8, and physalin A had no growth inhibitory effect on normal cells. Physalin A can also inhibit cancer cell proliferation by participating in the p38 MAPK/reactive oxygen species (ROS) pathway to induce G2/M cell cycle block in human non-small cell lung cancer A549 cells, as well as inhibit tumour cell xenograft growth and promote apoptosis by inhibiting the janus kinase 2 (JAK2)/3-STAT3 signalling pathway [127,128]. Shin et al. [129] found that physalin A could also increase the expression of detoxifying enzymes by activating NRF2 and its target genes through the regulation of extracellular regulated protein kinases and p38 kinases in Hepa-1c1c7 and HepG2 hepatocellular carcinoma cells, thereby inhibiting cancer progression at the initial stages of carcinogenesis. Hao et al. [130] found that physalin A also induced iNOS expression and NO production in human melanoma A375-S2 cells, thereby inducing apoptosis and autophagy in A375-S2 cells. In addition, physalin A can also treat breast cancer through various pathways by increasing the mRNA expression level of the apoptosis-specific gene *Bax*, inducing autophagy in EGFR2 cancer cells, and inhibiting the Hedgehog and Hippo signalling pathways, cancer stem cell-specific genes, and mammosphere formation [131–133]. Wang et al. [134] showed that physalin B significantly reduced the activity of three human breast cancer cell lines: MCF-7, MDA-MB-231, and T-47D. The mechanism of action may be to induce cell cycle arrest in the G2/M phase in a p53-dependent manner and to promote the cleavage of poly ADP-ribose polymerase (PARP), caspase-3, caspase-7, and caspase-9 to stimulate apoptosis. In addition, it has been shown that physalin B induced G2/M block and inhibited proliferation of human non-small cell lung cancer A549 cells by altering mitochondrial function through upregulating p21, and downregulating cyclin B1, cell division control protein cell cycle protein-dependent kinase 1 (CDK1) and oxidative phosphorylation multi-subunit activity [135]. Sun et al. [57] isolated withanolides from the calyx of *P. alkekengi*, in which withaphysalin B and a new withanolide compound exhibited strong cytotoxicity against A549 and K562 cell lines and induced apoptosis, with a possible mechanism of action through inhibition of the PI3K–Akt–mammalian target of rapamycin (mTOR) signalling pathway to exert anti-tumour effects.

Moreover, Ji [136] showed that luteoloside could block gastric cancer cells in S-phase by inhibiting the protein expression levels of

the S-phase-related proteins cyclin-dependent kinase 2 (CDK2) and cyclin E1, inhibit the migration and invasion ability of gastric cancer cells, and up-regulate the protein expression of the apoptotic substrate PARP and the shedder of apoptotic core protein caspase-3, thereby regulating the apoptotic signalling pathway to promote apoptosis. This has the effect of promoting the ubiquitous degradation of mesenchymal-epithelial transition protein (MET) to inhibit the PI3K/Akt/mTOR pathway, which ultimately inhibits the proliferation, migration, and invasion of gastric cancer cells. In addition to this, Zhang et al. [85] also found that sesquiterpenoids have some cytotoxic properties. In conclusion, *P. alkekengi* has certain inhibitory effects on a variety of tumours, and its mechanism may be related to inducing G2/M phase arrest of cancer cells through various pathways to promote apoptosis and inhibit the proliferation of cancer cells. The main active ingredients of *P. alkekengi* with anti-tumour effects are steroidal compounds, especially the physalins, while the flavonoids and terpenoids in *P. alkekengi* also have anti-tumour activities. Therefore, the inhibitory effect of many types of cancer by various components of *P. alkekengi* demonstrates its potential as a prospective natural, anti-tumour medicine and warrants further research.

4.8. Anti-asthma effects

Asthma is a common multifactorial respiratory disease that is usually characterised by airway inflammation, immune cell aggregation, reversible airflow obstruction, and bronchial hyperresponsiveness. It has been shown that the methanol extract of *P. alkekengi* can inhibit airway hyperresponsiveness in ovalbumin (OVA)-induced asthmatic mice [137]. Bao [138] found that the aqueous extract of *P. alkekengi* can effectively reduce the total leukocyte count and eosinophil count in the blood of sensitised asthmatic mice, decrease the expression of interleukin-5 (IL-5) and interferon γ (IFN-γ) in lung tissue, selectively reduce the intensity of Th1 and Th2 expression in lung tissue, and reverse the imbalanced Th1/Th2 ratio. Liu et al. [139] found that different concentrations of *P. alkekengi* could significantly inhibit the release of histamine in the lung tissues of OVA-sensitised asthmatic mice, alleviate the inflammation of lung tissues of asthmatic mice, and reduce lung tissue damage, thus improving the symptoms of asthmatic mice and prolonging the latency period of asthma induction. Furthermore, Wu [140] showed that flavonols in *P. alkekengi* could activate the Nrf2-regulated defence system and are effective components in the treatment of respiratory diseases. In conclusion, the extracts of *P. alkekengi* have an anti-asthma effect, with flavonoids being the likely active ingredients contributing to this effect, and the mechanism of action may be related to reducing the expression of IL-5 and IFN-γ. Since the symptoms associated with asthma are related to inflammation and the immune system, the mechanisms of anti-asthmatic effect of *P. alkekengi* are also related to its anti-inflammatory and immunomodulatory effects.

4.9. Other effects

Furthermore, *P. alkekengi* has been shown have hypolipidemic, diuretic, vasodilatory, nephroprotective, and antifertility effects. Dong et al. [141] investigated the hypolipidemic effects of the aqueous and alcohol extracts of the calyx and fruit of *P. alkekengi* by establishing a hyperlipidaemic rat model and noted that the extracts of *P. alkekengi* were all effective in preventing hyperlipidaemia, with the aqueous extract of the calyx having the best therapeutic effect. Experimental results by Yang [27] showed that the diuretic effect of the calyx of *P. alkekengi* is not only related to its glycolic acid content, but also to the high potassium and magnesium content of *P. alkekengi*. Liu et al. [142] found that the aqueous extracts of *P. alkekengi* inhibited calcium inflow and the protein kinase C (PKC) signalling pathway, thereby relaxing phenylephrine and potassium chloride-induced vasoconstriction in a concentration- and non-endothelium-dependent manner in rat thoracic aorta. Ashtiyani et al. [143] showed that alcohol extracts from *P. alkekengi* could reduce urea nitrogen, serum creatinine, and sodium/potassium levels elevated due to cisplatin, thereby improving cisplatin-induced nephrotoxicity. Vessal et al. [144] found that aqueous extracts of the fruit and calyx of *P. alkekengi* can reduce progesterone levels and time-dependently inhibit the activity of the uterine creatine kinase BB-isoenzyme in mothers, thereby reducing the birth rate of pups and producing a antifertility effect.

5. Conclusions and future perspectives

This paper reviews the phylogenetic origin, chemical composition, pharmacological effects, and mechanism of action of *P. alkekengi*. More than 530 chemical components have been isolated and identified in *P. alkekengi*, mainly including steroids, flavonoids, alkaloids, volatile oils, polysaccharides, and other components. Among these, steroids, flavonoids, and volatile oils account for the largest proportion of components. However, volatile oils evaporate easily and are not suitable medicinal components; therefore, little research has been conducted on these oils. Among the sterols, the most researched components are the physalins, which are unique to *Physalis* L. A large number of pharmacological studies have demonstrated the anti-inflammatory, anti microbial, antioxidative, hypoglycaemic, analgesic, immunomodulatory, anti-tumour, and anti-asthma effects and their mechanisms of action in *P. alkekengi*. In addition, its diuretic, hypolipidemic, vasodilatory, nephroprotective, and antifertility activities have also been demonstrated, providing a theoretical basis for its use in clinical settings and as a health food. Among them, the main focus is on its anti-inflammatory, anti microbial, antioxidative, hypoglycaemic, and anti-tumour effects. Combined with phytochemical and pharmacological analysis, steroids, flavonoids, and polysaccharides are the main active ingredients of *P. alkekengi*. Among these, physalins are the main active ingredients contributing to the anti-inflammatory, anti microbial, analgesic, anti-tumour, and antioxidative effects of *P. alkekengi*. The flavonoids mainly contribute to the anti-inflammatory, antioxidative, anti-tumour, and anti-asthma effects, and the polysaccharides mainly contribute to the antioxidative, hypoglycaemic, and immunomodulatory effects of *P. alkekengi*. As a natural medicine unique to the northeast region of China, *P. alkekengi* is cheap, widely cultivated, rich in resources, and has a variety and high

content of pharmacologically active ingredients, most notably physalins. Therefore, *P. alkekengi* is highly valuable and warrants further in-depth research.

Although *P. alkekengi* and its active ingredients have been used in the treatment of several diseases and have been extensively studied pharmacologically in animal studies, the conclusions of these studies are still limited.

Although scholars at home and abroad have done a lot of research on *P. alkekengi*, there are still some problems to be solved. First, the pharmacological mechanisms of action of the anti microbial, analgesic, diuretic, and hypolipidemic effects are still unclear, and the conformational relationship of many pharmacological activities at the level of animal models, metabolomics, and macro-genomics of intestinal microflora is also less studied and warrants further in-depth research. Second, there are more studies on fruits and calyx, but few studies on roots, stems and leaves. These organs also contain medicinal components and therefore warrant further research. Third, because *P. alkekengi* appears mostly in the north-eastern region of China and is rare in other regions, it is not widely used as a food and health product, and research progress is slow. Fourth, although *P. alkekengi* showed good activity in both *in vivo* and *ex vivo* models, further confirmation of its effective use and possible clinical application is needed. In summary, as a natural medicinal and dual-use plant with a variety of functional properties, the development of related products has great potential and development prospects.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

No data was used for the research described in the article.

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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.

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